

# A PRACTICAL GUIDE TO FEDORA™ AND RED HAT® ENTERPRISE LINUX®

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FIFTH EDITION

**MARK G. SOBELL**



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# BRIEF CONTENTS

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*CONTENTS* *xiii*

*PREFACE* *xxxvii*

1 WELCOME TO LINUX 1

## **PART I INSTALLING FEDORA AND RED HAT ENTERPRISE LINUX 21**

2 INSTALLATION OVERVIEW 23

3 STEP-BY-STEP INSTALLATION 51

## **PART II GETTING STARTED WITH FEDORA AND RED HAT ENTERPRISE LINUX 87**

4 INTRODUCTION TO FEDORA AND RED HAT ENTERPRISE LINUX 89

5 THE LINUX UTILITIES 147

6 THE LINUX FILESYSTEM 187

7 THE SHELL 223

## **PART III DIGGING INTO FEDORA AND RED HAT ENTERPRISE LINUX 253**

8 LINUX GUIs: X AND GNOME 255

9 THE BOURNE AGAIN SHELL 279

10 NETWORKING AND THE INTERNET 357

## **PART IV SYSTEM ADMINISTRATION 401**

- 11 SYSTEM ADMINISTRATION: CORE CONCEPTS 403
- 12 FILES, DIRECTORIES, AND FILESYSTEMS 467
- 13 DOWNLOADING AND INSTALLING SOFTWARE 497
- 14 PRINTING WITH CUPS 519
- 15 REBUILDING THE LINUX KERNEL 543
- 16 ADMINISTRATION TASKS 555
- 17 CONFIGURING AND MONITORING A LAN 595

## **PART V USING CLIENTS AND SETTING UP SERVERS 619**

- 18 OPENSSH: SECURE NETWORK COMMUNICATION 621
- 19 FTP: TRANSFERRING FILES ACROSS A NETWORK 643
- 20 **sendmail**: SETTING UP MAIL CLIENTS, SERVERS, AND MORE 669
- 21 NIS AND LDAP 695
- 22 NFS: SHARING FILESYSTEMS 727
- 23 SAMBA: INTEGRATING LINUX AND WINDOWS 749
- 24 DNS/BIND: TRACKING DOMAIN NAMES AND ADDRESSES 773
- 25 **iptables**: SETTING UP A FIREWALL 819
- 26 **APACHE (httpd)**: SETTING UP A WEB SERVER 841

## **PART VI PROGRAMMING TOOLS 885**

- 27 PROGRAMMING THE BOURNE AGAIN SHELL 887
- 28 THE PERL SCRIPTING LANGUAGE 975

## **PART VII APPENDIXES 1021**

- A REGULAR EXPRESSIONS 1023
- B HELP 1033
- C SECURITY 1043
- D THE FREE SOFTWARE DEFINITION 1063

*GLOSSARY 1067*

*INDEX 1117*



# CONTENTS

---

## *PREFACE xxxvii*

## CHAPTER 1: WELCOME TO LINUX 1

- The GNU–Linux Connection 2
  - The History of GNU–Linux 2
  - The Code Is Free 4
  - Have Fun! 5
- The Linux 2.6 Kernel 5
- The Heritage of Linux: UNIX 5
- What Is So Good About Linux? 6
  - Why Linux Is Popular with Hardware Companies and Developers 7
  - Linux Is Portable 8
  - Standards 8
  - The C Programming Language 9
- Overview of Linux 10
  - Linux Has a Kernel Programming Interface 10
  - Linux Can Support Many Users 10
  - Linux Can Run Many Tasks 11
  - Linux Provides a Secure Hierarchical Filesystem 11
  - The Shell: Command Interpreter and Programming Language 12
  - A Large Collection of Useful Utilities 14
  - Interprocess Communication 14
  - System Administration 14

Additional Features of Linux	14
GUIs: Graphical User Interfaces	15
(Inter)Networking Utilities	16
Software Development	16
Conventions Used in This Book	16
Chapter Summary	19
Exercises	19

## **PART I   INSTALLING FEDORA AND RED HAT ENTERPRISE LINUX   21**

### **CHAPTER 2: INSTALLATION OVERVIEW   23**

The Desktop Live CD and the Install DVD	24
Planning the Installation	24
Considerations	25
Requirements	25
Processor Architecture	26
Interfaces: Installer and Installed System	28
Which Are You Installing: Fedora or Red Hat Enterprise Linux?	28
Upgrading an Existing Fedora/RHEL System Versus Installing a Fresh Copy	29
Setting Up the Hard Disk	30
RAID	37
LVM: Logical Volume Manager	38
The Installation Process	39
The Medium: Where Is the Source Data?	40
Downloading a CD/DVD ( <i>FEDORA</i> )	41
The Easy Way to Download a CD ISO Image File	41
Finding a Mirror Site to Download From	42
Using BitTorrent to Download a CD/DVD ISO Image File	44
Checking and Burning the CD/DVD	45
Checking the File	45
Burning the CD/DVD	46
Rescue Selection of the Install DVD	46
Gathering Information About the System	46
Finding the Installation Manual	47
More Information	48
Chapter Summary	48
Exercises	49
Advanced Exercises	49

### **CHAPTER 3: STEP-BY-STEP INSTALLATION   51**

Running a Fedora Live Session	52
Booting the System	52

Installing Fedora/RHEL	55
Installing from a Live Session	55
Installing/Upgrading from the Install DVD	55
The Anaconda Installer	57
Firstboot: When You Reboot	66
Initializing Databases and Updating the System	67
Installation Tasks	68
Modifying Boot Parameters (Options)	68
Partitioning the Disk	71
LVs: Logical Volumes	73
Partitions	76
palimpsest: The GNOME Disk Utility ( <i>FEDORA</i> )	78
Using the Kickstart Configurator	82
Setting Up a Dual-Boot System	82
The X Window System	84
gnome-display-properties: Configures the Display	84
More Information	85
Chapter Summary	85
Exercises	85
Advanced Exercises	86

## **PART II GETTING STARTED WITH FEDORA AND RED HAT ENTERPRISE LINUX 87**

### **CHAPTER 4: INTRODUCTION TO FEDORA AND RED HAT ENTERPRISE LINUX 89**

Curbing Your Power (Superuser/root Privileges)	90
A Tour of the Fedora/RHEL Desktop	90
Logging In on the System	91
Introduction	92
Launching Programs from the Desktop	93
Switching Workspaces	95
Setting Personal Preferences	96
Mouse Preferences	97
Working with Windows	98
Using Nautilus to Work with Files	98
The Update Applet	104
Changing Appearance (Themes)	105
Desktop Effects ( <i>FEDORA</i> )	108
Session Management	108
Getting Help	108
Feel Free to Experiment	109
Logging Out	109

Getting the Most Out of the Desktop	109
GNOME Desktop Terminology	110
Opening Files	110
Panels	111
The Main Menu	114
Windows	115
The Object Context Menu	119
Updating, Installing, and Removing Software Packages	122
Updates ( <i>FEDORA</i> )	122
Add/Remove Software	123
Where to Find Documentation	124
GNOME Help Browser	125
man: Displays the System Manual	125
apropos: Searches for a Keyword	127
info: Displays Information About Utilities	127
The <code>--help</code> Option	130
HOWTOs: Finding Out How Things Work	130
Getting Help with the System	131
More About Logging In	132
The Login Screen	133
What to Do If You Cannot Log In	134
Logging In Remotely: Terminal Emulators, <code>ssh</code> , and Dial-Up Connections	135
Logging In from a Terminal (Emulator)	135
Changing Your Password	136
Using Virtual Consoles	137
Working from the Command Line	138
Correcting Mistakes	138
Repeating/Editing Command Lines	140
Controlling Windows: Advanced Operations	141
Changing the Input Focus	141
Changing the Resolution of the Display	142
The Window Manager	142
Chapter Summary	143
Exercises	144
Advanced Exercises	145

## CHAPTER 5: THE LINUX UTILITIES 147

Special Characters	148
Basic Utilities	149
ls: Lists the Names of Files	149
cat: Displays a Text File	149
rm: Deletes a File	150
less Is more: Display a Text File One Screen at a Time	150
hostname: Displays the System Name	151

---

Working with Files	151
cp: Copies a File	151
mv: Changes the Name of a File	152
lpr: Prints a File	153
grep: Searches for a String	153
head: Displays the Beginning of a File	154
tail: Displays the End of a File	154
sort: Displays a File in Order	155
uniq: Removes Duplicate Lines from a File	156
diff: Compares Two Files	157
file: Tests the Contents of a File	157
l (Pipe): Communicates Between Processes	158
Four More Utilities	159
echo: Displays Text	159
date: Displays the Time and Date	159
script: Records a Shell Session	160
unix2dos: Converts Linux and Macintosh Files to Windows Format	161
Compressing and Archiving Files	161
bzip2: Compresses a File	162
bunzip2 and bzip2: Decompress a File	162
gzip: Compresses a File	163
tar: Packs and Unpacks Archives	163
Locating Commands	166
which and whereis: Locate a Utility	166
apropos: Searches for a Keyword	167
locate: Searches for a File	168
Obtaining User and System Information	168
who: Lists Users on the System	169
finger: Lists Users on the System	169
w: Lists Users on the System	171
Communicating with Other Users	172
write: Sends a Message	172
mesg: Denies or Accepts Messages	173
Email	174
Tutorial: Creating and Editing a File Using vim	174
Starting vim	175
Command and Input Modes	176
Entering Text	177
Getting Help	178
Ending the Editing Session	181
The <b>compatible</b> Parameter	181
Chapter Summary	181
Exercises	184
Advanced Exercises	185

**CHAPTER 6: THE LINUX FILESYSTEM 187**

- The Hierarchical Filesystem 188
- Directory Files and Ordinary Files 188
  - Filenames 189
  - The Working Directory 192
  - Your Home Directory 192
- Pathnames 193
  - Absolute Pathnames 193
  - Relative Pathnames 194
- Directory Commands 195
  - mkdir**: Creates a Directory 195
  - Important Standard Directories and Files 198
- Working with Directories 200
  - rmdir**: Deletes a Directory 200
  - Using Pathnames 201
  - mv, cp**: Move or Copy Files 201
  - mv**: Moves a Directory 202
- Access Permissions 202
  - ls -l**: Displays Permissions 203
  - chmod**: Changes Access Permissions 204
  - Setuid and Setgid Permissions 205
  - Directory Access Permissions 206
- ACLs: Access Control Lists 207
  - Enabling ACLs 208
  - Working with Access Rules 208
  - Setting Default Rules for a Directory 211
- Links 212
  - Hard Links 214
  - Symbolic Links 216
  - rm**: Removes a Link 218
- Chapter Summary 218
- Exercises 220
- Advanced Exercises 222

**CHAPTER 7: THE SHELL 223**

- The Command Line 224
  - Syntax 224
  - Processing the Command Line 227
  - Executing the Command Line 229
  - Editing the Command Line 229

Standard Input and Standard Output	230
The Screen as a File	230
The Keyboard and Screen as Standard Input and Standard Output	231
Redirection	232
Pipes	238
Running a Program in the Background	241
Filename Generation/Pathname Expansion	243
The ? Special Character	243
The * Special Character	244
The [ ] Special Characters	245
Builtins	247
Chapter Summary	248
Utilities and Builtins Introduced in This Chapter	249
Exercises	249
Advanced Exercises	251

## **PART III    DIGGING INTO FEDORA AND RED HAT ENTERPRISE LINUX    253**

### **CHAPTER 8: LINUX GUIs: X AND GNOME    255**

X Window System	256
Using X	258
Desktop Environments/Managers	263
The Nautilus File Browser Window	264
The View Pane	265
The Side Pane	265
Control Bars	266
Menubar	267
The Nautilus Spatial View	270
GNOME Utilities	272
Font Preferences ( <i>FEDORA</i> )	272
Pick a Font Window ( <i>FEDORA</i> )	272
Pick a Color Window	273
Run Application Window	274
Searching for Files	274
GNOME Terminal Emulator/Shell	275
Chapter Summary	276
Exercises	277
Advanced Exercises	277

**CHAPTER 9: THE BOURNE AGAIN SHELL 279**

Background	280
Shell Basics	281
Startup Files	281
Commands That Are Symbols	284
Redirecting Standard Error	284
Writing a Simple Shell Script	286
Separating and Grouping Commands	290
Job Control	294
Manipulating the Directory Stack	296
Parameters and Variables	299
User-Created Variables	300
Variable Attributes	303
Keyword Variables	305
Special Characters	313
Processes	314
Process Structure	314
Process Identification	314
Executing a Command	316
History	316
Variables That Control History	316
Reexecuting and Editing Commands	318
The Readline Library	326
Aliases	332
Single Versus Double Quotation Marks in Aliases	333
Examples of Aliases	334
Functions	335
Controlling <code>bash</code> Features and Options	338
Command-Line Options	338
Shell Features	338
Processing the Command Line	342
History Expansion	342
Alias Substitution	342
Parsing and Scanning the Command Line	342
Command-Line Expansion	343
Chapter Summary	351
Exercises	353
Advanced Exercises	355



---

## CHAPTER 10: NETWORKING AND THE INTERNET 357

Types of Networks and How They Work	359
Broadcast Networks	360
Point-to-Point Networks	360
Switched Networks	360
LAN: Local Area Network	361
WAN: Wide Area Network	362
Internetworking Through Gateways and Routers	362
Network Protocols	365
Host Address	367
CIDR: Classless Inter-Domain Routing	371
Hostnames	372
Communicate Over a Network	374
finger: Displays Information About Remote Users	374
Sending Mail to a Remote User	375
Mailing List Servers	376
Network Utilities	376
Trusted Hosts	376
OpenSSH Tools	377
telnet: Logs In on a Remote System	377
ftp: Transfers Files Over a Network	379
ping: Tests a Network Connection	379
traceroute: Traces a Route Over the Internet	380
host and dig: Query Internet Nameservers	382
jwhois: Looks Up Information About an Internet Site	382
Distributed Computing	383
The Client/Server Model	384
DNS: Domain Name Service	385
Ports	387
NIS: Network Information Service	387
NFS: Network Filesystem	387
Internet Services	388
Proxy Servers	391
RPC Network Services	391
Usenet	392
WWW: World Wide Web	395
URL: Uniform Resource Locator	396
Browsers	396
Search Engines	396
Chapter Summary	397
Exercises	398
Advanced Exercises	399

<b>PART IV</b>	<b>SYSTEM ADMINISTRATION</b>	<b>401</b>
<b>CHAPTER 11:</b>	<b>SYSTEM ADMINISTRATION: CORE CONCEPTS</b>	<b>403</b>
System Administrator and Superuser	405	
System Administration Tools	407	
Rescue Mode	411	
Avoiding a Trojan Horse	412	
Getting Help	413	
SELinux	414	
More Information	415	
<b>config</b> : The SELinux Configuration File	415	
getenforce, setenforce, and sestatus: Work with SELinux	416	
Setting the Targeted Policy with <b>system-config-selinux</b>	416	
The Upstart Event-Based <b>init</b> Daemon ( <i>FEDORA</i> )	417	
Definitions	418	
Jobs	420	
System Operation	424	
Runlevels	424	
Booting the System	425	
Init Scripts: Start and Stop System Services	426	
Single-User Mode	430	
Going to Multiuser Mode	431	
Graphical Multiuser Mode	431	
Logging In	431	
Logging Out	433	
Bringing the System Down	433	
Crash	436	
System Administration Utilities	436	
Fedora/RHEL Configuration Tools	437	
Command-Line Utilities	438	
Setting Up a Server	441	
Standard Rules in Configuration Files	441	
rpcinfo: Displays Information About <b>rpcbind</b>	443	
The <b>xinetd</b> Superserver	445	
Securing a Server	447	
DHCP: Configures Hosts	451	
<b>nsswitch.conf</b> : Which Service to Look at First	455	
How <b>nsswitch.conf</b> Works	455	
PAM	458	
More Information	459	
Configuration Files, Module Types, and Control Flags	459	
Example	462	
Modifying the PAM Configuration	463	
Chapter Summary	464	
Exercises	464	
Advanced Exercises	465	

---

## CHAPTER 12: FILES, DIRECTORIES, AND FILESYSTEMS 467

- Important Files and Directories 468
- File Types 480
  - Ordinary Files, Directories, Links, and Inodes 481
  - Special Files 482
- Filesystems 485
  - mount**: Mounts a Filesystem 487
  - umount**: Unmounts a Filesystem 490
  - fstab**: Keeps Track of Filesystems 490
  - fsck**: Checks Filesystem Integrity 492
  - tune2fs**: Changes Filesystem Parameters 492
  - RAID Filesystem 494
- Chapter Summary 495
- Exercises 495
- Advanced Exercises 496

## CHAPTER 13: DOWNLOADING AND INSTALLING SOFTWARE 497

- yum**: Keeps the System Up-to-Date 498
  - Configuring yum 498
  - Using yum to Update, Install, and Remove Packages 500
  - yum Groups 503
  - Other yum Commands 504
  - yum-updatesd**: Runs yum Automatically 504
  - Upgrading a System with yum 505
  - Downloading rpm Package Files with yumdownloader 505
- Adding and Removing Software Packages 505
  - piput**: Adds and Removes Software Packages (*RHEL*) 505
- BitTorrent 507
- rpm**: Red Hat Package Manager 510
  - Querying Packages and Files 511
  - Installing, Upgrading, and Removing Packages 512
  - Installing a Linux Kernel Binary 512
- Installing Non-rpm Software 513
  - The **/opt** and **/usr/local** Directories 513
  - GNU Configure and Build System 513
- Keeping Software Up-to-Date 515
  - Bugs 515
  - Errata 516
  - Red Hat Network (*RHEL*) 516
- wget**: Downloads Files Noninteractively 517
- Chapter Summary 518
- Exercises 518
- Advanced Exercises 518

## CHAPTER 14: PRINTING WITH CUPS 519

- Introduction 520
  - Prerequisites 520
  - More Information 521
  - Notes 521
- JumpStart I: Configuring a Local Printer 521
- system-config-printer: Configuring a Printer 522
  - Configuration Selections 522
  - Setting Up a Remote Printer 524
- JumpStart II: Setting Up a Local or Remote Printer Using the CUPS Web Interface 527
- Traditional UNIX Printing 530
- Configuring Printers 532
  - The CUPS Web Interface 532
  - CUPS on the Command Line 533
  - Sharing CUPS Printers 537
- Printing from Windows 538
  - Printing Using CUPS 538
  - Printing Using Samba 539
- Printing to Windows 540
- Chapter Summary 540
- Exercises 541
- Advanced Exercises 541

## CHAPTER 15: REBUILDING THE LINUX KERNEL 543

- Preparing the Source Code 544
  - Locating the Kernel Source Code 544
  - Installing the Kernel Source Code 545
- Read the Documentation 546
- Configuring and Compiling the Linux Kernel 547
  - Cleaning the Source Tree 547
  - Configuring the Linux Kernel 547
  - Compiling the Kernel 549
  - Using Loadable Kernel Modules 549
- Installing the Kernel and Associated Files 550
- Rebooting the System 550
- Boot Loader 551
  - grub: The Linux Loader 551
- dmesg**: Displays Kernel Messages 553
- Chapter Summary 553
- Exercises 554
- Advanced Exercises 554

---

## CHAPTER 16: ADMINISTRATION TASKS 555

- Configuring User and Group Accounts 556
  - system-config-users: Manages User Accounts 556
  - useradd: Adds a User Account 557
  - userdel: Removes a User Account 558
  - groupadd: Adds a Group 558
- Backing Up Files 558
  - Choosing a Backup Medium 559
  - Backup Utilities 560
  - Performing a Simple Backup 562
  - dump, restore: Back Up and Restore Filesystems 563
- Scheduling Tasks 565
  - crond and crontab: Schedule Routine Tasks 565
  - at: Runs Occasional Tasks 565
- System Reports 566
  - vmstat: Reports Virtual Memory Statistics 566
  - top: Lists Processes Using the Most Resources 567
- parted: Reports on and Partitions a Hard Disk 568
- Keeping Users Informed 572
- Creating Problems 572
  - Failing to Perform Regular Backups 573
  - Not Reading and Following Instructions 573
  - Failing to Ask for Help When Instructions Are Not Clear 573
  - Deleting or Mistyping a Critical File 573
- Solving Problems 574
  - Helping When a User Cannot Log In 574
  - Speeding Up the System 575
  - lsof: Finds Open Files 576
  - Keeping a Machine Log 576
  - Keeping the System Secure 577
  - Log Files and Mail for root 577
  - Monitoring Disk Usage 578
  - logrotate: Manages Log Files 579
  - Removing Unused Space from Directories 581
  - Disk Quota System 582
  - rsyslogd: Logs System Messages 582
- MySQL 584
  - More Information 585
  - Terminology 585
  - Syntax and Conventions 585
  - Prerequisites 585
  - Notes 586
  - Jumpstart: Setting Up MySQL 586
  - Options 587
  - The .my.cnf Configuration File 587
  - Working with MySQL 588

Chapter Summary	592
Exercises	593
Advanced Exercises	593

## CHAPTER 17: CONFIGURING AND MONITORING A LAN 595

Setting Up the Hardware	596
Connecting the Computers	596
Gateways and Routers	597
NIC: Network Interface Card	597
Configuring the Systems	598
NetworkManager: Configures Network Connections	599
The NetworkManager Applet	599
The Network Configuration Window ( <b>system-config-network</b> )	601
Adding a Device	603
Editing a Device	603
Setting Up Networking for a Server	605
<b>iwconfig</b> : Configures a Wireless NIC	605
Setting Up Servers	606
Introduction to Cacti	607
Configuring SNMP	608
Setting Up LAMP	608
Enabling the Cacti Poller	611
Configuring Cacti	611
Basic Cacti Administration	612
Setting Up a Remote Data Source	614
More Information	617
Chapter Summary	617
Exercises	618
Advanced Exercises	618

## PART V USING CLIENTS AND SETTING UP SERVERS 619

### CHAPTER 18: OPENSSH: SECURE NETWORK COMMUNICATION 621

Introduction	622
About OpenSSH	622
Files	622
How OpenSSH Works	624
More Information	624

OpenSSH Clients	625
Prerequisites	625
JumpStart: Using <code>ssh</code> and <code>scp</code>	625
Setup	626
<code>ssh</code> : Connects to or Executes Commands on a Remote System	627
<code>scp</code> : Copies Files from/to a Remote System	630
<code>sftp</code> : A Secure FTP Client	631
<code>~/.ssh/config</code> and <code>/etc/ssh/ssh_config</code> Configuration Files	631
<code>sshd</code> : OpenSSH Server	633
Prerequisites	633
Notes	633
JumpStart: Starting the <code>sshd</code> Daemon	633
Authorized Keys: Automatic Login	634
Command-Line Options	636
<code>/etc/ssh/sshd_config</code> Configuration File	636
Troubleshooting	637
Tunneling/Port Forwarding	638
Chapter Summary	641
Exercises	641
Advanced Exercises	642

## CHAPTER 19: FTP: TRANSFERRING FILES ACROSS A NETWORK 643

Introduction	644
More Information	645
FTP Client	645
Prerequisites	645
JumpStart: Downloading Files Using <code>ftp</code>	646
Notes	649
Anonymous FTP	649
Automatic Login	649
Binary Versus ASCII Transfer Mode	650
<code>ftp</code> Specifics	650
FTP Server ( <code>vsftpd</code> )	654
Prerequisites	654
Notes	654
JumpStart: Starting a <code>vsftpd</code> Server	655
Testing the Setup	655
<code>vsftpd.conf</code> : The <code>vsftpd</code> Configuration File	656
Chapter Summary	666
Exercises	667
Advanced Exercises	667

## CHAPTER 20: **sendmail**: SETTING UP MAIL CLIENTS, SERVERS, AND MORE 669

- Introduction 670
  - Prerequisites 671
  - Notes 671
  - More Information 672
- JumpStart I: Configuring **sendmail** on a Client 672
- JumpStart II: Configuring **sendmail** on a Server 673
- How **sendmail** Works 674
  - Mail Logs 674
  - Aliases and Forwarding 675
  - Related Programs 676
- Configuring **sendmail** 677
  - The **sendmail.mc** and **sendmail.cf** Files 677
  - Other Files in **/etc/mail** 680
- Additional Email Tools 682
  - SpamAssassin 682
  - Configuring SpamAssassin 684
  - Webmail 686
  - Mailing Lists 688
  - Setting Up an IMAP or POP3 Server 689
- Authenticated Relaying 689
- Alternatives to **sendmail** 691
- Chapter Summary 692
- Exercises 692
- Advanced Exercises 693

## CHAPTER 21: NIS AND LDAP 695

- Introduction to NIS 696
- How NIS Works 696
  - More Information 698
- Setting Up an NIS Client 699
  - Prerequisites 699
  - Notes 699
  - Step-by-Step Setup 699
  - Testing the Setup 701
  - yppasswd**: Changes NIS Passwords 702
- Setting Up an NIS Server 703
  - Prerequisites 703
  - Notes 704
  - Step-by-Step Setup 704
  - Testing 709
  - yppasswdd**: The NIS Password Update Daemon 709



LDAP	710
More Information	712
Setting Up an LDAP Server	713
Prerequisites	713
Note	713
Step-by-Step Setup	713
Other Tools for Working with LDAP	720
Evolution Mail	720
Konqueror	722
Chapter Summary	723
Exercises	724
Advanced Exercises	724

## CHAPTER 22: NFS: SHARING FILESYSTEMS 727

Introduction	728
More Information	730
Setting Up an NFS Client	730
Prerequisites	730
JumpStart I: Mounting a Remote Directory Hierarchy	730
mount: Mounts a Directory Hierarchy	732
Improving Performance	734
/etc/fstab: Mounts Directory Hierarchies Automatically	735
Setting Up an NFS Server	736
Prerequisites	736
Notes	736
JumpStart II: Configuring an NFS Server Using system-config-nfs	737
Exporting a Directory Hierarchy	738
exports: Maintains the List of Exported Directory Hierarchies	742
Testing the Server Setup	743
automount: Automatically Mounts Directory Hierarchies	744
Chapter Summary	746
Exercises	746
Advanced Exercises	747

## CHAPTER 23: SAMBA: INTEGRATING LINUX AND WINDOWS 749

Introduction	750
About Samba	751
Prerequisites	751
More Information	751
Notes	751
Samba Users, User Maps, and Passwords	752
JumpStart: Configuring a Samba Server Using system-config-samba	753
swat: Configures a Samba Server	755

Manually Configuring a Samba Server	759
Parameters in the <b>smbd.conf</b> File	760
The [homes] Share: Sharing Users' Home Directories	765
Accessing Linux Shares from Windows	765
Browsing Shares	765
Mapping a Share	766
Accessing Windows Shares from Linux	766
smbtree: Displays Windows Shares	766
smbclient: Connects to Windows Shares	767
Browsing Windows Networks	767
Mounting Windows Shares	767
Troubleshooting	768
Chapter Summary	770
Exercises	771
Advanced Exercises	771

## CHAPTER 24: DNS/BIND: TRACKING DOMAIN NAMES AND ADDRESSES 773

Introduction to DNS	774
Nodes, Domains, and Subdomains	774
Zones	776
Queries	777
Servers	778
Resource Records	779
DNS Query and Response	782
Reverse Name Resolution	783
About DNS	785
How DNS Works	785
Prerequisites	785
More Information	786
Notes	786
JumpStart I: Setting Up a DNS Cache	787
JumpStart II: Setting Up a Domain Using <b>system-config-bind</b>	789
Notes	789
Using the BIND Configuration GUI Window	790
Setting Up a Domain Server	791
Adding Resource Records	792
Setting Up BIND	793
<b>named.conf</b> : The <b>named</b> Configuration File	794
Zone Files	796
A DNS Cache	797
DNS Glue Records	802
TSIGs: Transaction Signatures	803
Running BIND in a chroot Jail	804

Troubleshooting	805
A Full-Functioned Nameserver	807
A Slave Server	810
A Split Horizon Server	811
Chapter Summary	816
Exercises	816
Advanced Exercises	817

## CHAPTER 25: iptables: SETTING UP A FIREWALL 819

How iptables Works	820
About iptables	822
More Information	822
Prerequisites	823
Notes	823
JumpStart: Building a Firewall Using system-config-firewall	824
Anatomy of an iptables Command	825
Building a Set of Rules	826
Commands	827
Packet Match Criteria	828
Display Criteria	828
Match Extensions	829
Targets	831
Copying Rules to and from the Kernel	832
system-config-firewall: Generates a Set of Rules	833
Sharing an Internet Connection Using NAT	835
Connecting Several Clients to a Single Internet Connection	836
Connecting Several Servers to a Single Internet Connection	838
Chapter Summary	839
Exercises	839
Advanced Exercises	839

## CHAPTER 26: APACHE (httpd): SETTING UP A WEB SERVER 841

Introduction	842
About Apache	842
Prerequisites	843
More Information	843
Notes	844
JumpStart I: Getting Apache Up and Running	844
Modifying the httpd.conf Configuration File	845
Testing Apache	845
Putting Your Content in Place	846
JumpStart II: Setting Up Apache Using system-config-httpd	846

Filesystem Layout	848
Configuration Directives	850
Directives I: Directives You May Want to Modify as You Get Started	850
Contexts and Containers	854
Directives II: Advanced Directives	858
The Fedora/RHEL <code>httpd.conf</code> File	870
Section 1: Global Environment	871
Section 2: Main Server Configuration	872
Section 3: Virtual Hosts	873
Redirects	873
Multiviews	874
Server-Generated Directory Listings (Indexing)	874
Virtual Hosts	874
Troubleshooting	875
Modules	876
Module List	876
<code>mod_cgi</code> and CGI Scripts	877
<code>mod_ssl</code>	877
Authentication Modules and <code>.htaccess</code>	880
Scripting Modules	881
<code>webalizer</code> : Analyzes Web Traffic	881
<code>MRTG</code> : Monitors Traffic Loads	882
Error Codes	882
Chapter Summary	883
Exercises	884
Advanced Exercises	884

## PART VI PROGRAMMING TOOLS 885

### CHAPTER 27: PROGRAMMING THE BOURNE AGAIN SHELL 887

Control Structures	888
<code>if...then</code>	888
<code>if...then...else</code>	892
<code>if...then...elif</code>	895
<code>for...in</code>	901
<code>for</code>	902
<code>while</code>	904
<code>until</code>	908
<code>break</code> and <code>continue</code>	910
<code>case</code>	911
<code>select</code>	917
Here Document	919

File Descriptors	921
Parameters and Variables	924
Array Variables	924
Locality of Variables	926
Special Parameters	928
Positional Parameters	930
Expanding Null and Unset Variables	935
Builtin Commands	936
type: Displays Information About a Command	937
read: Accepts User Input	937
exec: Executes a Command	940
trap: Catches a Signal	943
kill: Aborts a Process	946
getopts: Parses Options	946
A Partial List of Builtins	949
Expressions	950
Arithmetic Evaluation	950
Logical Evaluation (Conditional Expressions)	951
String Pattern Matching	952
Operators	953
Shell Programs	958
A Recursive Shell Script	959
The <b>quiz</b> Shell Script	962
Chapter Summary	968
Exercises	970
Advanced Exercises	972

## CHAPTER 28: THE PERL SCRIPTING LANGUAGE 975

Introduction to Perl	976
More Information	976
Help	977
perldoc	977
Terminology	979
Running a Perl Program	980
Syntax	981
Variables	983
Scalar Variables	985
Array Variables	987
Hash Variables	990
Control Structures	991
if/unless	991
if...else	993
if...elsif...else	994
foreach/for	995
last and next	996
while/until	998

Working with Files	1000
Sort	1003
Subroutines	1005
Regular Expressions	1007
Syntax and the =~ Operator	1008
CPAN Modules	1013
Examples	1015
Chapter Summary	1019
Exercises	1019
Advanced Exercises	1020

## **PART VII APPENDICES 1021**

### **APPENDIX A: REGULAR EXPRESSIONS 1023**

Characters	1024
Delimiters	1024
Simple Strings	1024
Special Characters	1024
Periods	1025
Brackets	1025
Asterisks	1026
Caret and Dollar Signs	1026
Quoting Special Characters	1027
Rules	1027
Longest Match Possible	1027
Empty Regular Expressions	1028
Bracketing Expressions	1028
The Replacement String	1028
Ampersand	1029
Quoted Digit	1029
Extended Regular Expressions	1029
Appendix Summary	1031

### **APPENDIX B: HELP 1033**

Solving a Problem	1034
Finding Linux-Related Information	1035
Documentation	1035
Useful Linux Sites	1036
Linux Newsgroups	1037
Mailing Lists	1037
Words	1038
Software	1038
Office Suites and Word Processors	1040
Specifying a Terminal	1040

**APPENDIX C: SECURITY 1043**

Encryption	1044
Public Key Encryption	1045
Symmetric Key Encryption	1046
Encryption Implementation	1047
GnuPG/PGP	1048
File Security	1049
Email Security	1049
MTAs (Mail Transfer Agents)	1049
MUAs (Mail User Agents)	1050
Network Security	1050
Network Security Solutions	1051
Network Security Guidelines	1051
Host Security	1053
Login Security	1054
Remote Access Security	1055
Viruses and Worms	1056
Physical Security	1056
Security Resources	1058
Appendix Summary	1061

**APPENDIX D: THE FREE SOFTWARE DEFINITION 1063*****GLOSSARY 1067******INDEX 1117***

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# PREFACE

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**The book** Whether you are an end user, a system administrator, or a little of both, this book explains with step-by-step examples how to get the most out of a Fedora or Red Hat Enterprise Linux (RHEL) system. In 28 chapters, this book takes you from installing a Fedora or RHEL system through understanding its inner workings to setting up secure servers that run on the system.

**The audience** This book is designed for a wide range of readers. It does not require you to have programming experience, although having some experience using a general-purpose computer, such as a Windows, Macintosh, UNIX, or other Linux system, is certainly helpful. This book is appropriate for

- **Students** who are taking a class in which they use Linux
- **Home users** who want to set up and/or run Linux
- **Professionals** who use Linux at work
- **System administrators** who need an understanding of Linux and the tools that are available to them including the `bash` and Perl scripting languages
- **Computer science students** who are studying the Linux operating system
- **Technical executives** who want to get a grounding in Linux

**Benefits** *A Practical Guide to Fedora™ and Red Hat® Enterprise Linux®, Fifth Edition*, gives you a broad understanding of many facets of Linux, from installing Fedora/RHEL through using and customizing it. No matter what your background, this book delivers the knowledge you need to get on with your work. You will come away from this book understanding how to use Linux, and this book will remain a valuable reference for years to come.

New in this edition This edition includes many updates to the previous edition:

- An all-new chapter on the Perl programming language (Chapter 28; page 975)
- Coverage of the MySQL relational database, which has been added to Chapter 16 (page 584)
- Coverage of the Cacti network monitoring tool, which has been added to Chapter 17 (page 607)
- Updated chapters to reflect the Fedora 12 and Red Hat Enterprise Linux 5.4 releases

Overlap If you read *A Practical Guide to Linux® Commands, Editors, and Shell Programming, Second Edition*, you will notice some overlap between that book and the one you are reading now. The first chapter; the chapters on the utilities, the filesystem, and Perl; and the appendix on regular expressions are very similar in the two books, as are the three chapters on the Bourne Again Shell (bash). Chapters that appear in this book but not in *A Practical Guide to Linux® Commands, Editors, and Shell Programming, Second Edition*, include Chapters 2 and 3 (installation), Chapters 4 and 8 (Fedora/RHEL and the GUI), Chapter 10 (networking), all of the chapters in Part IV (system administration) and Part V (servers), and Appendix C (security).

Differences While this book explains how to use Linux from a graphical interface and from the command line (a textual interface), *A Practical Guide to Linux® Commands, Editors, and Shell Programming, Second Edition*, works exclusively with the Linux and Mac OS X command line. It includes full chapters on the vi and emacs editors, as well as chapters on the gawk pattern processing language and the sed stream editor. In addition, it has a command reference section that provides extensive examples of the use of 100 of the most important Linux and Mac OS X utilities. You can use these utilities to solve problems without resorting to programming in C.

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## THIS BOOK INCLUDES FEDORA 12 ON A DVD

*A Practical Guide to Fedora™ and Red Hat® Enterprise Linux®, Fifth Edition*, includes a DVD that you can use to install or upgrade to Fedora 12. Chapter 2 helps you get ready to install Fedora. Chapter 3 provides step-by-step instructions for installing Fedora from this DVD. This book guides you through learning about, using, and administrating Fedora or RHEL.

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## WHAT IS NEW IN THIS EDITION?

The fifth edition of *A Practical Guide to Fedora™ and Red Hat® Enterprise Linux®* covers Fedora 12 and Red Hat Enterprise Linux version 5.4. Chapters 2 and 3 describe the process of booting into a live session and installing from live media.

There is a new section on MySQL in Chapter 16 and new coverage of Cacti in Chapter 17. All of the changes—both large and small—that have been made to Fedora/RHEL since the previous edition of this book was published have been incorporated into the explanations and examples.

---

## FEATURES OF THIS BOOK

This book is designed and organized so you can get the most out of it in the least amount of time. You do not have to read this book straight through in page order. Instead, once you are comfortable using Linux, you can use this book as a reference: Look up a topic of interest in the table of contents or index and read about it. Or think of the book as a catalog of Linux topics: Flip through the pages until a topic catches your eye. The book includes many pointers to Web sites where you can obtain additional information: Consider the Internet to be an extension of this book.

*A Practical Guide to Fedora™ and Red Hat® Enterprise Linux®, Fifth Edition*, is structured with the following features:

- In this book, the term “Fedora/RHEL” refers to both **Fedora** and **Red Hat Enterprise Linux**. Features that apply to only one operating system or the other are marked as such using these indicators: *FEDORA* or *RHEL*.
- **Optional sections** enable you to read the book at different levels, returning to more difficult material when you are ready to delve into it.
- **Caution boxes** highlight procedures that can easily go wrong, giving you guidance before you run into trouble.
- **Tip boxes** highlight ways that you can save time by doing something differently or situations when it may be useful or just interesting to have additional information.
- **Security boxes** point out places where you can make a system more secure. The **security appendix** presents a quick background in system security issues.
- Concepts are illustrated by **practical examples** throughout the book.
- **Chapter summaries** review the important points covered in each chapter.
- **Review exercises** are included at the end of each chapter for readers who want to further hone their skills. Answers to even-numbered exercises can be found at [www.sobell.com](http://www.sobell.com).
- This book provides resources for **finding software** on the Internet. It also explains how to **download** and **install** software using yum, BitTorrent, and, for Red Hat Enterprise Linux, Red Hat Network (RHN).
- The **glossary** defines more than 500 common terms.

- The chapters that cover servers include **JumpStart** sections that get you off to a quick start using clients and setting up servers. Once a server is up and running, you can test and modify its configuration as explained in the rest of each of these chapters.
- This book describes in detail many important **GNU tools**, including the GNOME desktop, the Nautilus File Browser, the parted and palimpsest partition editors, the gzip compression utility, and many command-line utilities that come from the GNU project.
- Pointers throughout the text provide help in obtaining **online documentation** from many sources, including the local system, the Red Hat Web site, the Fedora Project Web site, and other locations on the Internet.
- Many **useful URLs** (Internet addresses) point to sites where you can obtain software, security programs and information, and more.
- The comprehensive index helps you locate topics quickly and easily.

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## KEY TOPICS COVERED IN THIS BOOK

This book contains a lot of information. This section distills and summarizes its contents. In addition, “Details” (starting on page xliii) describes what each chapter covers. Finally, the table of contents provides more detail. This book:

- |              |   |
|--------------|---|
| Installation | <ul style="list-style-type: none"><li>• Describes how to download Fedora ISO image files from the Internet and burn both Fedora Desktop Live Media CD/DVDs and Fedora Install Media CD/DVDs.</li><li>• Helps you plan the layout of the system’s hard disk and assists you in using Disk Druid or the GNOME palimpsest disk utility to partition the hard disk.</li><li>• Explains how to set up a dual-boot system so you can install Fedora or RHEL on a Windows system and boot either operating system.</li><li>• Explains how to use the Logical Volume Manager (LVM2) to set up, grow, and migrate logical volumes, which are similar in function to traditional disk partitions.</li><li>• Discusses booting into a live Fedora session and installing Fedora from that session.</li><li>• Describes in detail how to install Fedora/RHEL from a DVD, CD, a hard disk, or over a network using FTP, NFS, or HTTP.</li><li>• Covers boot command-line parameters (<i>FEDORA</i>), responses to the <b>boot:</b> prompt (<i>RHEL</i>), and working with <b>Anaconda</b>, Fedora/RHEL’s installation program.</li></ul> |
|--------------|---|

Working with  
Fedora/RHEL

- Introduces the GNOME desktop (GUI) and explains how to use desktop tools, including the Top and Bottom panels, panel objects, the Main menu, object context menus, the Workspace Switcher, the Nautilus File Browser, and the GNOME terminal emulator.
- Explains how to use the Appearance Preferences window to add and modify themes to customize your desktop to please your senses and help you work more efficiently.
- Details how to set up 3D desktop visual effects that take advantage of Compiz Fusion.
- Covers the Bourne Again Shell (bash) in three chapters, including an entire chapter on shell programming that includes many sample shell scripts. These chapters provide clear explanations and extensive examples of how bash works both from the command line in day-to-day work and as a programming language in which to write shell scripts.
- Explains the textual (command-line) interface and introduces more than 30 command-line utilities.
- Presents a tutorial on the vim textual editor.
- Covers types of networks, network protocols, and network utilities.
- Explains hostnames, IP addresses, and subnets, and explores how to use host and dig to look up domain names and IP addresses on the Internet.
- Covers distributed computing and the client/server model.
- Explains how to use ACLs (access control lists) to fine-tune user access permissions.

System  
administration

- Explains how to use the Fedora/RHEL graphical and textual (command-line) tools to configure the display, DNS, NFS, Samba, Apache, a firewall, a network interface, and more. You can also use these tools to add users and manage local and remote printers.
- Describes how to use the following tools to download software and keep a system current:
  - ◆ yum—Downloads and installs software packages from the Internet, keeping a system up-to-date and resolving dependencies as it processes the packages. You can run yum manually or set it up to run automatically every night.
  - ◆ BitTorrent—Good for distributing large amounts of data such as the Fedora installation DVD and the live media CD/DVD. The more people who use BitTorrent to download a file, the faster it works.
  - ◆ up2date—The Red Hat Enterprise Linux tool for keeping system software current.

- Covers graphical system administration tools, including the many tools available from the GNOME Main menu.
- Explains system operation, including the boot process, init scripts, rescue mode, single-user and multiuser modes, and steps to take if the system crashes.
- Describes how to use and program the new Upstart **init** daemon, which replaces the System V **init** daemon.
- Describes files, directories, and filesystems, including types of files and filesystems, **fstab** (the filesystem table), automatically mounted filesystems, filesystem integrity checks, filesystem utilities, and fine-tuning of filesystems.
- Explains how to set up and use the **Cacti** network monitoring tool to graph system and network information over time.
- Covers backup utilities, including **tar**, **cpio**, **dump**, and **restore**.
- Explains how to customize and build a Linux kernel.

## Security

- Helps you manage basic system security issues using **ssh** (secure shell), **vsftpd** (secure FTP server), Apache (the **httpd** Web server), **iptables** (firewall), and more.
- Presents a complete section on SELinux (Security Enhanced Linux), including instructions for using **system-config-selinux** to configure SELinux.
- Covers the use of **system-config-firewall** to set up a basic firewall to protect the system.
- Provides instructions on using **iptables** to share an Internet connection over a LAN and to build advanced firewalls.
- Describes how to set up a **chroot** jail to protect a server system.
- Explains how to use TCP wrappers to control who can access a server.
- Covers controlling servers using the **xinetd** superserver.

## Clients and servers

- Explains how to set up and use the most popular Linux servers, providing a chapter on each: Apache, Samba, OpenSSH, **sendmail**, DNS, NFS, FTP, NIS and LDAP, and **iptables** (all of which are included with Fedora/RHEL).
- Describes how to set up a CUPS printer server.
- Explains how to set up and use a MySQL relational database.
- Describes how to set up and use a DHCP server.

## Programming

- Provides an all-new chapter on the Perl programming language and a full chapter covering shell programming using **bash**, including many examples.

## DETAILS

- Chapter 1 **Chapter 1** presents a brief history of Linux and explains some of the features that make it a cutting-edge operating system. The “Conventions Used in This Book” (page 16) section details the typefaces and terminology used in this book.
- Part I Part I, “Installing Fedora and Red Hat Enterprise Linux,” discusses how to install both Fedora and RHEL. **Chapter 2** presents an overview of the process of installing Fedora and RHEL, including hardware requirements, downloading and burning a CD or DVD, and planning the layout of the hard disk. **Chapter 3** is a step-by-step guide to installing either Fedora or Red Hat Enterprise Linux; it covers installing from a CD/DVD, in a live session, from a local hard disk, and over the network using FTP, NFS, or HTTP. It also shows how to customize your graphical desktop (GUI).
- Part II Part II, “Getting Started with Fedora and Red Hat Enterprise Linux,” familiarizes you with Fedora/RHEL, covering logging in, the GUI, utilities, the filesystem, and the shell. **Chapter 4** introduces desktop features, including the Top and Bottom panels and the Main menu; explains how to use the Nautilus File Browser to manage files, run programs, and connect to FTP and HTTP servers; covers finding documentation, dealing with login problems, and using the window manager; and presents some suggestions on where to find documentation, including manuals, tutorials, software notes, and HOWTOs. **Chapter 5** introduces the shell command-line interface, describes more than 30 useful utilities, and presents a tutorial on the vim text editor. **Chapter 6** discusses the Linux hierarchical filesystem, covering files, filenames, pathnames, working with directories, access permissions, and hard and symbolic links. **Chapter 7** introduces the Bourne Again Shell (bash) and discusses command-line arguments and options, redirecting input to and output from commands, running programs in the background, and using the shell to generate and expand filenames.

### Experienced users may want to skim Part II

- tip** If you have used a UNIX or Linux system before, you may want to skim or skip some or all of the chapters in Part II. Two sections that all readers should take a look at “Conventions Used in This Book” (page 16), which explains the typographic and layout conventions used in this book, and “Where to Find Documentation” (page 124), which points out both local and remote sources of Linux/Fedora/RHEL documentation.
- Part III Part III, “Digging into Fedora and Red Hat Enterprise Linux,” goes into more detail about working with the system. **Chapter 8** discusses the GUI (desktop) and includes a section on how to run a graphical program on a remote system and have the display appear locally. The section on GNOME describes several GNOME utilities and goes into more depth about the Nautilus File Browser. **Chapter 9** extends the bash coverage from Chapter 7, explaining how to redirect error output, avoid overwriting files, and work with job control, processes, startup files, important shell

builtin commands, parameters, shell variables, and aliases. **Chapter 10** explains networks, network security, and the Internet and discusses types of networks, subnets, protocols, addresses, hostnames, and various network utilities. The section on distributed computing describes the client/server model and some of the servers you can use on a network. Details of setting up and using clients and servers are reserved until Part V.

**Part IV** Part IV covers system administration. **Chapter 11** discusses core concepts such as working with **root** privileges (working as Superuser), SELinux (Security Enhanced Linux), system operation, general information about how to set up a server, DHCP, and PAM. **Chapter 12** explains the Linux filesystem, going into detail about types of files, including special and device files, the use of **fsck** to verify the integrity of and repair filesystems, and the use of **tune2fs** to change filesystem parameters. **Chapter 13** explains how to keep a system up-to-date by downloading software from the Internet and installing it, including examples that use **yum**, **BitTorrent**, and RHEL's **up2date** utility. **Chapter 14** explains how to set up the CUPS printing system so you can print on the local system as well as on remote systems. **Chapter 15** details customizing and building a Linux kernel. **Chapter 16** covers additional administration tasks, including setting up user accounts, backing up files, scheduling automated tasks, tracking disk usage, solving general problems, and installing and running MySQL. **Chapter 17** explains how to set up a local area network (LAN), including both hardware (including wireless) and software setup. It also discusses using **Cacti** to monitor a network.

**Part V** Part V goes into detail about setting up and running servers and connecting to them with clients. The chapters in this part of the book cover the following clients/servers:

- **OpenSSH**—Set up an OpenSSH server and use **sh**, **scp**, and **sftp** to communicate securely over the Internet.
- **FTP**—Set up a **vsftpd** secure FTP server and use any of several FTP clients to exchange files with the server.
- **Mail**—Configure **sendmail** and use Webmail, POP3, or IMAP to retrieve email; use **SpamAssassin** to combat spam.
- **NIS and LDAP**—Set up NIS to facilitate system administration of a LAN and LDAP to distribute information and authenticate users over a network.
- **NFS**—Share filesystems between systems on a network.
- **Samba**—Share filesystems and printers between Windows and Linux systems.
- **DNS/BIND**—Set up a domain nameserver to let other systems on the Internet know the names and IP addresses of local systems they may need to contact.
- **iptables**—Share a single Internet connection between systems on a LAN and set up a firewall to protect local systems.
- **Apache**—Set up an HTTP server that serves Web pages, which browsers can then display.



- Part VI Part VI covers two important programming tools that are used extensively in Fedora/RHEL system administration and general-purpose programming. **Chapter 27** continues where Chapter 9 left off, going into greater depth about shell programming using `bash`, with the discussion enhanced by extensive examples. **Chapter 28** introduces the popular, feature-rich Perl programming language, including coverage of regular expressions and file handling.
- Part VII Part VII includes appendixes on regular expressions, helpful Web sites, system security, and free software. This part also includes an extensive glossary with more than 500 entries and a comprehensive index.

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## SUPPLEMENTS

The author's home page ([www.sobell.com](http://www.sobell.com)) contains downloadable listings of the longer programs from this book as well as pointers to many interesting and useful Linux sites on the World Wide Web, a list of corrections to the book, answers to even-numbered exercises, and a solicitation for corrections, comments, and suggestions.

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## THANKS

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I take responsibility for any errors and omissions in this book. If you find one or just have a comment, let me know ([mgs@sobell.com](mailto:mgs@sobell.com)) and I will fix it in the next printing. My home page ([www.sobell.com](http://www.sobell.com)) contains a list of errors and credits those who found them. It also offers copies of the longer scripts from the book and pointers to many interesting Linux pages.

*Mark G. Sobell*  
*San Francisco, California*

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# WELCOME TO LINUX

## IN THIS CHAPTER

The GNU–Linux Connection . . . . .	2
The Linux 2.6 Kernel . . . . .	5
The Heritage of Linux: UNIX . . . . .	5
What Is So Good About Linux? . . . . .	6
Overview of Linux . . . . .	10
Additional Features of Linux. . . . .	14
Conventions Used in This Book . . . .	16

The Linux *kernel* was developed by Finnish undergraduate student Linus Torvalds, who used the Internet to make the source code immediately available to others for free. Torvalds released Linux version 0.01 in September 1991.

The new operating system came together through a lot of hard work. Programmers around the world were quick to extend the kernel and develop other tools, adding functionality to match that already found in both BSD UNIX and System V UNIX (SVR4) as well as new functionality.

The Linux operating system, developed through the cooperation of many, many people around the world, is a *product of the Internet* and is a *free* operating system. In other words, all the source code is free. You are free to study it, redistribute it, and modify it. As a result, the code is available free of cost—no charge for the software, source, documentation, or support (via newsgroups, mailing lists, and other Internet

resources). As the GNU Free Software Definition (reproduced in Appendix D) puts it:

Free beer

“Free software” is a matter of liberty, not price. To understand the concept, you should think of “free” as in “free speech,” not as in “free beer.”

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## THE GNU–LINUX CONNECTION

An operating system is the low-level software that schedules tasks, allocates storage, and handles the interfaces to peripheral hardware, such as printers, disk drives, the screen, keyboard, and mouse. An operating system has two main parts: the *kernel* and the *system programs*. The kernel allocates machine resources, including memory, disk space, and *CPU* (page 1077) cycles, to all other programs that run on the computer. The system programs perform higher-level housekeeping tasks, often acting as servers in a client/server relationship. *Linux* is the name of the kernel that Linus Torvalds presented to the world in 1991 and that many others have worked on since then to enhance, stabilize, expand, and make more secure.

## THE HISTORY OF GNU–LINUX

This section presents some background on the relationship between GNU and Linux.

### FADE TO 1983

Richard Stallman ([www.stallman.org](http://www.stallman.org)) announced<sup>1</sup> the GNU Project for creating an operating system, both kernel and system programs, and presented the GNU Manifesto,<sup>2</sup> which begins as follows:

GNU, which stands for Gnu’s Not UNIX, is the name for the complete UNIX-compatible software system which I am writing so that I can give it away free to everyone who can use it.

Some years later, Stallman added a footnote to the preceding sentence when he realized that it was creating confusion:

The wording here was careless. The intention was that nobody would have to pay for \*permission\* to use the GNU system. But the words don’t make this clear, and people often interpret them as saying that copies of GNU should always be distributed at little or no charge. That was never the intent; later on, the manifesto mentions the possibility of companies providing the service of distribution for a profit. Subsequently I have learned to distinguish

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1. [www.gnu.org/gnu/initial-announcement.html](http://www.gnu.org/gnu/initial-announcement.html)

2. [www.gnu.org/gnu/manifesto.html](http://www.gnu.org/gnu/manifesto.html)

carefully between “free” in the sense of freedom and “free” in the sense of price. Free software is software that users have the freedom to distribute and change. Some users may obtain copies at no charge, while others pay to obtain copies—and if the funds help support improving the software, so much the better. The important thing is that everyone who has a copy has the freedom to cooperate with others in using it.

In the manifesto, after explaining a little about the project and what has been accomplished so far, Stallman continues:

### **Why I Must Write GNU**

I consider that the golden rule requires that if I like a program I must share it with other people who like it. Software sellers want to divide the users and conquer them, making each user agree not to share with others. I refuse to break solidarity with other users in this way. I cannot in good conscience sign a nondisclosure agreement or a software license agreement. For years I worked within the Artificial Intelligence Lab to resist such tendencies and other inhospitalities, but eventually they had gone too far: I could not remain in an institution where such things are done for me against my will.

So that I can continue to use computers without dishonor, I have decided to put together a sufficient body of free software so that I will be able to get along without any software that is not free. I have resigned from the AI Lab to deny MIT any legal excuse to prevent me from giving GNU away.

## **NEXT SCENE, 1991**

The GNU Project has moved well along toward its goal. Much of the GNU operating system, except for the kernel, is complete. Richard Stallman later writes:

By the early '90s we had put together the whole system aside from the kernel (and we were also working on a kernel, the GNU Hurd,<sup>3</sup> which runs on top of Mach<sup>4</sup>). Developing this kernel has been a lot harder than we expected, and we are still working on finishing it.<sup>5</sup>

...[M]any believe that once Linus Torvalds finished writing the kernel, his friends looked around for other free software, and for no particular reason most everything necessary to make a UNIX-like system was already available.

3. [www.gnu.org/software/hurd/hurd.html](http://www.gnu.org/software/hurd/hurd.html)

4. [www.gnu.org/software/hurd/microkernel/mach.html](http://www.gnu.org/software/hurd/microkernel/mach.html)

5. [www.gnu.org/software/hurd/hurd-and-linux.html](http://www.gnu.org/software/hurd/hurd-and-linux.html)

What they found was no accident—it was the GNU system. The available free software<sup>6</sup> added up to a complete system because the GNU Project had been working since 1984 to make one. The GNU Manifesto had set forth the goal of developing a free UNIX-like system, called GNU. The Initial Announcement of the GNU Project also outlines some of the original plans for the GNU system. By the time Linux was written, the [GNU] system was almost finished.<sup>7</sup>

Today the GNU “operating system” runs on top of the FreeBSD ([www.freebsd.org](http://www.freebsd.org)) and NetBSD ([www.netbsd.org](http://www.netbsd.org)) kernels with complete Linux binary compatibility and on top of Hurd pre-releases and Darwin ([developer.apple.com/opensource](http://developer.apple.com/opensource)) without this compatibility.

## THE CODE IS FREE

The tradition of free software dates back to the days when UNIX was released to universities at nominal cost, which contributed to its portability and success. This tradition died as UNIX was commercialized and manufacturers regarded the source code as proprietary, making it effectively unavailable. Another problem with the commercial versions of UNIX related to their complexity. As each manufacturer tuned UNIX for a specific architecture, it became less portable and too unwieldy for teaching and experimentation.

MINIX Two professors created their own stripped-down UNIX look-alikes for educational purposes: Doug Comer created XINU ([www.cs.purdue.edu/research/xinu.html](http://www.cs.purdue.edu/research/xinu.html)) and Andrew Tanenbaum created MINIX ([www.minix3.org](http://www.minix3.org)). Linus Torvalds created Linux to counteract the shortcomings in MINIX. Every time there was a choice between code simplicity and efficiency/features, Tanenbaum chose simplicity (to make it easy to teach with MINIX), which meant that this system lacked many features people wanted. Linux goes in the opposite direction.

*You can obtain Linux at no cost over the Internet* (page 41). You can also obtain the GNU code via the U.S. mail at a modest cost for materials and shipping. You can support the Free Software Foundation ([www.fsf.org](http://www.fsf.org)) by buying the same (GNU) code in higher-priced packages, and you can buy commercial packaged releases of Linux (called *distributions*), such as Fedora/RHEL, that include installation instructions, software, and support.

GPL Linux and GNU software are distributed under the terms of the GNU General Public License (GPL, [www.gnu.org/licenses/licenses.html](http://www.gnu.org/licenses/licenses.html)). The GPL says you have the right to copy, modify, and redistribute the code covered by the agreement. When you redistribute the code, however, you must also distribute the same license with the code, making the code and the license inseparable. If you get source code off the

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6. See Appendix D or [www.gnu.org/philosophy/free-sw.html](http://www.gnu.org/philosophy/free-sw.html).

7. [www.gnu.org/gnu/linux-and-gnu.html](http://www.gnu.org/gnu/linux-and-gnu.html)



Internet for an accounting program that is under the GPL and then modify that code and redistribute an executable version of the program, you must also distribute the modified source code and the GPL agreement with it. Because this arrangement is the reverse of the way a normal copyright works (it gives rights instead of limiting them), it has been termed a *copyleft*. (This paragraph is not a legal interpretation of the GPL; it is here merely to give you an idea of how it works. Refer to the GPL itself when you want to make use of it.)

## HAVE FUN!

Two key words for Linux are “Have Fun!” These words pop up in prompts and documentation. The UNIX—now Linux—culture is steeped in humor that can be seen throughout the system. For example, *less* is *more*—GNU has replaced the UNIX paging utility named *more* with an improved utility named *less*. The utility to view PostScript documents is named *ghostscript*, and one of several replacements for the *vi* editor is named *elvis*. While machines with Intel processors have “Intel Inside” logos on their outside, some Linux machines sport “Linux Inside” logos. And Torvalds himself has been seen wearing a T-shirt bearing a “Linus Inside” logo.

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## THE LINUX 2.6 KERNEL

The Linux 2.6 kernel was released on December 17, 2003. This kernel has many features that offer increased security and speed. Some of these features benefit end users directly; others help developers produce better code and find problems more quickly.

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## THE HERITAGE OF LINUX: UNIX

The UNIX system was developed by researchers who needed a set of modern computing tools to help them with their projects. The system allowed a group of people working together on a project to share selected data and programs while keeping other information private.

Universities and colleges played a major role in furthering the popularity of the UNIX operating system through the “four-year effect.” When the UNIX operating system became widely available in 1975, Bell Labs offered it to educational institutions at nominal cost. The schools, in turn, used it in their computer science programs, ensuring that computer science students became familiar with it. Because UNIX was such an advanced development system, the students became acclimated to a sophisticated programming environment. As these students graduated and went into industry, they expected to work in a similarly advanced environment. As more of them worked their way up the ladder in the commercial world, the UNIX operating system found its way into industry.

In addition to introducing students to the UNIX operating system, the Computer Systems Research Group (CSRG) at the University of California at Berkeley made significant additions and changes to it. In fact, it made so many popular changes that one version of the system is called the Berkeley Software Distribution (BSD) of the UNIX system (or just Berkeley UNIX). The other major version is UNIX System V (SVR4), which descended from versions developed and maintained by AT&T and UNIX System Laboratories.

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## WHAT IS SO GOOD ABOUT LINUX?

In recent years Linux has emerged as a powerful and innovative UNIX work-alike. Its popularity is surpassing that of its UNIX predecessors. Although it mimics UNIX in many ways, the Linux operating system departs from UNIX in several significant ways: The Linux kernel is implemented independently of both BSD and System V, the continuing development of Linux is taking place through the combined efforts of many capable individuals throughout the world, and Linux puts the power of UNIX within easy reach of business and personal computer users. Using the Internet, today's skilled programmers submit additions and improvements to the operating system to Linus Torvalds, GNU, or one of the other authors of Linux.

- Applications A rich selection of applications is available for Linux—both free and commercial—as well as a wide variety of tools: graphical, word processing, networking, security, administration, Web server, and many others. Large software companies have recently seen the benefit in supporting Linux and now have on-staff programmers whose job it is to design and code the Linux kernel, GNU, KDE, or other software that runs on Linux. For example, IBM ([www.ibm.com/linux](http://www.ibm.com/linux)) is a major Linux supporter. Linux conforms increasingly more closely to POSIX standards, and some distributions and parts of others meet this standard. (See “Standards” on page 8 for more information.) These developments mean that Linux is becoming more mainstream and is respected as an attractive alternative to other popular operating systems.
- Peripherals Another aspect of Linux that appeals to users is the amazing range of peripherals that is supported and the speed with which support for new peripherals emerges. Linux often supports a peripheral or interface card before any company does. Unfortunately some types of peripherals—particularly proprietary graphics cards—lag in their support because the manufacturers do not release specifications or source code for drivers in a timely manner, if at all.
- Software Also important to users is the amount of software that is available—not just source code (which needs to be compiled) but also prebuilt binaries that are easy to install and ready to run. These include more than free software. Netscape, for example, has been available for Linux from the start and included Java support before it was available from many commercial vendors. Now its sibling Mozilla/Thunderbird/Firefox is also a viable browser, mail client, and newsreader, performing many other functions as well.
- Platforms Linux is not just for Intel-based platforms: It has been ported to and runs on the Power PC—including Apple computers (ppclinux), Compaq's (née Digital Equipment

Corporation) Alpha-based machines, MIPS-based machines, Motorola's 68K-based machines, various 64-bit systems, and IBM's S/390x. Nor is Linux just for single-processor machines: As of version 2.0, it runs on multiple-processor machines (SMPs). It also includes an  $O(1)$  scheduler, which dramatically increases scalability on SMP systems.

**Emulators** Linux supports programs, called *emulators*, that run code intended for other operating systems. By using emulators you can run some DOS, Windows, and Macintosh programs under Linux. Wine ([www.winehq.com](http://www.winehq.com)) is an open-source implementation of the Windows API on top of the X Window System and UNIX/Linux; QEMU ([www.nongnu.org/qemu](http://www.nongnu.org/qemu)) is a CPU-only emulator that executes x86 Linux binaries on non-x86 Linux systems.

**Xen** Xen, which was created at the University of Cambridge and is now being developed in the open-source community, is an open-source virtual machine monitor (VMM). A VMM enables several virtual machines (VMs), each running an instance of a separate operating system, to run on a single computer. Xen isolates the VMs so that if one crashes it does not affect any of the others. In addition, Xen introduces minimal performance overhead when compared with running each of the operating systems natively.

Using VMs, you can experiment with cutting-edge releases of operating systems and applications without concern for the base (stable) system, all on a single machine. You can also set up and test networks of systems on a single machine. Xen presents a *sandbox*, an area (system) that you can work in without regard for the results of your work or for the need to clean up.

Fedora 12 includes Xen 3.4. This book does not cover the installation or use of Xen. See [fedoraproject.org/wiki/Tools/Xen](http://fedoraproject.org/wiki/Tools/Xen) for installation instructions.

For more information on Xen, refer to the wiki at [wiki.xensource.com/xenwiki](http://wiki.xensource.com/xenwiki) and the Xen home page at [www.cl.cam.ac.uk/research/srg/netos/xen](http://www.cl.cam.ac.uk/research/srg/netos/xen).

## WHY LINUX IS POPULAR WITH HARDWARE COMPANIES AND DEVELOPERS

Two trends in the computer industry set the stage for the popularity of UNIX and Linux. First, advances in hardware technology created the need for an operating system that could take advantage of available hardware power. In the mid-1970s, minicomputers began challenging the large mainframe computers because, in many applications, minicomputers could perform the same functions less expensively. More recently, powerful 64-bit processor chips, plentiful and inexpensive memory, and lower-priced hard disk storage have allowed hardware companies to install multiuser operating systems on desktop computers.

**Proprietary operating systems** Second, with the cost of hardware continually dropping, hardware manufacturers could no longer afford to develop and support proprietary operating systems. A *proprietary* operating system is written and owned by the manufacturer of the hardware (for example, DEC/Compaq owns VMS). Today's manufacturers need a generic operating system that they can easily adapt to their machines.

Generic operating systems A *generic* operating system is written outside of the company manufacturing the hardware and is sold (UNIX, Windows) or given (Linux) to the manufacturer. Linux is a generic operating system because it runs on different types of hardware produced by different manufacturers. Of course, if manufacturers can pay only for development and avoid per-unit costs (as they have to pay to Microsoft for each copy of Windows they sell), manufacturers are much better off. In turn, software developers need to keep the prices of their products down; they cannot afford to convert their products to run under many different proprietary operating systems. Like hardware manufacturers, software developers need a generic operating system.

Although the UNIX system once met the needs of hardware companies and researchers for a generic operating system, over time it has become more proprietary as each manufacturer added support for specialized features and introduced new software libraries and utilities.

Linux emerged to serve both needs. It is a generic operating system that takes advantage of available hardware power.

## LINUX IS PORTABLE

A *portable* operating system is one that can run on many different machines. More than 95 percent of the Linux operating system is written in the C programming language, and C is portable because it is written in a higher-level, machine-independent language. (The C compiler is written in C.)

Because Linux is portable, it can be adapted (ported) to different machines and can meet special requirements. For example, Linux is used in embedded computers, such as the ones found in cellphones, PDAs, and the cable boxes on top of many TVs. The file structure takes full advantage of large, fast hard disks. Equally important, Linux was originally designed as a multiuser operating system—it was not modified to serve several users as an afterthought. Sharing the computer's power among many users and giving them the ability to share data and programs are central features of the system.

Because it is adaptable and takes advantage of available hardware, Linux runs on many different microprocessor-based systems as well as mainframes. The popularity of the microprocessor-based hardware drives Linux; these microcomputers are getting faster all the time, at about the same price point. Linux on a fast microcomputer has become good enough to displace workstations on many desktops. Linux benefits both users, who do not like having to learn a new operating system for each vendor's hardware, and system administrators, who like having a consistent software environment.

The advent of a standard operating system has aided the development of the software industry. Now software manufacturers can afford to make one version of a product available on machines from different manufacturers.

## STANDARDS

Individuals from companies throughout the computer industry have joined together to develop the POSIX (Portable Operating System Interface for Computer

Environments) standard, which is based largely on the UNIX System V Interface Definition (SVID) and other earlier standardization efforts. These efforts have been spurred by the U.S. government, which needs a standard computing environment to minimize its training and procurement costs. Now that these standards are gaining acceptance, software developers are able to develop applications that run on all conforming versions of UNIX, Linux, and other operating systems.

## THE C PROGRAMMING LANGUAGE

Ken Thompson wrote the UNIX operating system in 1969 in PDP-7 assembly language. Assembly language is machine dependent: Programs written in assembly language work on only one machine or, at best, one family of machines. The original UNIX operating system therefore could not easily be transported to run on other machines (it was not portable).

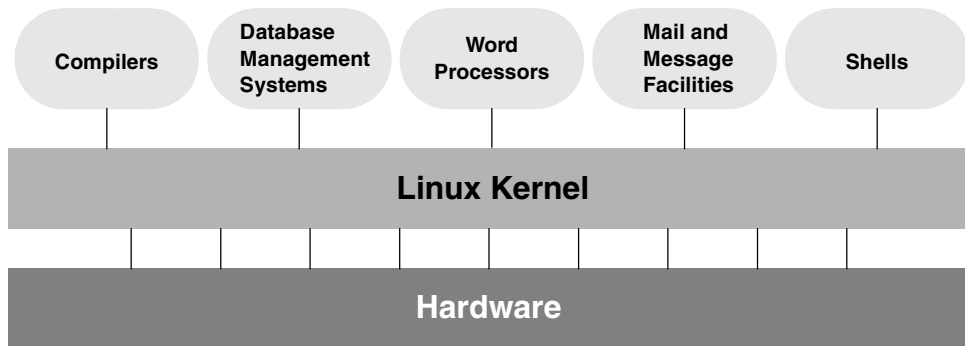
To make UNIX portable, Thompson developed the B programming language, a machine-independent language, from the BCPL language. Dennis Ritchie developed the C programming language by modifying B and, with Thompson, rewrote UNIX in C in 1973. The revised operating system could be transported more easily to run on other machines.

That development marked the start of C. Its roots reveal some of the reasons why it is such a powerful tool. C can be used to write machine-independent programs. A programmer who designs a program to be portable can easily move it to any computer that has a C compiler. C is also designed to compile into very efficient code. With the advent of C, a programmer no longer had to resort to assembly language to get code that would run well (that is, quickly—although an assembler will always generate more efficient code than a high-level language).

C is a good systems language. You can write a compiler or an operating system in C. It is highly structured but is not necessarily a high-level language. C allows a programmer to manipulate bits and bytes, as is necessary when writing an operating system. But it also has high-level constructs that allow efficient, modular programming.

In the late 1980s the American National Standards Institute (ANSI) defined a standard version of the C language, commonly referred to as *ANSI C* or *C89* (for the year the standard was published). Ten years later the *C99* standard was published; it is mostly supported by the GNU Project's C compiler (named *gcc*). The original version of the language is often referred to as *Kernighan & Ritchie* (or *K&R*) C, named for the authors of the book that first described the C language.

Another researcher at Bell Labs, Bjarne Stroustrup, created an object-oriented programming language named C++, which is built on the foundation of C. Because object-oriented programming is desired by many employers today, C++ is preferred over C in many environments. Another language of choice is Objective-C, which was used to write the first Web browser. The GNU Project's C compiler supports C, C++, and Objective-C.



**Figure 1-1** A layered view of the Linux operating system

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## OVERVIEW OF LINUX

The Linux operating system has many unique and powerful features. Like other operating systems, Linux is a control program for computers. But like UNIX, it is also a well-thought-out family of utility programs (Figure 1-1) and a set of tools that allow users to connect and use these utilities to build systems and applications.

### LINUX HAS A KERNEL PROGRAMMING INTERFACE

The Linux kernel—the heart of the Linux operating system—is responsible for allocating the computer’s resources and scheduling user jobs so that each one gets its fair share of system resources, including access to the CPU; peripheral devices, such as disk, DVD, and CD-ROM storage; printers; and tape drives. Programs interact with the kernel through *system calls*, special functions with well-known names. A programmer can use a single system call to interact with many kinds of devices. For example, there is one `write()` system call, not many device-specific ones. When a program issues a `write()` request, the kernel interprets the context and passes the request to the appropriate device. This flexibility allows old utilities to work with devices that did not exist when the utilities were originally written. It also makes it possible to move programs to new versions of the operating system without rewriting them (provided that the new version recognizes the same system calls).

### LINUX CAN SUPPORT MANY USERS

Depending on the hardware and the types of tasks that the computer performs, a Linux system can support from 1 to more than 1,000 users, each concurrently running a different set of programs. The per-user cost of a computer that can be used by many people at the same time is less than that of a computer that can be used by only a single person at a time. It is less because one person cannot generally take advantage of all the resources a computer has to offer. That is, no one can keep all

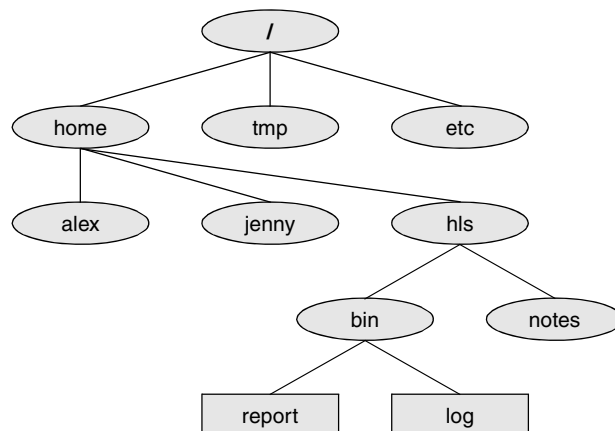
the printers going constantly, keep all the system memory in use, keep all the disks busy reading and writing, keep the Internet connection in use, and keep all the terminals busy at the same time. A multiuser operating system allows many people to use all the system resources almost simultaneously. The use of costly resources can be maximized and the cost per user can be minimized—the primary objectives of a multiuser operating system.

## LINUX CAN RUN MANY TASKS

Linux is a fully protected multitasking operating system, allowing each user to run more than one job at a time. Processes can communicate with one another but remain fully protected from one another, just as the kernel remains protected from all processes. You can run several jobs in the background while giving all your attention to the job being displayed on the screen, and you can switch back and forth between jobs. If you are running the X Window System (page 15), you can run different programs in different windows on the same screen and watch all of them. This capability ensures that users can be more productive.

## LINUX PROVIDES A SECURE HIERARCHICAL FILESYSTEM

A *file* is a collection of information, such as text for a memo or report, an accumulation of sales figures, an image, a song, or an executable program. Each file is stored under a unique identifier on a storage device, such as a hard disk. The Linux filesystem provides a structure whereby files are arranged under *directories*, which are like folders or boxes. Each directory has a name and can hold other files and directories. Directories, in turn, are arranged under other directories, and so forth, in a treelike organization. This structure helps users keep track of large numbers of files by grouping related files into directories. Each user has one primary directory and as many subdirectories as required (Figure 1-2).



**Figure 1-2** The Linux filesystem structure

- Standards With the idea of making life easier for system administrators and software developers, a group got together over the Internet and developed the Linux Filesystem Standard (FSSTND), which has since evolved into the Linux Filesystem Hierarchy Standard (FHS). Before this standard was adopted, key programs were located in different places in different Linux distributions. Today you can sit down at a Linux system and know where to expect to find any given standard program (page 198).
- Links A *link* allows a given file to be accessed by means of two or more names. The alternative names can be located in the same directory as the original file or in another directory. Links can make the same file appear in several users' directories, enabling those users to share the file easily. Windows uses the term *shortcut* in place of *link*. Macintosh users will be more familiar with the term *alias*. Under Linux, an *alias* is different from a *link*; it is a command macro feature provided by the shell (page 332).
- Security Like most multiuser operating systems, Linux allows users to protect their data from access by other users. It also allows users to share selected data and programs with certain other users by means of a simple but effective protection scheme. This level of security is provided by file access permissions, which limit which users can read from, write to, or execute a file. Access Control Lists (ACLs) have recently been added to the Linux kernel and are available in Fedora/RHEL. ACLs give users and administrators finer-grained control over file access permissions.

## THE SHELL: COMMAND INTERPRETER AND PROGRAMMING LANGUAGE

In a textual environment, the shell—the command interpreter—acts as an interface between you and the operating system. When you enter a command on the screen, the shell interprets the command and calls the program you want. A number of shells are available for Linux. The three most popular ones are described here:

- The Bourne Again Shell (*bash*), an enhanced version of the original Bourne Shell. It is one of the original UNIX shells.
- The TC Shell (*tcsh*), an enhanced version of the C Shell. It was developed as part of BSD UNIX.
- The Z Shell (*zsh*). It incorporates features from a number of shells, including the Korn Shell.

Because users often prefer different shells, multiuser systems can have several different shells in use at any given time. The choice of shells demonstrates one of the advantages of the Linux operating system: the ability to provide a customized interface for each user.

- Shell scripts Besides performing its function of interpreting commands from a keyboard and sending those commands to the operating system, the shell is a high-level programming language. Shell commands can be arranged in a file for later execution (Linux calls these files *shell scripts*; Windows call them *batch files*). This flexibility allows users to perform complex operations with relative ease, often with rather short



commands, or to build with surprisingly little effort elaborate programs that perform highly complex operations.

## FILENAME GENERATION

Wildcards and  
ambiguous file  
references

When you are typing commands to be processed by the shell, you can construct patterns using characters that have special meanings to the shell. These characters are called *wildcard* characters. The patterns, which are called *ambiguous file references*, are a kind of shorthand: Rather than typing in complete filenames, users can type in patterns and the shell will expand them into matching filenames. An ambiguous file reference can save you the effort of typing in a long filename or a long series of similar filenames. For example, the shell might expand the pattern **mak\*** to **make-3.80.tar.gz**. Patterns can also be useful when you know only part of a filename or cannot remember the exact spelling.

## DEVICE-INDEPENDENT INPUT AND OUTPUT

Redirection

Devices (such as a printer or terminal) and disk files appear as files to Linux programs. When you give a command to the Linux operating system, you can instruct it to send the output to any one of several devices or files. This diversion is called output *redirection*.

Device  
independence

In a similar manner, a program's input that normally comes from a keyboard can be redirected so that it comes from a disk file instead. Input and output are *device independent*; they can be redirected to or from any appropriate device.

As an example, the `cat` utility normally displays the contents of a file on the screen. When you run a `cat` command, you can easily cause its output to go to a disk file instead of the screen.

## SHELL FUNCTIONS

One of the most important features of the shell is that users can use it as a programming language. Because the shell is an interpreter, it does not compile programs written for it but rather interprets programs each time they are loaded from the disk. Loading and interpreting programs can be time-consuming.

Many shells, including the Bourne Again Shell, include shell functions that the shell holds in memory so that it does not have to read them from the disk each time you want to execute them. The shell also keeps functions in an internal format so that it does not have to spend as much time interpreting them.

## JOB CONTROL

*Job control* is a shell feature that allows users to work on several jobs at once, switching back and forth between them as desired. When you start a job, it is frequently in the foreground so it is connected to the terminal. Using job control, you can move the job you are working with into the background and continue running it there while working on or observing another job in the foreground. If a background

job then needs your attention, you can move it into the foreground so that it is once again attached to the terminal. The concept of job control originated with BSD UNIX, where it appeared in the C Shell.

## A LARGE COLLECTION OF USEFUL UTILITIES

Linux includes a family of several hundred utility programs, often referred to as *commands*. These utilities perform functions that are universally required by users. The *sort* utility, for example, puts lists (or groups of lists) in alphabetical or numerical order and can be used to sort lists by part number, last name, city, ZIP code, telephone number, age, size, cost, and so forth. The *sort* utility is an important programming tool and is part of the standard Linux system. Other utilities allow users to create, display, print, copy, search, and delete files as well as to edit, format, and typeset text. The *man* (for manual) and *info* utilities provide online documentation for Linux itself.

## INTERPROCESS COMMUNICATION

**Pipes and filters** Linux allows users to establish both pipes and filters on the command line. A *pipe* sends the output of one program to another program as input. A *filter* is a special kind of pipe that processes a stream of input data to yield a stream of output data. A filter processes another program's output, altering it as a result. The filter's output then becomes input to another program.

Pipes and filters frequently join utilities to perform a specific task. For example, you can use a pipe to send the output of the *cat* utility to *sort*, a filter, and can then use another pipe to send the output of *sort* to a third utility, *lp*, that sends the data to a printer. Thus, in one command line, you can use three utilities together to sort and print a file.

## SYSTEM ADMINISTRATION

On a Linux system the system administrator is frequently the owner and only user of the system. This person has many responsibilities. The first responsibility may be to set up the system and install the software.

Once the system is up and running, the system administrator is responsible for downloading and installing software (including upgrading the operating system), backing up and restoring files, and managing such system facilities as printers, terminals, servers, and a local network. The system administrator is also responsible for setting up accounts for new users on a multiuser system, bringing the system up and down as needed, and taking care of any problems that arise.

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## ADDITIONAL FEATURES OF LINUX

The developers of Linux included features from BSD, System V, and Sun Microsystems' Solaris, as well as new features, in their operating system. Although most of the tools found on UNIX exist for Linux, in some cases these tools have been replaced by more modern counterparts. This section describes some of the popular tools and features available under Linux.

## GUIs: GRAPHICAL USER INTERFACES

The X Window System (also called X or X11) was developed in part by researchers at MIT (Massachusetts Institute of Technology) and provides the foundation for the GUIs available with Linux. Given a terminal or workstation screen that supports X, a user can interact with the computer through multiple windows on the screen, display graphical information, or use special-purpose applications to draw pictures, monitor processes, or preview formatted output. X is an across-the-network protocol that allows a user to open a window on a workstation or computer system that is remote from the CPU generating the window.

**Desktop manager** Usually two layers run under X: a desktop manager and a window manager. A *desktop manager* is a picture-oriented user interface that enables you to interact with system programs by manipulating icons instead of typing the corresponding commands to a shell. Fedora/RHEL includes GNOME (Figure 1-3, [www.gnome.org](http://www.gnome.org)) and KDE ([www.kde.org](http://www.kde.org)), the most popular desktop managers.

**Window manager** A *window manager* is a program that runs under the desktop manager and allows you to open and close windows, run programs, and set up a mouse so it does various things depending on how and where you click. The window manager also gives the screen its personality. Whereas Microsoft Windows allows you to change the color

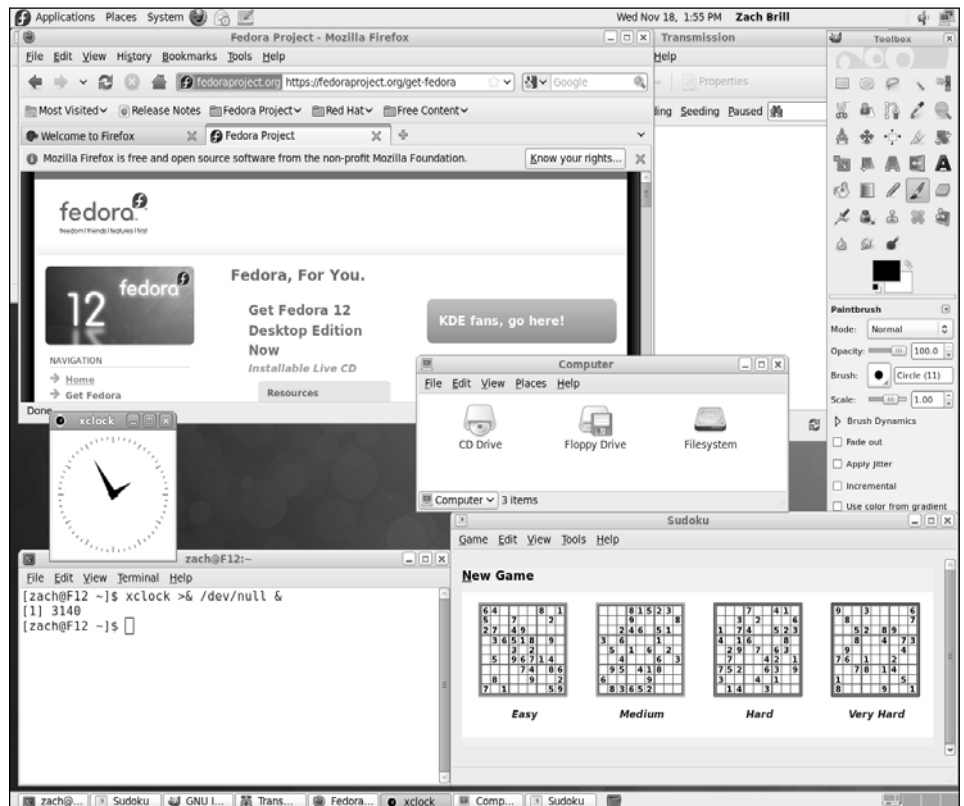


Figure 1-3 A GNOME workspace

of key elements in a window, a window manager under X allows you to customize the overall look and feel of the screen: You can change the way a window looks and works (by giving it different borders, buttons, and scrollbars), set up virtual desktops, create menus, and more.

Several popular window managers run under X and Linux. Fedora/RHEL provides Metacity (the default under GNOME) and kwin (the default under KDE). Other window managers, such as Sawfish and WindowMaker, are also available. Chapters 4 and 8 have more information on GUIs.

## **(INTER)NETWORKING UTILITIES**

Linux network support includes many utilities that enable you to access remote systems over a variety of networks. In addition to sending email to users on other systems, you can access files on disks mounted on other computers as if they were located on the local system, make your files available to other systems in a similar manner, copy files back and forth, run programs on remote systems while displaying the results on the local system, and perform many other operations across local area networks (LANs) and wide area networks (WANs), including the Internet.

Layered on top of this network access is a wide range of application programs that extend the computer's resources around the globe. You can carry on conversations with people throughout the world, gather information on a wide variety of subjects, and download new software over the Internet quickly and reliably. Chapter 10 discusses networks, the Internet, and the Linux network facilities.

## **SOFTWARE DEVELOPMENT**

One of Linux's most impressive strengths is its rich software development environment. You can find compilers and interpreters for many computer languages. Besides C and C++, languages available for Linux include Ada, Fortran, Java, Lisp, Pascal, Perl, and Python. The bison utility generates parsing code that makes it easier to write programs to build compilers (tools that parse files containing structured information). The flex utility generates scanners (code that recognizes lexical patterns in text). The make utility and the GNU Configure and Build System make it easier to manage complex development projects. Source code management systems, such as CVS, simplify version control. Several debuggers, including ups and gdb, help in tracking down and repairing software defects. The GNU C compiler (gcc) works with the gprof profiling utility to help programmers identify potential bottlenecks in a program's performance. The C compiler includes options to perform extensive checking of C code that can make the code more portable and reduce debugging time. Table B-4 on page 1038 lists some sites that you can download software from.

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## **CONVENTIONS USED IN THIS BOOK**

This book uses conventions to make its explanations shorter and clearer. The following paragraphs describe these conventions.

Fedora/RHEL	In this book, the term Fedora/RHEL refers to both Fedora and Red Hat Enterprise Linux. Features that apply to one operating system or the other only are marked as such, using these markers: <i>FEDORA</i> or <i>RHEL</i> .
Text and examples	The text is set in this type, whereas examples are shown in a monospaced font (also called a <i>fixed-width</i> font): <div style="margin-left: 40px;"> <pre>\$ cat practice This is a small file I created with a text editor.</pre> </div>
Items you enter	Everything you enter at the keyboard is shown in a bold typeface: Within the text, <b>this bold typeface</b> is used; within examples and screens, <b>this one</b> is used. In the previous example, the dollar sign (\$) on the first line is a prompt that Linux displays, so it is not bold; the remainder of the first line is entered by a user, so it is bold.
Utility names	Names of utilities are printed in this sans serif typeface. This book references the <b>emacs</b> text editor and the <b>ls</b> utility or <b>ls</b> command (or just <b>ls</b> ) but instructs you to enter <b>ls -a</b> on the command line. In this way the text distinguishes between utilities, which are programs, and the instructions you give on the command line to invoke the utilities.
Filenames	Filenames appear in a bold typeface. Examples are <b>memo5</b> , <b>letter.1283</b> , and <b>reports</b> . Filenames may include uppercase and lowercase letters; however, Linux is <i>case sensitive</i> (page 1073), so <b>memo5</b> , <b>MEMO5</b> , and <b>Memo5</b> name three different files.
Character strings	Within the text, characters and character strings are marked by putting them in a bold typeface. This convention avoids the need for quotation marks or other delimiters before and after a string. An example is the following string, which is displayed by the <b>passwd</b> utility: <b>Sorry, passwords do not match.</b>
Buttons and labels	Words appear in a bold typeface in the sections of the book that describe a GUI. This font indicates that you can click a mouse button when the mouse pointer is over these words on the screen or over a button with this name.
Keys and characters	This book uses SMALL CAPS for three kinds of items: <ul style="list-style-type: none"> <li>• Keyboard keys, such as the SPACE bar and the RETURN,<sup>8</sup> ESCAPE, and TAB keys.</li> <li>• The characters that keys generate, such as the SPACES generated by the SPACE bar.</li> <li>• Keyboard keys that you press with the CONTROL key, such as CONTROL-D. (Even though D is shown as an uppercase letter, you do not have to press the SHIFT key; enter CONTROL-D by holding the CONTROL key down and pressing d.)</li> </ul>
Prompts and RETURNS	Most examples include the <i>shell prompt</i> —the signal that Linux is waiting for a command—as a dollar sign (\$), a pound sign (#), or sometimes a percent sign (%).

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8. Different keyboards use different keys to move the *cursor* (page 1077) to the beginning of the next line. This book always refers to the key that ends a line as the RETURN key. Your keyboard may have a RET, NEWLINE, ENTER, RETURN, or other key. Use the corresponding key on your keyboard each time this book asks you to press RETURN.

The prompt is not in a bold typeface because you do not enter it. Do not type the prompt on the keyboard when you are experimenting with examples from this book. If you do, the examples will not work.

Examples *omit* the RETURN keystroke that you must use to execute them. An example of a command line is

```
$ vim memo.1204
```

To use this example as a model for running the vim text editor, give the command **vim memo.1204** and press the RETURN key. (Press ESCAPE ZZ to exit from vim; see page 174 for a vim tutorial.) This method of entering commands makes the examples in the book correspond to what appears on the screen.

**Menu selection path** The menu selection path is the name of the menu or the location of the menu, followed by a colon, a SPACE, and the menu selection(s) separated by ⇨s. The entire menu selection path is in **bold** type. You can read **Konqueror menubar: Tools⇨Find** as “From the Konqueror menubar, select **Tools**; from **Tools**, select **Find**.”

**Definitions** All glossary entries marked with <sup>FOLDOC</sup> are courtesy of Denis Howe, editor of the Free Online Dictionary of Computing ([www.foldoc.org](http://www.foldoc.org)), and are used with permission. This site is an ongoing work containing definitions, anecdotes, and trivia.

## **optional** OPTIONAL INFORMATION

Passages marked as optional appear in a gray box and are not central to the ideas presented in the chapter but often involve more challenging concepts. A good strategy when reading a chapter is to skip the optional sections and then return to them when you are comfortable with the main ideas presented in the chapter. This is an optional paragraph.

**URLs (Web addresses)** Web addresses, or URLs, have an implicit **http://** prefix, unless **ftp://** or **https://** is shown. You do not normally need to specify a prefix when the prefix is **http://**, but you must use a prefix from a browser when you specify an FTP or secure HTTP site. Thus you can specify a URL in a browser exactly as shown in this book.

**Tip, caution, and security boxes** The following boxes highlight information that may be helpful while you are using or administrating a Linux system.

### **This is a tip box**

**tip** A tip box may help you avoid repeating a common mistake or may point toward additional information.

### **This box warns you about something**

**caution** A caution box warns you about a potential pitfall.

### **This box marks a security note**

**security** A security box highlights a potential security issue. These notes are usually for system administrators, but some apply to all users.

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## CHAPTER SUMMARY

The Linux operating system grew out of the UNIX heritage to become a popular alternative to traditional systems (that is, Windows) available for microcomputer (PC) hardware. UNIX users will find a familiar environment in Linux. Distributions of Linux contain the expected complement of UNIX utilities, contributed by programmers around the world, including the set of tools developed as part of the GNU Project. The Linux community is committed to the continued development of this system. Support for new microcomputer devices and features is added soon after the hardware becomes available, and the tools available on Linux continue to be refined. With many commercial software packages available to run on Linux platforms and many hardware manufacturers offering Linux on their systems, it is clear that the system has evolved well beyond its origin as an undergraduate project to become an operating system of choice for academic, commercial, professional, and personal use.

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## EXERCISES

1. What is free software? List three characteristics of free software.
2. Why is Linux popular? Why is it popular in academia?
3. What are multiuser systems? Why are they successful?
4. What is the Free Software Foundation/GNU? What is Linux? Which parts of the Linux operating system did each provide? Who else has helped build and refine this operating system?
5. In what language is Linux written? What does the language have to do with the success of Linux?
6. What is a utility program?
7. What is a shell? How does it work with the kernel? With the user?
8. How can you use utility programs and a shell to create your own applications?
9. Why is the Linux filesystem referred to as *hierarchical*?
10. What is the difference between a multiprocessor and a multiprocessing system?
11. Give an example of when you would want to use a multiprocessing system.
12. Approximately how many people wrote Linux? Why is this unique?
13. What are the key terms of the GNU General Public License?

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# PART I

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## INSTALLING FEDORA AND RED HAT ENTERPRISE LINUX

### CHAPTER 2

INSTALLATION OVERVIEW 23

### CHAPTER 3

STEP-BY-STEP INSTALLATION 51

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# INSTALLATION OVERVIEW

## IN THIS CHAPTER

Planning the Installation .....	24
Setting Up the Hard Disk .....	30
LVM: Logical Volume Manager ....	38
The Installation Process .....	39
The Medium: Where Is the Source Data? .....	40
Downloading a CD/DVD ( <i>FEDORA</i> ) .....	41
Using BitTorrent to Download a CD/DVD ISO Image File .....	44
Rescue Selection of the Install DVD .....	46
Gathering Information About the System .....	46
More Information .....	48

Installing Fedora/RHEL is the process of copying operating system files from media to the local system and setting up configuration files so Linux runs properly on the hardware. You can install Linux from many types of media, including a CD/DVD, the local hard disk, a USB flash drive, or a hard disk on another system that is accessed over a network. Several types of installations are possible, including fresh installations, upgrades from older versions of Fedora/RHEL, dual-boot installations, and virtual machine installations. You can perform the installation manually or set up Kickstart to install Fedora/RHEL automatically.

This chapter discusses the installation process in general: planning, partitioning the hard disk, obtaining the files for the installation, burning a CD/DVD if necessary, and collecting information about the hardware. Chapter 3 covers the process of installing Fedora/RHEL.

Red Hat developed Anaconda, an installation tool that performs an interactive installation using a graphical or textual interface, to automate and make friendlier the process of

installing Linux. To install Linux on standard hardware, you can typically insert a CD/DVD, boot the system, and press RETURN a few times. Sometimes, however, you may want to customize the system or you may be installing on nonstandard hardware: Anaconda gives you many choices as the installation process unfolds. Refer to “The Anaconda Installer” on page 57 and “Modifying Boot Parameters (Options)” on page 68 for information about customizing a Fedora/RHEL installation.

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## THE DESKTOP LIVE CD AND THE INSTALL DVD

**Live CD** This book refers to the Fedora Desktop Live Media as a *live CD*. A live CD runs Fedora without installing it on the system. When you boot from this CD, it brings up a GNOME desktop: You are running a live session. If you boot from the Fedora KDE Live Media CD, it brings up a KDE desktop running a live session. When you exit from a live session, the system is as it was before you booted from the CD. If the system has a swap partition (most Linux systems have one; see page 34), the live session uses it to improve its performance but does not otherwise write to the hard disk. You can install Fedora from a live session. Red Hat Enterprise Linux does not provide a live session.

Booting a live CD is a good way to test hardware and fix a system that will not boot from the hard disk. A live session is ideal for people who are new to Fedora or Linux and want to experiment with Fedora but who are not ready to install it on their system. It also provides a simpler path for installing Fedora than does an install DVD.

**Install DVD** This book refers to the Install Media, which is provided as a single DVD (included with this book) or as a set of CDs, as an *install DVD*. An install DVD does not bring up a desktop before you install Fedora/RHEL. When you boot an install DVD, it brings up a menu that allows you to install Fedora/RHEL. An install DVD gives you more choices when you install Fedora than does a live CD. For example, an install DVD allows you to use the graphical installer or the textual installer (use the **text** parameter when booting; see page 71) or to rescue an installed system (select **Rescue installed system** from the Welcome menu; see page 56). You can also rescue an installed system using the first installation CD or the Net Boot CD.

**Net Boot CD** The Net Boot CD (formerly the Boot CD) boots a system and displays the same menu as an install DVD (above). It does not hold the software packages needed to install Fedora/RHEL but does allow you to install a new system from a hard disk or over a network. See **askmethod** on page 70 for more information.

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## PLANNING THE INSTALLATION

The major decisions when planning an installation are determining how to divide the hard disk into partitions or, in the case of a dual-boot system, where to put the

Linux partitions, and, in some cases, deciding which software packages to install. When you install Fedora/RHEL on a virtual machine, you must decide where to put the virtual machine files. In addition to these topics, this section discusses hardware requirements for Fedora/RHEL, Fedora versus RHEL, and fresh installations versus upgrades.

## CONSIDERATIONS

**SELinux** SELinux (Security Enhanced Linux) improves system security by implementing mandatory access control policies in the Fedora/RHEL kernel (page 414). By default, Fedora installs SELinux in Enforcing mode. If you do not plan to use SELinux, you can change it to Permissive mode once the system is installed. When you install RHEL, if you plan to use SELinux under RHEL, allow it to remain in Enforcing mode, or change it to Permissive mode, but do not disable it during First-boot (page 67). Because SELinux sets extended attributes on files, it can be a time-consuming process to enable SELinux on a system on which it has been turned off.

**GUI** On most installations (except for servers), you will probably want to install a graphical desktop environment. GNOME is installed by default. You can also install KDE or both GNOME and KDE.

On a server, you normally dedicate as many resources to the server as possible and few resources to anything not required by the server. For this reason, dedicated servers rarely include a graphical interface.

**Software and services** As you install more software packages on a system, the number of updates and the interactions between the packages increase. Server packages that listen for network connections make the system more vulnerable by increasing the number of ways in which the system can be attacked. Additional services can also slow the system down.

If you want a system to learn on, or if you want a development system, additional packages and services may be useful. If the goal is a more secure production system, it is best to install and maintain the minimum number of packages required and to enable only the services you need.

## REQUIREMENTS

**Hardware** Fedora/RHEL can run on many different types of hardware. This section details installation on 32-bit Intel and compatible platforms such as AMD and VIA as well as 64-bit platforms such as AMD64 processors (both Athlon64 and Opteron), Intel processors with Intel Extended Memory 64 Technology (EM64T) including the Core and Core 2 series, and Intel Itanium (IA-64) processors.

Within these platforms, Fedora/RHEL runs on much of the available hardware. You can find Red Hat's list of compatible and supported hardware at [hardware.redhat.com](http://hardware.redhat.com). Although these lists apply to Red Hat Enterprise Linux, they serve as a good guide to what Fedora will run on. The release notes also provide hardware information (see the installation DVD, the first installation CD, or the Fedora/RHEL Web sites). Many Internet sites discuss Linux hardware; use Google

([www.google.com/linux](http://www.google.com/linux)) to search on **linux hardware**, **fedora hardware**, or **linux** and the specific hardware you want more information on (e.g., **linux sata** or **linux a8n**). In addition, many HOWTOs (page 130) cover specific hardware. There is also a *Linux Hardware Compatibility HOWTO*, although it becomes dated rather quickly.

Fedora/RHEL usually runs on the same systems that Windows runs on, unless the system includes a very new or unusual component.

**Memory (RAM)** You need a minimum of 128 megabytes of RAM for a 32-bit x86 system that runs in text mode (no GUI) and 192–256 megabytes for a graphical system. For a 64-bit x86\_64 system, you need at least 256 megabytes for text mode and 384–512 megabytes for a graphical system. Linux makes good use of extra memory: The more memory a system has, the faster it will run. Adding memory is one of the most cost-effective ways you can speed up a system.

**CPU** Fedora requires a minimum of a 200-megahertz Pentium-class processor or the equivalent AMD or other processor for textual mode. Fedora graphical mode and RHEL require at least a 400-megahertz Pentium Pro or Pentium II processor or the equivalent.

**Hard disk space** The amount of hard disk space you need depends on which version of Fedora/RHEL you install, which packages you install, how many languages you install, and how much space you need for user data (your files). The operating system can occupy from about 300 megabytes to more than 9 gigabytes.

**BIOS setup** Modern computers can be set to boot from a CD/DVD, floppy diskette, hard disk, or USB flash drive, and from the network via a PXE server. The BIOS determines the order in which the system tries to boot from each device. You may need to change this order: Make sure the BIOS is set up to try booting first from the device you are using.

**CMOS** CMOS is the persistent memory that stores system configuration information. To change the BIOS setup, you need to edit the information stored in CMOS. When the system boots, it displays a brief message about how to enter System Setup or CMOS Setup mode. Usually you need to press **Del** or **F2** while the system is booting. Press the key that is called for and then move the cursor to the screen and line that deal with booting the system. Generally there is a list of three or four devices the system tries to boot from; if the first attempt fails, the system tries the second device, and so on. Manipulate the list so the device you are using is the first choice, save your choices, and reboot. Refer to the hardware/BIOS manual for more information.

## PROCESSOR ARCHITECTURE

Fedora/RHEL CDs and DVDs hold programs compiled to run on a specific processor architecture (class of processors, or CPUs). The following list describes each of the architectures Fedora/RHEL is compiled for. See [docs.fedoraproject.org/install-guide/f12/en-US/html/ch-new-users.html#sn-which-arch](http://docs.fedoraproject.org/install-guide/f12/en-US/html/ch-new-users.html#sn-which-arch) for a detailed list of processors in each architecture. Because Linux source code is available to everyone, a knowledgeable user can compile Fedora/RHEL to run on other processor architectures.

## Should I install 32-bit or 64-bit Fedora/RHEL on a 64-bit-capable processor?

**tip** The following list may help you decide whether to install 32-bit or 64-bit Fedora/RHEL on a 64-bit-capable processor.

- EM64T/AMD64 processors can run either version of Fedora/RHEL equally well.
- A 64-bit distribution allows each process to address more than 4 gigabytes of RAM. Larger address space is the biggest advantage of a 64-bit distribution and is typically useful only for certain engineering/scientific computational work and when you are running multiple virtual systems.
- A 64-bit processor is not faster than a 32-bit processor in general. Most benchmarks show more or less similar performance. In some cases the performance is better and in some cases it is worse. There is no clear performance advantage for either type of processor.
- The memory model for 64-bit Linux makes pointers twice as big as for 32-bit Linux. This size difference translates to a more than 5 percent RAM usage increase depending on the application. If a system is low on RAM, this overhead may make performance worse.
- Because more people are using 32-bit Linux, bugs in 32-bit Linux tend to be discovered and fixed faster than those in 64-bit Linux.
- Fedora/RHEL can set up Flashplayer and Java with a single click on 64-bit systems just as it can on 32-bit systems. However, for some applications, such as Skype, you must apply ugly workarounds to run them on 64-bit systems.
- There is no simple way to go back and forth between 32-bit and 64-bit versions of Fedora/RHEL without reinstalling Fedora/RHEL.
- If you are not sure which distribution to use, install the 32-bit version of Fedora/RHEL.

PC (i386) Software on an Fedora/RHEL i386 CD/DVD is compiled to run on Intel x86-compatible processors, including most machines with Intel and AMD processors, almost all machines that run Microsoft Windows, and newer Apple Macintosh machines that use Intel processors. If you are not sure which type of processor a machine has, assume it has this type of processor. Exceptions are the following Intel processors: Atom 230, Atom 330, Core 2 Duo, Centrino Core2 Duo, and newer Xeon; the following AMD processors: Athlon 64, Athlon x2, Sempron 64, and Opteron; and the C3 and C7 VIA processors.

64-bit PC (x86\_64) Software on an Fedora/RHEL 64-bit PC CD/DVD is compiled to run on Intel processors, including the Intel Atom 230, Atom 330, Core 2 Duo, Centrino Core 2 Duo, and Xeon; AMD processors including the Athlon 64, Athlon x2, Sempron64, and Opteron; and the Apple MacBook, MacBook Pro, and MacBook Air.

Because some features of proprietary third-party applications are not available for 64-bit architecture, you may want to run Fedora/RHEL compiled for a 32-bit (i386) processor on a system with a 64-bit processor (see the preceding tip).

Mac PowerPC (ppc) The Fedora/RHEL PPC release runs on the Apple Macintosh G3, G4, G5, PowerBook, and PPC-based Macintoshes.

## INTERFACES: INSTALLER AND INSTALLED SYSTEM

When you install Fedora/RHEL, you have a choice of interfaces to use while you install it (to work with the installer) and a choice of interfaces to use when you work with the installed system. This section describes the two basic interfaces: textual and graphical.

**Textual interface (CLI)** A textual interface, also called a command-line interface (CLI) or character-based interface, displays characters and some simple graphical symbols. It is line oriented; you give it instructions using a keyboard only.

**Pseudographical interface** A pseudographical interface, sometimes referred to as a textual user interface (TUI), takes advantage of graphical elements on a text-based display device such as a terminal. It may also use color. This interface uses text elements, including simple graphical symbols, to draw rudimentary boxes that emulate GUI windows and buttons. The TAB key frequently moves the cursor from one element to the next and the RETURN or SPACE key selects the element the cursor is on; you give it instructions using a keyboard only.

**Graphical interface (GUI)** A graphical user interface (GUI) typically displays a desktop (such as GNOME or KDE) and windows; you give it instructions using a mouse and keyboard. You can run a textual interface within a GUI by opening a terminal emulator window (page 118). A GUI uses more computer resources (CPU time and memory) than a textual interface does.

**Advantages** A GUI is user friendly, whereas a textual interface is compact, uses fewer system resources, and can work on a text-only terminal. You can run GUI tools remotely (over a network) using ssh (page 638). Because it is more efficient, a textual interface is useful for older, slower systems and systems with minimal amounts of RAM. Server systems frequently use textual interfaces because they allow the system to dedicate more resources to the job it is set up to do and fewer resources to pleasing the system administrator. Not running a GUI can also improve system security.

**Installer interfaces** Fedora/RHEL provides a user-friendly, graphical installer interface and an efficient, pseudographical installer interface (Figure 2-1). Both interfaces accomplish the same task: They enable you to tell the installer how you want it to configure Fedora/RHEL. The pseudographical interface gives you fewer choices, however.

## WHICH ARE YOU INSTALLING: FEDORA OR RED HAT ENTERPRISE LINUX?

This book describes two products: Fedora and Red Hat Enterprise Linux. This section briefly highlights the differences between these products.

**FEDORA** The Fedora Project is sponsored by Red Hat and supported by the open-source community. With releases, called Fedora, coming out about every six months, this Linux distribution incorporates cutting-edge code. It is *not* a supported Red Hat product and is *not* recommended for production environments where the set of software packages and features must remain constant over a longer period of time.





**Figure 2-1** Graphical (left) and textual (pseudographical, inset) installers

Fedora aims to reflect the upstream projects it incorporates, including the kernel. It is widely regarded as the most stable “free” Linux distribution. In contrast, Red Hat Enterprise Linux includes many changes introduced by Fedora.

**RHEL** Red Hat Enterprise Linux is typically sold through an annual subscription that includes access to the Red Hat Network (RHN; page 516) and technical support. It is more stable but less cutting edge than Fedora. RHEL provides at least 7 years of updates; Fedora provides 13 months.

Red Hat Enterprise Linux and Red Hat Enterprise Linux Advanced Platform function identically and are designed to run servers. The former is licensed for systems with one or two physical CPU chips and up to four virtual guests. The latter is licensed for systems with any number of CPU chips and virtual guests.

Red Hat Enterprise Linux Desktop runs office productivity and software development applications. This operating system comes in several versions that support systems with one or two CPUs, various amounts of RAM, and various numbers of virtual clients. It is not designed for a production server environment. See [www.redhat.com/rhel/compare](http://www.redhat.com/rhel/compare) for more information on the various versions of RHEL.

**CentOS** CentOS ([www.centos.org](http://www.centos.org)) is a free, RHEL-compatible Linux distribution. It has more long-term stability than Fedora but has less support than RHEL. Because CentOS is RHEL compatible, this book also describes CentOS.

## UPGRADING AN EXISTING FEDORA/RHEL SYSTEM VERSUS INSTALLING A FRESH COPY

**Upgrade** An *upgrade* replaces the Linux kernel and utilities on an already-installed version of Fedora/RHEL with newer versions. During an upgrade, the installation program

attempts to preserve both system and user data files. An upgrade brings utilities that are present in the old version up-to-date but does not install new utilities except as needed to satisfy dependencies (you can install them later if you like). Existing, modified configuration files are preserved; new ones are added with a **.rpmnew** file-name extension. A log of the upgrade is kept in **/root/upgrade.log**. Before you upgrade a system, back up all files on the system.

**Preupgrade (FEDORA)** A preupgrade provides a GUI interface that allows you to upgrade from a previous version of Fedora (9 or higher) to the current version. It performs all downloads in the background while you work. After downloading the necessary software packages and rebooting, Fedora starts the installer and performs the upgrade. See [fedoraproject.org/wiki/How\\_to\\_use\\_PreUpgrade](http://fedoraproject.org/wiki/How_to_use_PreUpgrade) for more information.

**Clean install** An *installation*, sometimes referred to as a *clean install*, writes all fresh data to a hard disk. The installation program overwrites all system programs and data as well as the kernel. You can preserve some user data during an installation depending on where it is located and how you format/partition the hard disk. Be sure to back up all data and configuration files that will be overwritten by a clean install.

---

### A clean install yields a more stable system than an upgrade

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**caution** For better system consistency, Red Hat recommends that you back up data on a system and perform a clean install rather than an upgrade.

---

## SETTING UP THE HARD DISK

**Free space** A hard disk must be prepared in several ways so Linux can write to and read from it. Low-level formatting is the first step in preparing a disk for use. You do not need to perform this task, as it is done at the factory. The next steps in preparing a hard disk for use are to write a partition table to it and to create partitions on the disk. Finally, you need to create filesystems on the partitions. The area of the disk not occupied by partitions is called *free space*. A new disk has no partition table and no partitions. Under DOS/Windows, the term *formatting* means creating a filesystem on a partition; see “Filesystems” on the next page.

**Partitions** A *partition*, or *slice*, is a logical section of a hard disk that has a device name, such as **/dev/sda1**, so you can refer to it separately from other sections. For normal use, you must create at least one partition on a hard disk (pages 31 and following). From a live session, and after you install Fedora/RHEL, you can use the **palimpsest** disk utility (page 78) to view, resize, and create partitions on an existing system. During installation, you can use the Disk Druid partitioner (page 60) to create partitions. After installation, you can use **parted** (page 568), **palimpsest** (page 78), or **fdisk** to manipulate partitions. See **/dev** on page 468 for more information on device names.

**Partition table** A partition table holds information about the partitions on a hard disk. Before the first partition can be created on a disk, the program creating the partition must set up an empty partition table on the disk. As partitions are added, removed, and modified, information about these changes is recorded in the partition table. If you remove the partition table, you can no longer access information on the disk except by extraordinary means.

- LVM** By default, during installation Disk Druid sets up logical volumes (LVs) that function like partitions. With LVs, you can use the Logical Volume Manager (LVM; page 38) to change the sizes of volumes. Using LVM to manipulate LVs is more convenient than working with one of the tools that manipulates partitions.
- Filesystems** Before most programs can write to a partition, a *data structure* (page 1078), called a *filesystem*, needs to be written to the partition. This data structure holds inodes (page 481) that map locations on the disk that store files to the names of the files. At the top of the data structure is a single unnamed directory. As will be explained shortly, this directory joins the system directory structure when the filesystem is mounted.

When the Fedora/RHEL installer creates a partition, it also automatically writes a filesystem to the partition. You can use the `mkfs` (make filesystem; page 439) utility, which is similar to the DOS/Windows `format` utility, to manually create a filesystem on a partition. Table 12-1 on page 485 lists some common types of filesystems. Fedora 11 and later create `ext4` filesystems, whereas RHEL 5.4 and Fedora 10 and earlier create `ext3` filesystems. Unless you have reason to use another filesystem type, use `ext4` (Fedora) or `ext3` (RHEL). Windows uses FAT16, FAT32, and NTFS filesystems. Apple uses HFS (Hierarchical Filesystem) and HFS+. OS X uses either HFS+ or UFS. Different types of filesystems can coexist in different partitions on a single hard disk, including both Windows and Linux filesystems.

## PRIMARY, EXTENDED, AND LOGICAL PARTITIONS

You can divide a disk into a maximum of 15 partitions. You can use each partition independently for swap devices, filesystems, databases, other resources, and even other operating systems. Fedora/RHEL recommend the use of LVM (page 38) for partition management.

- Primary and extended partitions** Unfortunately, disk partitions follow the template established for DOS machines a long time ago. At most, a disk can hold four *primary partitions*. You can divide one (and only one) of these primary partitions into multiple *logical partitions*; this divided primary partition is called an *extended partition*. If you want more than four partitions on a drive—and you frequently do—you must set up an extended partition.

A typical disk is divided into three primary partitions (frequently numbered 1, 2, and 3) and one extended partition (frequently numbered 4). The three primary partitions are the sizes you want the final partitions to be. The extended partition occupies the rest of the disk. Once you establish the extended partition, you can subdivide it into additional logical partitions (numbered 5 or greater), each of which is the size you want. You cannot use the extended partition (number 4)—only the logical partitions it holds. Figure 16-3 on page 569 illustrates the disk described in this paragraph. See the *Linux Partition HOWTO* ([tldp.org/HOWTO/Partition](http://tldp.org/HOWTO/Partition)) for more information.

LVM solves the issue of extended partitions: It allows you to create many filesystems within a single partition in a much more elegant way than is possible with extended partitions.

## THE LINUX DIRECTORY HIERARCHY

### Skip this section for a basic installation

**tip** This section briefly describes the Linux directory hierarchy so you may better understand some of the decisions you may need to make when you divide the hard disk into partitions while installing Linux. You do not have to read this section to install Linux. You can use the default partitioning layout (pages 61) to set up the disk and return to this section when and if you want to. See the beginning of Chapter 6 for a more thorough explanation of the Linux directory hierarchy.

---

Namespace	A <i>namespace</i> is a set of names (identifiers) in which each name is unique.
Windows versus Linux	As differentiated from a Windows machine, a Linux system presents a single namespace that holds all files, including directories, on the local system. The Linux system namespace is called the <i>directory hierarchy</i> or <i>directory tree</i> . Under Windows, C:\ is a separate namespace from D:\. The directory hierarchy rooted at C:\ is separate from the directory hierarchy rooted at D:\ and there is no path or connection between them. Under Linux, the single system namespace is rooted at /, which is the <i>root directory</i> . Under the root directory are top-level subdirectories such as <b>bin</b> , <b>boot</b> , etc, <b>home</b> , and <b>usr</b> .
Absolute pathnames	All files on a Linux system, including directories, have a unique identifier called an <i>absolute pathname</i> . An absolute pathname traces a path through the directory hierarchy starting at the root directory and ending at the file or directory identified by the pathname. Thus the absolute pathname of the top-level directory named <b>home</b> is <b>/home</b> . See page 193 for more information.
Slashes (/) in pathnames	Within a pathname, a slash (/) follows (appears to the right of) the name of a directory. Thus <b>/home/sam</b> specifies that the ordinary or directory file named <b>sam</b> is located in the directory named <b>home</b> , which is a subdirectory of the root directory (/). The pathname <b>/home/sam/</b> specifies that <b>sam</b> is a directory file. In most instances this distinction is not important. The root directory is implied when a slash appears at the left end of a pathname or when it stands alone.
Linux system namespace	The Linux system namespace comprises the set of absolute pathnames of all files, including directories, in the directory hierarchy of a system.

## MOUNT POINTS

A filesystem on a partition holds no information about where it will be mounted in the directory hierarchy (the top-level directory of a filesystem does not have a name). When you use the installer to create most partitions, you specify the type of filesystem to be written to the partition and the name of a directory that Fedora/RHEL associates with the partition.

Mounting a filesystem associates the filesystem with a directory in the directory hierarchy. You can mount a filesystem on any directory in the directory hierarchy. The directory that you mount a filesystem on is called a *mount point*. The directory you specify when you use the installer to create a partition is the mount point for the partition. Most mount points are top-level subdirectories, with a few exceptions (such as **/usr/local**, which is frequently used as a mount point).

## Do not create files on mount points before mounting a filesystem

**caution** Do not put any files in a directory that is a mount point while a filesystem is not mounted on that mount point. Any files in a directory that is used as a mount point are covered up while the filesystem is mounted on that directory; you will not be able to access them. They reappear when the filesystem is unmounted.

For example, suppose the second partition on the first hard disk has the device name `/dev/sda2`. To create an `ext4` filesystem that will appear as `/home` in the directory hierarchy, you must instruct Linux to mount the `/dev/sda2` partition on `/home` when the system boots. With this filesystem mounted on its normal mount point, you can access it as the `/home` directory.

**Filesystem independence** The state of one filesystem does not affect other filesystems: One filesystem on a drive may be corrupt and unreadable, while other filesystems function normally. One filesystem may be full so you cannot write to it, while others have plenty of room for more data.

**/etc/fstab** The file that holds the information relating partitions to mount points is `/etc/fstab` (filesystem table; page 490). The associations stored in the `fstab` file are normal for the system, but you can easily override them. When you work in recovery mode, you may mount a filesystem on the `/target` directory so you can repair the filesystem. For example, if you mount on `/target` the partition holding the filesystem normally mounted on `/home`, the directory you would normally find at `/home/sam` will be found at `/target/sam`.

**Naming partitions and filesystems** A partition and any filesystem it holds have no name or identification other than a device name (and a related UUID value—see page 490). The partition and the filesystem are frequently referred to by the name of the partition's normal mount point. Thus “the `/home` partition” and “the `/home` filesystem” refer to the partition that holds the filesystem normally mounted on the `/home` directory. See page 487 for more information on mounting filesystems.

## PARTITIONING A DISK

During installation, Anaconda calls the partitioner to set up disk partitions. This section discusses how to plan partition sizes. Although this section uses the term *partition*, planning and sizing LVs (logical volumes; page 38) works the same way. For more information refer to page 60 and to the *Linux Partition HOWTO* at [www.tldp.org/HOWTO/Partition](http://www.tldp.org/HOWTO/Partition).

### GiB versus GB

**tip** Historically a *gigabyte* (GB) meant either  $2^{30}$  (1,073,741,824) or  $10^9$  (1,000,000,000) bytes. Recently the term *gibibyte* (giga binary byte; abbreviated as GiB) has been used to mean  $2^{30}$  bytes; in turn, *gigabyte* is used more frequently to mean  $10^9$  bytes. Similarly, a *mebibyte* (MiB) is  $2^{20}$  (1,048,576) bytes. The Fedora/RHEL partitioner still uses megabytes and gigabytes for specifying the size of partitions.

## DEFAULT PARTITIONING

It can be difficult to plan partition sizes appropriately if you are not familiar with Linux. During installation, Fedora/RHEL provides *default partitioning*. Without asking any questions, default partitioning divides the portion of the disk allotted to Fedora/RHEL into three partitions. One partition is the boot partition (**/boot**), which is generally 200–500 megabytes (page 35). The rest of the disk is set up as a volume group that you can control with LVM (Logical Volume Manager; page 38). Default partitioning divides the volume group into two logical volumes (partitions). The first logical volume, which holds swap space, can be any size from 512 megabytes to 2 or more gigabytes. The other logical volume is designated as **/** (root) and contains the remainder of the disk space. See the next section for a discussion of the advantages of manual partitioning.

## MANUAL PARTITIONING: PLANNING PARTITIONS

This section discusses additional partitions you may want to create. Consider setting up LVM (page 38) *before* you create partitions (LVs); LVM allows you to change partition sizes easily after the system is installed. Default partitioning uses LVM.

If you decide to manually partition the hard disk and set up partitions other than a root partition (**/**) and a swap partition, first consider which kinds of activities will occur under each top-level subdirectory. Then decide whether it is appropriate to isolate that subdirectory by creating a filesystem and mounting it on its own partition. Advantages of creating additional filesystems include these points:

- Separating data that changes frequently (e.g., **/var** and **/home**) from data that rarely changes (e.g., **/usr** and **/boot**) can reduce fragmentation on the less frequently changing filesystems, helping to maintain optimal system performance.
- Isolating filesystems (e.g., **/home**) can preserve data when you upgrade or reinstall Linux.
- Additional filesystems can simplify backing up data on a system.
- If all directories are part of a single filesystem, and if a program runs amok or the system is the target of a *DoS attack* (page 1080), the entire disk can fill up. System accounting and logging information, which may contain data that can tell you what went wrong, may be lost. On a system with multiple filesystems, such problems typically fill a single filesystem and do not affect other filesystems. Data that may help determine what went wrong will likely be preserved and the system is less likely to crash.

**/ (root)** The following paragraphs discuss the advantages of making each of the major top-level subdirectories a separate, mountable filesystem. Any directories you do not create filesystems for automatically become part of the root (**/**) filesystem. For example, if you do not create a **/home** filesystem, **/home** is part of the root (**/**) filesystem.

**(swap)** Linux temporarily stores programs and data on a swap partition when it does not have enough RAM to hold all the information it is processing. The swap partition is also used when you hibernate (suspend to disk) a system. The size of the swap partition should be between one and two times the size of the RAM in the system, with

a minimum size of 256 megabytes. The worst-case hibernation requires a swap size that is one and a half times the size of RAM. For example, a system with 1 gigabyte of RAM should have a 1- to 2-gigabyte swap partition. Although a swap partition is not required, most systems perform better when one is present. Also, some applications (e.g., Oracle) use swap space directly. On a system with more than one drive, having swap partitions on each drive can further improve performance. A swap partition is not mounted, so it is not associated with a mount point. See **swap** on page 479 for more information.

**/boot** The **/boot** partition holds the kernel and other data the system needs when it boots; it cannot be under the control of LVM. This partition is typically approximately 200 megabytes, although the amount of space required depends on how many kernel images you want to keep on hand. It can be as small as 50 megabytes. For installation, a minimum of 300 megabytes is recommended for Fedora systems.

Although you can omit the **/boot** partition, it is useful in many cases. Many administrators put an **ext2** filesystem on this partition because the data on it does not change frequently enough to justify the overhead of the **ext3** journal. Some older BIOSs require the **/boot** partition [or the **/** (root) partition if there is no **/boot** partition] to appear near the beginning of the disk.

### Where to put the **/boot** partition

**caution** On older systems, the **/boot** partition must reside *completely below cylinder 1023* of the hard disk. An easy way to ensure compliance with this restriction is to make the **/boot** partition one of the first partitions on the disk. When a system has more than one hard disk, the **/boot** partition must also reside on a drive on the following locations:

- Multiple IDE or EIDE drives: the primary controller
- Multiple SCSI drives: ID 0 or ID 1
- Multiple IDE and SCSI drives: the primary IDE controller or SCSI ID 0

**/var** The name **var** is short for *variable*: The data in this partition changes frequently. Because it holds the bulk of system logs, package information, and accounting data, making **/var** a separate partition is a good idea. In this way, if a user runs a job that consumes all of the users' disk space, system log files in **/var/log** will not be affected. The **/var** partition can occupy from 500 megabytes to as much as several gigabytes for extremely active systems with many verbose daemons and a lot of printer and mail activity (the print queues reside in **/var/spool/cups** and incoming mail is stored in **/var/mail**). For example, software license servers are often extremely active systems. By default, Apache content (the Web pages it serves) is stored on **/var** under Fedora/RHEL; you may want to change the location Apache uses.

Although such a scenario is unlikely, many files or a few large files may be created under the **/var** directory. Creating a separate filesystem to hold the files in **/var** will prevent these files from overrunning the entire directory structure, bringing the system to a halt, and possibly creating a difficult recovery problem.

**/var/log** Some administrators choose to put the log directory in a separate partition to isolate system logs from other files in the **/var** directory.

**/home** It is a common strategy to put user home directories on their own filesystem. This filesystem is usually mounted on **/home**. Having **/home** as a separate filesystem allows you to perform a clean install without risking damage to or loss of user files. Also, having a separate **/home** filesystem prevents a user from filling the directory structure with her data; at most she can fill the **/home** filesystem, which will affect other users but not bring the system down.

**Set up partitions to aid in making backups**

**tip** Plan partitions based on which data you want to back up and how often you want to back it up. One very large partition can be more difficult to back up than several smaller ones.

**/usr** Separating the **/usr** partition can be useful if you plan to export **/usr** to another system and want the security that a separate partition can give. Many administrators put an **ext2** filesystem on this partition because the data on it does not change frequently enough to justify the overhead of the **ext4** journal. The size of **/usr** depends on the number of packages you install. On a default system, it is typically 2–4 gigabytes.

**/usr/local and /opt** Both **/usr/local** and **/opt** are candidates for separation. If you plan to install many packages in addition to Fedora/RHEL, such as on an enterprise system, you may want to keep them on a separate partition. If you install the additional software in the same partition as the users’ home directories, for example, it may encroach on the users’ disk space. Many sites keep all **/usr/local** or **/opt** software on one server and export it to other systems. If you choose to create a **/usr/local** or **/opt** partition, its size should be appropriate to the software you plan to install.

Table 2-1 gives guidelines for minimum sizes for partitions used by Linux. Set the sizes of other partitions, such as those for **/home**, **/opt**, and **/usr/local**, according to need and the size of the hard disk. If you are not sure how you will use additional disk space, you can create extra partitions using whatever names you like (for example, **/b01**, **/b02**, and so on). Of course, you do not have to partition the entire drive when you install Linux. You can wait until later to divide the additional space into partitions.

**Table 2-1** Example minimum partition sizes<sup>a</sup>

Partition	Example size
<b>/boot</b>	100–200 megabytes, 300 megabytes to install Fedora
<b>/ (root)</b>	1 gigabyte
<b>(swap)</b>	One to two times the amount of RAM in the system with a minimum of 256 megabytes
<b>/home</b>	As large as necessary; depends on the number of users and the type of work they do
<b>/tmp</b>	Minimum of 500 megabytes



**Table 2-1** Example minimum partition sizes<sup>a</sup> (continued)

<b>/usr</b>	Minimum of 2–16 gigabytes; depends on which and how many software packages you install
<b>/var</b>	Minimum of 500 megabytes—much larger if you are running a server

a. The sizes in this table assume you create all partitions separately. For example, if you create a 1-gigabyte / (root) partition and do not create a /usr partition, in most cases you will not have enough room to store all the system programs.

# RAID

RAID (Redundant Array of Inexpensive/Independent Disks) employs two or more hard disk drives or partitions in combination to improve fault tolerance and/or performance. Applications and utilities see these multiple drives/partitions as a single logical device. RAID, which can be implemented in hardware or software (Fedora/RHEL gives you this option), spreads data across multiple disks. Depending on which level you choose, RAID can provide data redundancy to protect data in the case of hardware failure.

True hardware RAID requires hardware designed to implement RAID and is not covered in this book (but see “Fake RAID” below).

## Do not replace backups with RAID

**caution** Do not use RAID as a replacement for regular backups. If the system experiences a catastrophic failure, RAID is useless. Earthquake, fire, theft, and other disasters may leave the entire system inaccessible (if the hard disks are destroyed or missing). RAID also does not take care of the simple case of replacing a file when a user deletes it by accident. In these situations, a backup on a removable medium (which has been removed) or a network backup is the only way you will be able to restore a filesystem.

RAID can be an effective *addition* to a backup. Fedora/RHEL offers RAID software you can install either when you install a Fedora/RHEL system or as an afterthought. The Linux kernel automatically detects RAID arrays (sets of partitions) at boot time if the partition ID is set to 0xfd (**raid autodetect**).

Software RAID, as implemented in the kernel, is much cheaper than hardware RAID. Not only does this approach avoid the need for specialized RAID disk controllers, but it also works with the less expensive ATA disks as well as SCSI disks.

**Fake RAID** Fedora/RHEL provides support for motherboard-based RAID (known as *fake RAID*) through the **dmraid** driver set. Linux software RAID is almost always better than fake RAID.

The partitioner on a live CD and an install DVD gives you the choice of implementing RAID level 0, 1, 5, 6, or 10:

- **RAID level 0 (striping)**—Improves performance but offers no redundancy. The storage capacity of the RAID device is equal to that of the member partitions or disks.
- **RAID level 1 (mirroring)**—Provides simple redundancy, improving data reliability, and can improve the performance of read-intensive applications. The storage capacity of the RAID device is equal to one of the member partitions or disks.
- **RAID level 5 (disk striping with parity)**—Provides redundancy and improves performance (most notably, read performance). The storage capacity of the RAID device is equal to that of the member partitions or disks, minus one of the partitions or disks (assuming they are all the same size).
- **RAID level 6 (disk striping with double parity)**—Improves upon level 5 RAID by protecting data when two disks fail at once. Level 6 RAID is inefficient with a small number of drives.
- **RAID level 10 (RAID 1+0; multiple level 1 arrays stored on physical drives with a level 0 array [striping] on top of the level 1 arrays)**—Provides fault tolerance and improved performance but increases complexity. It requires a minimum of four disks and an even number of disks.

For more information refer to [wikipedia.org/wiki/RAID](http://wikipedia.org/wiki/RAID) and the *Software-RAID HOWTO* ([tldp.org/HOWTO/Software-RAID-HOWTO.html](http://tldp.org/HOWTO/Software-RAID-HOWTO.html)).

## LVM: LOGICAL VOLUME MANAGER

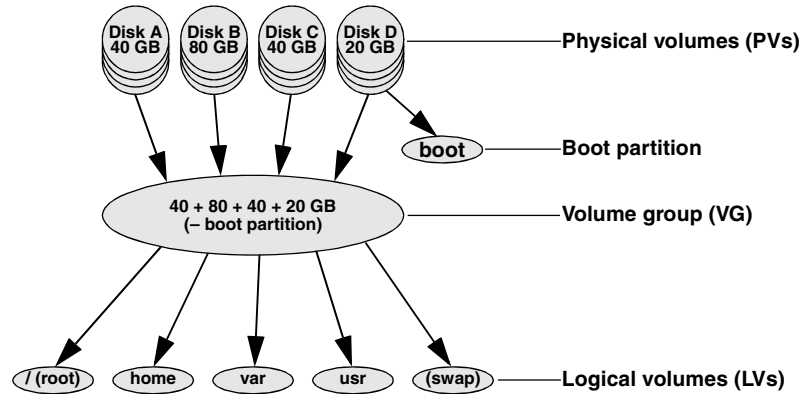
The Logical Volume Manager (LVM)<sup>1</sup> allows you to change the size of logical volumes (LVs, the LVM equivalent of partitions) on the fly. With LVM, if you make a mistake in setting up LVs or your needs change, you can use `system-config-lvm` (**Main menu: System**⇒**Administration**⇒**Logical Volume Management**) to make LVs either larger (assuming there is space in the volume group) or smaller easily without affecting user data. (You need to use `yum` [page 500] to install the `system-config-lvm` software package to run this utility.) LVM must be used at the time you install the system (as it is by default) or add a hard disk; you cannot retroactively apply it to a disk full of data. LVM supports IDE and SCSI drives as well as multiple devices such as those found in RAID partitions.

LVM groups disk components (partitions, hard disks, or storage device arrays), called *physical volumes* (PVs), into a storage pool, or virtual disk, called a *volume group* (VG) as shown in Figure 2-2. You allocate a portion of a VG to create a *logical volume* (LV).

An LV is similar in function to a traditional disk partition in that you can create a filesystem on an LV. It is much easier to change and move LVs than partitions,

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1. Because the Logical Volume Manager is in its second release, it is named LVM2. Many sources, including this book, refer to it simply as LVM.



**Figure 2-2** LVM: Logical Volume Manager

however: When you run out of space on a filesystem on an LV, you can grow (expand) the LV and its filesystem into empty or new disk space, or you can move the filesystem to a larger LV. LVM's disk space manipulation is transparent to users and does not interrupt service.

LVM also eases the burden of storage migration. When you outgrow the PVs or need to upgrade them, LVM can move data to new PVs without interrupting users. To read more about LVM, refer to the resources listing under “More Information” on page 48.

## THE INSTALLATION PROCESS

The following steps outline the process of installing Fedora/RHEL from an install DVD using Anaconda. Installation from other media follows similar steps. See Chapter 3 for the specifics of how to perform the installation.

1. Insert the install DVD in the computer and turn on or reset the computer.
2. After going through computer-specific hardware diagnostics, the system displays the install DVD Welcome menu (Figure 3-4, page 56).
3. You can make a selection from the menu, press **TAB**, and modify the boot parameters, or wait for a minute without entering anything; the computer brings up the installer from the DVD.
4. As part of the installation process, Fedora/RHEL creates *RAM disks* (page 1102) that it uses in place of the hard disk used for a normal boot operation. The installer copies tools required for the installation from the install DVD to the RAM disks. The use of RAM disks allows the installation process to run through the specification and design phases without writing to the hard disk and enables you to opt out of the installation at

any point before the system warns you it is about to write to the hard disk (or you complete the installation). If you opt out before this point, the system is left in its original state. The RAM disks also allow a system booted from a live CD to leave the hard disk untouched.

5. You can check the installation media at this point.
6. The Anaconda installer prompts you with a few questions about how you want to configure Fedora/RHEL, probes the hardware, starts the X Window System for a graphical installation, and then collects more information about how you want to install Fedora/RHEL.
7. When Anaconda is finished collecting information, it writes the operating system files to the hard disk.
8. When you reboot the system, Firstboot asks you questions that are required to complete the installation (page 66).
9. The Fedora/RHEL system is ready to use.

---

## THE MEDIUM: WHERE IS THE SOURCE DATA?

When you install Fedora/RHEL, you copy operating system files from a source—frequently a CD/DVD—to the target computer’s hard disk. The files that hold the data you use to burn a CD/DVD are called *ISO image files*. They are named for the standard that defines how the data is stored (ISO 9660). There are several sources for these files.

### CD OR DVD

**RHEL** Red Hat Enterprise Linux DVDs are sold by Red Hat and its distributors. ISO image files for Red Hat Enterprise Linux are available by subscription from Red Hat Network. You can download a 30-day evaluation copy of RHEL from the Red Hat Web site. See also “Checking and Burning the CD/DVD” (page 45).

**FEDORA** This book includes the DVD necessary for installing Fedora (the install DVD). Alternatively, you can purchase a Fedora CD/DVD from third-party vendors or you can download a Fedora ISO image file and then either install from the image or burn a CD/DVD (next section).

### HARD DISK

You can store ISO image files on the target system’s hard disk if it is already running Linux. You can use the first installation CD, the Net Boot CD, the install DVD, or a USB flash drive to boot the system for a hard disk installation. See **askmethod** on page 70 for more information. Alternatively, you can use a preupgrade (page 30) to install from the hard disk of a system running Fedora.

## NETWORK

ISO image files may be accessed on a server system that the machine you are installing Linux on can connect to over a network during installation. You can use FTP, NFS, or HTTP for network installations. Unless you have a fast Internet connection, however, it is not advisable to perform an installation over the Internet because it can take a very long time; downloading ISO image files is a more reliable and possibly less frustrating option. You can use the first installation CD, the Net Boot CD, the install DVD, or a USB flash drive to boot the system for a network installation. See **askmethod** (page 70) or **method** (page 71) for more information.

You can also boot a system using PXE (Preboot eXecution Environment) and then install Linux using one of the preceding methods. See “More Information” on page 48 for sources of information on PXE.

---

## DOWNLOADING A CD/DVD (*FEDORA*)

You can download an ISO image file and burn a Fedora CD/DVD. Although you will not get the customer support that comes with Red Hat Enterprise Linux, you will not need to pay Red Hat if you take this approach. One of the beauties of free software (Appendix D) is that it is always available for free. The Fedora Project makes it easy to obtain and use Fedora by providing ISO image files of its CD/DVDs online. These files are large—almost 700 megabytes for a CD and almost 4 gigabytes for a DVD—so they can take a long time to download.

This section tells you how to find the files you need, download them using a couple of different techniques, check whether they downloaded correctly, and burn them to a CD/DVD.

### You must use 700-megabyte CD-ROM blanks

---

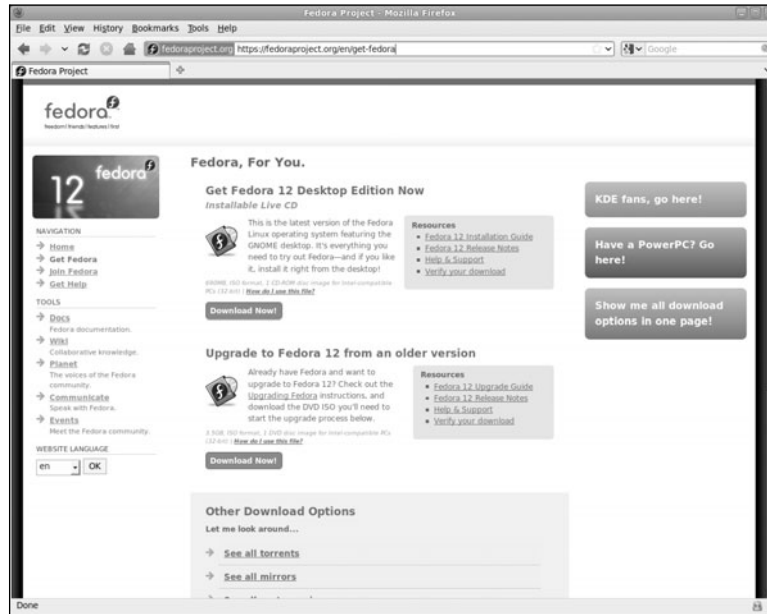
**tip** When you burn a Fedora CD from an ISO image file, you must use 700-megabyte blanks. The smaller 650-megabyte blanks will not work because there is too much data to fit on them.

---

There are several ways to obtain a Fedora CD/DVD. The Fedora Project makes available releases of Linux as CD and DVD ISO image files. This section describes how to download one of these image files and burn a CD/DVD. You can also order a CD/DVD and receive it through the postal mail: Point a browser at [fedoraproject.org/get-fedora](http://fedoraproject.org/get-fedora); at the bottom of the page, under *Slow Internet? No Internet?*, are links that enable you to request a free CD from the Fedora Project or purchase a CD/DVD from a store or Web site.

## THE EASY WAY TO DOWNLOAD A CD ISO IMAGE FILE

This section explains the easiest way to download a CD ISO image file. This technique works in most situations.



**Figure 2-3** The `fedoraproject.org/get-fedora` Web page

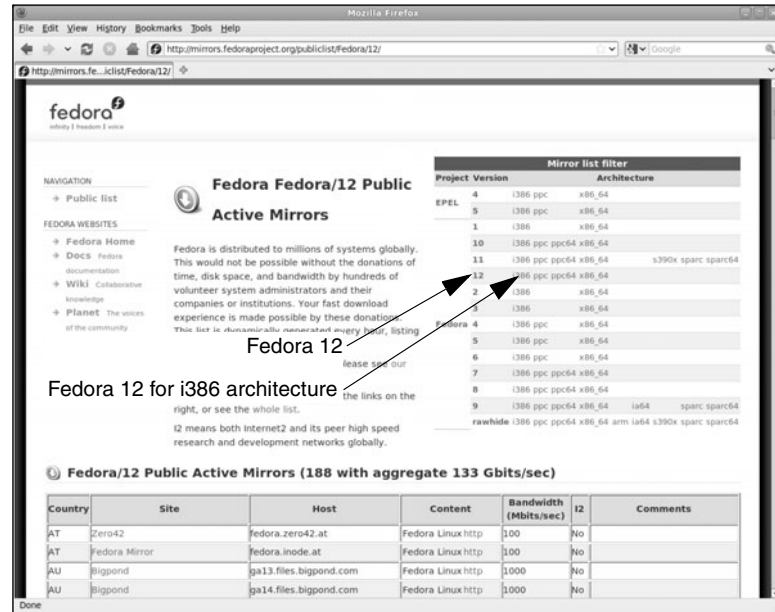
To begin, point a browser at `fedoraproject.org/get-fedora`. You can select from Fedora Desktop Edition (Live Media) or Upgrade to Fedora (Install Media). See Figure 2-3. For more information refer to “The Desktop Live CD and the Install DVD” on page 24.

The easiest way to download an ISO image file is to download it directly. For example, to download the Desktop Live CD for an Intel 32-bit processor (see “Processor Architecture” on page 26), click **i686 – Live CD** under **Direct Download** in the **Fedora Desktop Live Media** section of the page. Next click **Download Now** or **OK**. If the browser gives you a choice of what to do with the file, save it to the hard disk. The browser saves the ISO image file to the hard disk. Continue reading at “Checking and Burning the CD/DVD” on page 45.

## FINDING A MIRROR SITE TO DOWNLOAD FROM

As explained in the previous section, you can download a CD/DVD ISO image file from `fedoraproject.org/get-fedora`. Other (mirror) sites also maintain these images. You can use a Web browser or FTP client to download the files from one of these sites. Alternatively, you can use BitTorrent to download ISO image files; see page 44.

**Mirror sites** Locate a mirror site by pointing a browser at `mirrors.fedoraproject.org`. Below the heading information, the page displays Public Active Mirrors. Narrow your choices by clicking a selection in the Mirror list filter at the upper-right corner of the page (Figure 2-4). For example, click **12** to list sites from which you can download



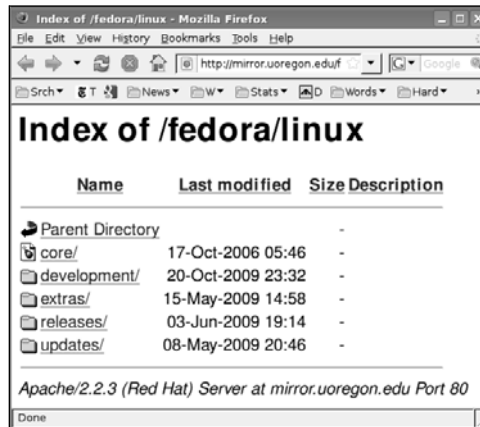
**Figure 2-4** The mirrors.fedoraproject.org Web page

Fedora 12 or click i386 in the row that starts with 12 to list sites from which you can download the i386 version of Fedora 12.

The list on this Web page is in country code order. For example, FR is France and US is the United States. To conserve network bandwidth, scroll to and download from a mirror site close to you. Look at the Content, Bandwidth, and Comments columns. Pick the row of an appropriate site and click the protocol you want to use in the Content column. From a browser there is little difference between the FTP and HTTP protocols, although accessing a site using FTP may be a bit faster.

When you click a protocol, the browser displays a page similar to the one shown in Figure 2-5 (next page). Follow these steps to download the ISO image file you want:

1. Click **releases**. The browser displays a list of Fedora releases starting with Fedora 7.
2. Click the number of the release of Fedora you want to download. The browser displays a list that includes **Fedora** and **Live**.
3. Click **Live** if you want to download a live CD and **Fedora** if you want to download an install DVD. Make sure you have room for the file on the hard disk: A DVD ISO image file occupies almost 4 gigabytes.
4. Click the architecture (page 26) you want to install Fedora on: **i386** or **i686** for 32-bit systems and **x86\_64** for 64-bit systems. Click **ppc** for PowerPC systems.



**Figure 2-5** A Fedora mirror site

5. If you are downloading an install ISO image, click **iso**. If you are downloading a live CD, go to the next step.
6. Download the **CHECKSUM** file.
7. Click the name of the ISO image file you want to download and choose to download (not install) the image. **Live** gives you the choice of a **Fedora-12-i686-Live.iso**, which runs and installs a Fedora/GNOME desktop and **Fedora-12-Live-i686-KDE.iso**, which runs and installs a KDE desktop. **Fedora** gives you the choice of downloading the Install DVD ISO image file, the Install CD ISO image files, or the Net Install CD ISO image file.

## USING BITTORRENT TO DOWNLOAD A CD/DVD ISO IMAGE FILE

When you use a Web browser to download a file, the browser contacts a Web (HTTP) or FTP server and downloads the file from that server. If too many people download files from a server at the same time, the downloads become slower.

BitTorrent efficiently distributes large amounts of static data, such as ISO image files. Unlike using a browser to download a file from a single server, BitTorrent distributes the functions of a server over its clients. As each client downloads a file, it becomes a server for the parts of the file it has downloaded. To use BitTorrent, you must download a small file called a *torrent* (or have a Web browser do it for you). This file, which holds information that allows clients to communicate with one another, has a filename extension of **.torrent**. As more people use a torrent to download a file at the same time, the downloads become faster.

Because BitTorrent is available for Windows, Mac OS X, and Linux, you can download and burn a Fedora CD/DVD under any of these operating systems. To download a torrent, point a browser at [fedoraproject.org/get-fedora](http://fedoraproject.org/get-fedora) or [torrent.fedoraproject.org](http://torrent.fedoraproject.org) and click the filename of the torrent you want to download. A BitTorrent client should start automatically and ask where to put the downloaded file. You can



also download the torrent manually. To do so, download the torrent instead of starting a BitTorrent client. You can then start downloading the file from the command line (page 508) or by clicking the file in the Nautilus File Browser (page 98).

### You can download and burn the CD/DVD on any operating system

**tip** You can download and burn the CD/ DVD on any computer that is connected to the Internet, has a browser, has enough space on the hard disk to hold the ISO image file (about 700 megabytes for a CD and almost 4 gigabytes for a DVD), and can burn a CD/DVD. You can often use ftp (page 646) or, on a Linux system running GNOME, **Main menu: Places⇒Connect to Server** in place of a browser to download the file.

## CHECKING AND BURNING THE CD/DVD

Once you have downloaded the CD/DVD ISO image file and the **CHECKSUM** file (*FEDORA*) or MD5 checksum value (*RHEL*), the next step is to check whether the ISO image file(s) are correct.

### CHECKING THE FILE

The **CHECKSUM** file contains the SHA-256 sums for each of the ISO image files. See page 1105 for more information on SHA sums. When you process a file using the `sha256sum` utility, `sha256sum` generates a number based on the file. If that number matches the corresponding number in the **CHECKSUM** file, the downloaded file is correct. With the `-c` option and the name of the **CHECKSUM** file, `sha256sum` checks each of the files listed in the **CHECKSUM** file. The following example shows the DVD is OK and the ISO image file for **disc1** is not present:

```
$ sha256sum -c Fedora-12-i386-CHECKSUM
Fedora-12-i386-DVD.iso: OK
sha256sum: Fedora-12-i386-disc1.iso: No such file or directory
Fedora-12-i386-disc1.iso: FAILED open or read
...
```

Check each of the ISO image files you downloaded in the same manner. Computing an SHA-256 sum for a large file takes a while. *RHEL* uses an MD5SUM value instead of an SHA-256 value; use the `md5sum` utility instead of `sha256sum`.

### Test the ISO image file and test the CD/DVD

**tip** It is a good idea to test the ISO image file and the burned CD/DVD before you use it to install Fedora/*RHEL*. When you boot the system from the CD/DVD, Fedora/*RHEL* gives you the option of checking the CD/DVD for defects (pages 53 and 57). A bad file on a CD/DVD may not show up until you finish installing Fedora/*RHEL* and have it running. At that point, it may be difficult and time-consuming to figure out where the problem lies. Testing the file and CD/DVD takes a few minutes, but it can save you hours of trouble if something is not right. If you want to perform one test only, test the CD/DVD.

## BURNING THE CD/DVD

An ISO image file is an exact image of what needs to be on the CD/DVD. Putting that image on a CD/DVD involves a different process than copying files to a CD/DVD. The CD/DVD burning software you use has a special selection for burning an ISO image file. It will be labeled something similar to **Record CD from CD Image** or **Burn CD Image**. Refer to the instructions for the software you are using for information on how to burn an ISO image file to a CD/DVD.

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### Make sure the software is set up to burn an ISO image file

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**tip** Burning an ISO image file is not the same as copying files to a CD/DVD. Make sure the CD/DVD burning software is set up to burn an ISO image file. If you simply copy the ISO image file to the CD/DVD, it will not work when you try to install Fedora/RHEL.

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## RESCUE SELECTION OF THE INSTALL DVD

**Rescue mode** You can use the first installation CD, the Net Boot CD, or the install DVD to bring the system up in rescue mode. Bringing a system up and working in rescue mode are discussed on page 411.

---

## GATHERING INFORMATION ABOUT THE SYSTEM

It is not difficult to install and bring up a Fedora/RHEL system. Nevertheless, the more you know about the process before you start, the easier it will be. The installation software collects information about the system and can help you make decisions during the installation process. However, the system will work better when you know how you want the disk partitioned rather than letting the installation program create partitions without your input. There are many details, and the more details you take control of, the more pleased you are likely to be with the finished product. Finding the information this section asks for will help ensure you end up with a system you understand and know how to change when necessary. To an increasing extent, the installation software probes the hardware and figures out what you have. Newer equipment is more likely to report on itself than older equipment is.

It is critical to have certain pieces of information before you start. One thing Linux can never figure out is all the relevant names and IP addresses (unless you are using DHCP, in which case the addresses are set up for you).

Following is a list of items you may need information about. Before you begin installing Linux, gather as much information about each item as you can: manufacturer, model number, size (megabytes, gigabytes, and so forth), number of buttons,

chipset (for cards), and so on. Some items, such as the network interface card, may be built into the motherboard.

- Hard disks.
- Memory (you may need this information to calculate the size of the swap partition).
- SCSI interface card.
- Network interface card (NIC).
- Video interface card (including the amount of video RAM/memory).
- Sound card and compatibility with standards, such as SoundBlaster.
- Mouse (PS/2, USB, AT, and number of buttons).
- Monitor (size and maximum resolution).
- IP addresses and names, unless you are using DHCP (page 451), in which case the IP addresses are automatically assigned to the system. Most of this information comes from the system administrator or ISP.
  - ◆ System hostname (anything you like)
  - ◆ System address
  - ◆ Network mask (netmask)
  - ◆ Gateway address (the connecting point to the network or Internet) or a phone number when you use a dial-up connection
  - ◆ Addresses for nameservers, also called DNS addresses
  - ◆ Domain name (not required)

---

## FINDING THE INSTALLATION MANUAL

The definitive resource for instructions on how to install Fedora/RHEL is the Installation Guide for the release you are installing and the platform you are installing it on. You can view or download installation guides at the following sites:

- *FEDORA* Go to [docs.fedoraproject.org](https://docs.fedoraproject.org) and select from the various formats and languages under **Installation Guide**.
- *RHEL* Go to [www.redhat.com/docs/manuals/enterprise](https://www.redhat.com/docs/manuals/enterprise). Additional installation, setup, and troubleshooting resources are available from Red Hat at [www.redhat.com/apps/support](https://www.redhat.com/apps/support). You can also search for a keyword or words using the box labeled **Search** at the upper-right corner of most Red Hat Web pages.

## MORE INFORMATION

Local **lvm** man page including the “See also” pages listed at the bottom

Web Fedora home: [fedoraproject.org](http://fedoraproject.org)

Fedora documentation: [docs.fedoraproject.org](http://docs.fedoraproject.org)

Linux-specific search engine: [www.google.com/linux](http://www.google.com/linux)

SELinux: See the entries for SELinux at [docs.fedoraproject.org](http://docs.fedoraproject.org)

X.org: [wiki.x.org](http://wiki.x.org)

memtest86+: [www.memtest.org](http://www.memtest.org)

Hardware compatibility: [hardware.redhat.com](http://hardware.redhat.com)

*Partition HOWTO*: [tldp.org/HOWTO/Partition](http://tldp.org/HOWTO/Partition)

*Software-RAID HOWTO*: [tldp.org/HOWTO/Software-RAID-HOWTO.html](http://tldp.org/HOWTO/Software-RAID-HOWTO.html)

LVM resource page (includes many links): [sourceware.org/lvm2](http://sourceware.org/lvm2)

*LVM HOWTO*: [www.tldp.org/HOWTO/LVM-HOWTO](http://www.tldp.org/HOWTO/LVM-HOWTO)

BitTorrent: [www.bittorrent.com](http://www.bittorrent.com), [www.transmissionbt.com](http://www.transmissionbt.com), [azureus.sourceforge.net](http://azureus.sourceforge.net)

PXE: [www.kegel.com/linux/pxe.html](http://www.kegel.com/linux/pxe.html)

PXE and Kickstart: [www.stanford.edu/~alfw/PXE-Kickstart/PXE-Kickstart.html](http://www.stanford.edu/~alfw/PXE-Kickstart/PXE-Kickstart.html)

Kernel boot parameters: [www.kernel.org/doc/Documentation/kernel-parameters.txt](http://www.kernel.org/doc/Documentation/kernel-parameters.txt),

[www.kernel.org/pub/linux/kernel/people/gregkh/lkn/lkn\\_pdf/ch09.pdf](http://www.kernel.org/pub/linux/kernel/people/gregkh/lkn/lkn_pdf/ch09.pdf); also search

the Web for **linux boot parameters**

Downloads Fedora download page: [fedoraproject.org/get-fedora](http://fedoraproject.org/get-fedora)

Fedora free media program: [fedoraproject.org/wiki/Distribution/FreeMedia](http://fedoraproject.org/wiki/Distribution/FreeMedia)

Fedora BitTorrent trackers: [torrent.fedoraproject.org](http://torrent.fedoraproject.org)

Fedora mirrors: [mirrors.fedoraproject.org/publiclist](http://mirrors.fedoraproject.org/publiclist)

RHEL Source code: [ftp://ftp.redhat.com/pub/redhat/linux/enterprise/5/Server/en/os/SRPMS](http://ftp://ftp.redhat.com/pub/redhat/linux/enterprise/5/Server/en/os/SRPMS)

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## CHAPTER SUMMARY

A live CD runs a live Fedora session without installing Fedora on the system. You can install Fedora from a live session. Booting a live CD is a good way to test hardware and fix a system that will not boot from the hard disk.

When you install Fedora/RHEL, you copy operating system files from media to the local system and set up configuration files so Linux runs properly on the local hardware. You can install Linux from many types of media, including CD(s), a DVD, a local hard disk, or a hard disk on another system that is accessed over a network. Operating system files are stored as CD/DVD ISO image files. You can use a browser, FTP, or BitTorrent to download an ISO image file. It is a good idea to test the CD/DVD ISO image files when they are downloaded and the burned CD/DVD before you use it to install Fedora/RHEL.

The major decisions to be made when planning an installation are how to divide the hard disk into partitions and which software packages to install. When you are installing RHEL, if you plan to use SELinux, leave it turned on during Firstboot, after you install Linux. Because SELinux sets extended attributes on files, it can be a time-consuming process to turn on SELinux after Linux is installed.

When you install Fedora/RHEL, you can let the installer decide how to partition the hard disk or you can manually specify how you want to partition it.

The Fedora Project is sponsored by Red Hat and supported by the open-source community. Fedora is a Linux release that contains cutting-edge code; it is not recommended for production environments. Red Hat Enterprise Linux is more stable than Fedora.

---

## EXERCISES

1. Briefly, what does the process of installing an operating system such as Fedora/RHEL involve?
2. What is Anaconda?
3. Would you set up a GUI on a server system? Why or why not?
4. A system boots from the hard disk. To install Linux, you want it to boot from a DVD. How can you make the system boot from a DVD?
5. What is free space on a hard disk? What is a filesystem?
6. What is an ISO image file? How do you burn an ISO image file to a CD/DVD?

---

## ADVANCED EXERCISES

7. Give two reasons why you should not use RAID to replace backups.
8. What are RAM disks and how are they used during installation?
9. What is SHA-256? How does it work to ensure that an ISO image file you download is correct?

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# STEP-BY-STEP INSTALLATION

## IN THIS CHAPTER

Running a Fedora Live Session . . .	52
Installing from a Live Session . . . .	55
Installing/Upgrading from the Install DVD . . . . .	55
The Anaconda Installer . . . . .	57
Using Disk Druid to Partition the Disk . . . . .	71
LVs: Logical Volumes . . . . .	73
Setting Up a Dual-Boot System . . .	82
The X Window System . . . . .	84

Chapter 2 covered planning the installation of Fedora/RHEL: determining the requirements; performing an upgrade versus a clean installation; planning the layout of the hard disk; obtaining the files you need for the installation, including how to download and burn CD/DVD ISO images; and collecting information about the system. This chapter focuses on installing Fedora/RHEL. Frequently the installation is quite simple, especially if you have done a good job of planning. Sometimes you may run into a problem or have a special circumstance; this chapter gives you tools to use in these cases. Read as much of this chapter as you need to; once you have installed Fedora/RHEL, continue with Chapter 4, which covers getting started using the Fedora/RHEL desktop. If you install a textual (command line) system, refer to Chapter 5.



**Figure 3-1** Live session, automatic boot screen

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## RUNNING A FEDORA LIVE SESSION

As discussed in Chapter 2, a live session is a Linux session that you run on a computer without installing Linux on the computer. When you reboot after a live session, the computer is untouched. If you are running Windows, after a live session Windows boots the way it did before the live session. If you choose, you can install Fedora from a live session. Red Hat Enterprise Linux does not offer live sessions.

A live session gives you a chance to preview Fedora without installing it. Boot from the live CD to begin a live session and work with Fedora as explained in Chapter 4. When you are finished, remove the CD and reboot the system. The system will then boot as it did before the live session took place.

Because a live session does not write to the hard disk (other than using a swap partition, if one is available), none of the work you save will be available once you reboot. You can use a USB flash drive, Webmail, or another method to transfer files you want to preserve to another system.

## BOOTING THE SYSTEM

Before Fedora can display the desktop of a live session or install itself on a hard disk, the Linux operating system must be read into memory (booted). This process can take a few minutes on older, slower systems and systems with minimal RAM (memory).





**Figure 3-2** The Fedora Live Welcome menu

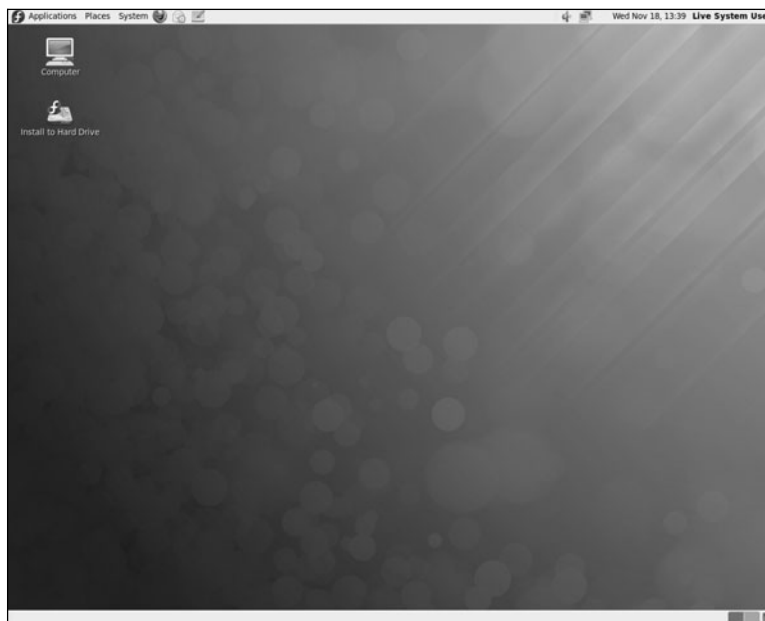
In most cases, you can boot Fedora to run a live session that displays a desktop without doing anything after you boot from a live CD. To begin, insert the live CD (the standard GNOME **Fedora Desktop Live Media**) into the CD drive and turn on or reset the system. Refer to “BIOS setup” on page 26 if the system does not boot from the CD. Refer to “Modifying Boot Parameters (Options)” on page 68 if Fedora does not boot or displays an error message.

A few moments after you start the system, Fedora displays a screen that says **Automatic boot in 10 seconds** and counts down from 10 to 1 (Figure 3-1). Next the system displays a graphical screen showing a progress bar.

**Checking the CD** The first time you use a CD, it is a good idea to check it for defects. To do so, interrupt the automatic boot by pressing a key such as the SPACE bar while Fedora is counting down. Fedora displays the Welcome menu (Figure 3-2). Use the DOWN ARROW key to highlight the **Verify and Boot** line and press RETURN (the mouse will not work yet). Fedora displays a progress bar as it verifies the contents of the CD; nothing happens for a while. If the CD is good, the system boots.

**Memory test** Selecting **Memory Test** from the Welcome menu runs **memtest86+**, a GPL-licensed, stand-alone memory test utility for x86-based computers. Press C to configure the test; press ESCAPE to exit and reboot. See [www.memtest.org](http://www.memtest.org) for more information.

**GNOME** If you are installing from Fedora Desktop Live Media (what this book refers to as the *live CD*), you are installing the GNOME desktop manager. When you boot from this CD, Fedora displays a login screen for a few seconds, automatically logs



**Figure 3-3** A GNOME Live desktop

in as the user named **liveuser**, and displays the GNOME desktop (Figure 3-3). To speed up this process, you can click the button labeled **Log In** when Fedora displays the login screen.

- KDE If you are installing from Fedora KDE Live Media, you are installing the KDE desktop manager. When you boot from this disk, Fedora next displays a KDE startup screen and then the KDE desktop—there is no need to log in.

### optional SEEING WHAT IS GOING ON

If you are curious and want to see what Fedora is doing as it boots from a live CD, remove **quiet**, which controls kernel messages, and **rhgb** (Red Hat graphical boot), which controls messages from the graphical installer, from the boot parameters. See Figure 3-13 on page 68; the list of parameters on the screen will be different from those in the figure. With the Fedora Live Welcome menu displayed (Figure 3-2), press **TAB** to display the boot command-line parameters. Use the **BACK ARROW** key to back up over—but not remove—any words to the right of **quiet**. Press **BACKSPACE** or **DEL** to back up over and erase **quiet** and **rhgb** from the boot command line. Press **RETURN**. Now as Fedora boots, it displays information about what it is doing. Text scrolls on the screen, although sometimes too rapidly to read. When you boot Fedora from a DVD and when you boot RHEL, this information is displayed by default: You do not have to change the command line.

## INSTALLING FEDORA/RHEL

You can install Fedora/RHEL from a live session (preceding section; *FEDORA* only) or from the install DVD (*RHEL+FEDORA*). Installing from a live session is simpler but does not give you the flexibility that installing from the install DVD does. For example, you cannot select the language the installer uses, nor can you choose which software packages you want to install when you install from a live session.

### Check to see what is on the hard disk before installing Fedora/RHEL

**caution** Unless you are certain the hard disk you are installing Fedora/RHEL on has nothing on it (it is a new disk) or you are sure the disk holds no information of value, it is a good idea to examine the contents of the disk before you start the installation. You can use *palimpsest* (page 78) from a live session for this purpose.

The install DVD holds many of the software packages that Fedora/RHEL supports. You can install whichever packages you like from this DVD without connecting to the Internet. However, without an Internet connection, you will not be able to update the software on the system.

The live CD holds a limited set of software packages. Once you install from this CD, you must connect to the Internet to update the software on the system and download and install additional packages.

To begin most installations, insert the live CD or the install DVD into the CD/DVD drive and turn on or reset the system. For hard disk and network-based installations, you can use the first installation CD, the Net Boot CD, the install DVD, or a USB flash drive.

## INSTALLING FROM A LIVE SESSION

Bring up a live GNOME session as explained on page 52. Double-click (left button) the object labeled **Install to Hard Drive** (Figure 3-3) to begin installing Linux. Continue reading at “The Anaconda Installer” on page 57.

## INSTALLING/UPGRADING FROM THE INSTALL DVD

*FEDORA* To install/upgrade Fedora from the install DVD, insert this DVD into the DVD drive and turn on or reset the system. After a few moments, Fedora displays the Welcome to Fedora menu (Figure 3-4, next page) and a message that says **Automatic boot in 60 seconds**.

Press a key, such as the **SPACE** bar, within 60 seconds to stop the countdown and display the message **Press [TAB] to edit options** as shown in Figure 3-4. If you do not press a key, after 60 seconds Fedora begins a graphical install/upgrade. Refer to “BIOS setup” on page 26 if the system does not boot from the DVD. Refer to “Modifying Boot Parameters (Options)” on page 68 if Fedora/RHEL does not boot or displays an error message.



**Figure 3-4** The install DVD Welcome menu

The Welcome menu has the following selections:

- |  |  |
|--|--|
| Install or upgrade an existing system  | Installs a graphical Fedora/RHEL system using the graphical installer.   |
| Install system with basic video driver | Installs a graphical Fedora/RHEL system using the graphical installer. Fedora/RHEL does not attempt to determine the type of display attached to the system; it uses a basic video driver that works with most displays. Choose this selection if the previous selection fails just after the Disc Found screen (page 57). |
| Rescue installed system                | Brings up Fedora/RHEL but does not install it. After detecting the system's disks and partitions, the system enters rescue mode and allows you to mount an existing Linux filesystem. For more information refer to "Rescue Mode" on page 411.   |
| Boot from local drive                  | Boots the system from the hard disk. This selection frequently has the same effect as booting the system without the CD/DVD (depending on how the BIOS [page 26] is set up).   |

## STARTING THE INSTALLATION

Make a selection from the Welcome menu and press RETURN to boot the system. Text scrolls by as the system boots.

- RHEL* The process of installing Red Hat Enterprise Linux is similar to that of installing Fedora. The biggest difference relates to the initial screen the two systems display. While *FEDORA* displays a menu, *RHEL* displays a **boot:** prompt. Follow the instructions on the screen for installing *RHEL* in graphical or textual mode. To bring the system up

in Rescue mode (page 411), enter **linux rescue** and press RETURN. Most parameters you enter at the **boot:** prompt begin with the word **linux**. You can use all the parameters discussed in “Modifying Boot Parameters (Options)” on page 68, but they must be preceded by the word **linux**. Press the function keys listed at the bottom of the screen for more information.

## THE DISC FOUND SCREEN

The first screen the install DVD installation process displays is the pseudographical Disc Found screen. Because it is not a true graphical screen, the mouse does not work. Instead, you must use the TAB or ARROW keys to highlight different choices and then press RETURN to select the highlighted choice. This screen allows you to test as many installation CD/DVDs as you like. Choose **OK** to test the media or **Skip** to bypass the test. See the following caution box.

### Test install DVDs

**caution** Many people download ISO image files from the Web and then burn disks using these files. It is possible for data to become corrupted while fetching an ISO image; it is also possible for a transient error to occur while writing an image to recordable media. When you boot Fedora/RHEL from an install DVD, Anaconda displays the Disc Found screen before starting the installation. From this screen, you can verify that the install DVD does not contain any errors. Testing the DVD takes a few minutes but can save you hours of aggravation if the installation fails due to bad media.

A DVD may fail the media test if the software that was used to burn the disk did not include padding. If a DVD fails the media test, try booting with the **nodma** parameter. See page 68 for information on adding parameters to the boot command line.

If the DVD passes the media test when you boot the system with the **nodma** parameter, the DVD is good; reboot the system without this parameter before installing Fedora/RHEL. If you install Linux after having booted with this parameter, the kernel will be set up to always use this parameter. As a consequence, the installation and operation of the system may be slow.

## THE ANACONDA INSTALLER

Anaconda, which is written in Python and C, identifies the hardware, builds the filesystems, and installs or upgrades the Fedora/RHEL operating system. Anaconda can run in textual or graphical (default) interactive mode or in batch mode (see “Using the Kickstart Configurator” on page 82).

Exactly which screens Anaconda displays depends on whether you are installing Fedora from a live session or from the install DVD, whether you are installing Red Hat Enterprise Linux, and which parameters you specify on the boot command line. With some exceptions—most notably if you are running a textual installation—Anaconda probes the video card and monitor, and starts a native X server.

While it is running, Anaconda opens the virtual consoles (page 137) shown in Table 3-1. You can display a virtual console by pressing `CONTROL-ALT-fx`, where *x* is the virtual console number and *fx* is the function key that corresponds to the virtual console number.

**Table 3-1** Virtual console assignments during installation

Information displayed during installation		
Virtual console	Install DVD	Live CD
1	Installation dialog	Installation dialog
2	Shell	Login prompt (log in as <b>liveuser</b> )
3	Installation log	Installation log
4	System messages	Login prompt (log in as <b>liveuser</b> )
5	X server output	Login prompt (log in as <b>liveuser</b> )
6	GUI interactive installation screen <sup>a</sup>	Login prompt (log in as <b>liveuser</b> )
7	GUI interactive installation screen <sup>a</sup>	GUI interactive installation

a. The GUI appears on virtual console 6 or 7.

At any time during the installation, you can switch to virtual console 2 (`CONTROL-ALT-F2`) and give commands to see what is going on. Do not give any commands that change any part of the installation process. To switch back to the graphical installation screen, press `CONTROL-ALT-F6` or `CONTROL-ALT-F7`.

USING ANACONDA

Anaconda displays a button labeled **Next** at the lower-right corner of each installation screen and a button labeled **Back** next to it on most screens. When you have completed the entries on an installation screen, click **Next** or press `F12`; from a textual installation, press the `TAB` key until the **Next** button is highlighted and then press `RETURN`. Select **Back** to return to the previous screen.

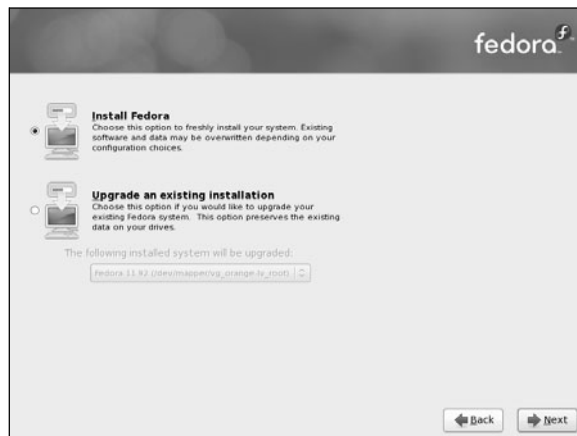
ANACONDA SCREENS

Anaconda displays different screens depending on which commands you give and which choices you make. During a graphical installation, Anaconda starts, loads drivers, and probes for the devices it will use during installation. After probing, it starts the X server. This section describes the screens that Anaconda displays during a default installation and explains the choices you can make on each of them.



**Figure 3-5** The logo screen

- Logo Anaconda displays the logo screen (Figure 3-5) after it obtains enough information to start the X Window System. There is nothing for you to do on this screen. Click **Next**.
- Language Select the language you want to use for the installation. This language is not necessarily the same language the installed system will display.
- Installation number RHEL asks if you want to provide an installation number or skip this step. See [www.redhat.com/support/resources/faqs/installation\\_numbers](http://www.redhat.com/support/resources/faqs/installation_numbers) for more information.
- (RHEL)
- Keyboard Select the type of keyboard attached to the system.
- Error processing Anaconda displays this warning if the hard disk has not been used before. The dialog box says the drive may need to be initialized. When you initialize a drive, all data on the drive is lost. Click **Re-initialize drive** if it is a new drive or if you do not need the data on the drive. Anaconda initializes the hard disk immediately.
- drive
- Hostname Fedora asks you to specify the name of the system. RHEL asks for this information on the Network Configuration screen.
- Time zone The time zone screen allows you to specify the time zone where the system is located (Figure 2-1, page 29). Use the scroll wheel on the mouse or the slider to the left of the map to zoom in or out on the selected portion of the map, drag the horizontal and vertical *thumbs* (page 1111) to position the map in the window, and then click a city in the local system's time zone. Alternatively, you can scroll through the drop-down list and highlight the appropriate selection. Remove the tick from the check box labeled **System clock uses UTC** if the system clock is not set to *UTC* (page 1114). Click **Next**.
- Root password Enter and confirm the password for the **root** user (Superuser). See page 405 for more information on **root** privileges. Click **Next**. If you enter a password that is not



**Figure 3-6** The Install or Upgrade screen

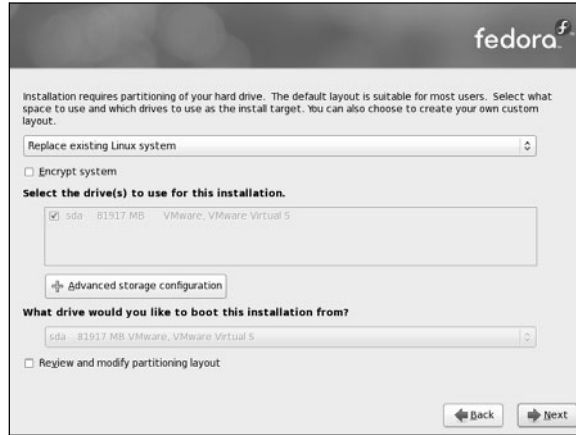
very secure, Anaconda displays a dialog box with the words **Weak password**; click **Cancel** or **Use Anyway**, as appropriate.

**Install or Upgrade** (This choice is not available from the live CD.) Anaconda displays the Install or Upgrade screen (Figure 3-6) only if it detects a version of Fedora/RHEL on the hard disk that it can upgrade. Anaconda gives you the choice of upgrading the existing installation or overwriting the existing installation with a new one. Refer to “Upgrading an Existing Fedora/RHEL System Versus Installing a Fresh Copy” on page 29 for help in making this selection. Select one of the entries and click **Next**.

**Disk Partitioning** The Disk Partitioning screen (Figure 3-7) allows you to specify partition information and to select the drives you want to install Fedora/RHEL on (assuming the system has more than one drive). Specify which drives you want to install Linux on in the frame labeled **Select the drive(s) to use for this installation**. Anaconda presents the following choices in the drop-down list near the top of the screen; click the arrow button at the right end of the list and then click the choice you want:

- **Use entire drive**—Deletes all data on the hard disk and creates a default layout on the entire hard disk, as though you were working with a new hard disk.
- **Replace existing Linux system**—Removes all Linux partitions, deleting the data on those partitions and creating a default layout in place of one or more of the removed partitions. If there is only a Linux system on the hard disk, this choice is the same as the previous one.
- **Shrink current system**—Shrinks the partitions that are in use by the operating system that is already installed on the hard disk. This choice





**Figure 3-7** The Disk Partitioning screen

creates a default layout in the space it has recovered from the installed operating system.

- **Use free space**—Installs Fedora/RHEL in the *free space* (page 30) on the disk. This choice does not work if there is not enough free space.
- **Create custom layout**—Does not alter hard disk partitions. This choice causes Anaconda to run Disk Druid (page 71) so you can preserve those partitions you want to keep and overwrite other partitions. It is a good choice for installing Fedora/RHEL over an existing system where you want to keep `/home`, for example, but want a clean installation and not an upgrade.

**Default layout** The default layout the first four choices create includes two logical volumes (swap and root [`/`]) and one standard partition (`/boot`). With this setup, most of the space on the disk is assigned to the root partition. For information on the Logical Volume Manager, see page 38.

Put a tick in the check box labeled **Encrypt system** to encrypt the filesystems you are creating. If you are installing on more than one disk, you can select which drive the system boots from. See the tip on page 35.

**Disk Druid** Anaconda runs Disk Druid only if you put a tick in the check box labeled **Review and modify partitioning layout** or if you select **Create custom layout** from the drop-down list as described earlier. You can use Disk Druid to verify and modify the layout before it is written to the hard disk. For more information refer to “Using Disk Druid to Partition the Disk” on page 71.

**Warning** Anaconda displays a warning if you are removing or formatting partitions. Click **Yes, Format**, or **Write changes to disk** to proceed.



Figure 3-8 The Boot Loader Configuration screen

**Boot Loader Configuration** Anaconda displays the Boot Loader Configuration screen (Figure 3-8) only when you put a tick in the check box labeled **Review and modify partitioning layout** or select **Create custom layout** from the drop-down list in the Partition the Disk screen. By default, Anaconda installs the grub boot loader (page 551). If you do not want to install a boot loader, remove the tick from the check box labeled **Install boot loader on /dev/xxx**. To change the device the boot loader is installed on, click **Change device**. When you install Fedora/RHEL on a machine that already runs another operating system, Anaconda frequently recognizes the other operating system and sets up grub so you can boot from either operating system. Refer to “Setting Up a Dual-Boot System” on page 82. To manually add other operating systems to grub’s list of bootable systems, click **Add** and specify a label and device to boot from. For a more secure system, specify a boot loader password.

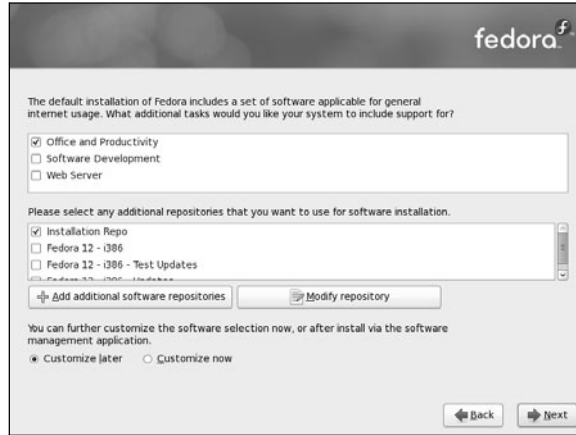
A live CD begins copying files at this point. See “Beginning Installation” on page 65.

**Enable Network Interface** (This window is displayed by the Net Install CD only). This window allows you to specify a network interface. See page 64 for more information.

**Network Configuration (RHEL)** The RHEL Network Configuration screen, which allows you to specify network configuration information, has three parts: Network Devices, Hostname, and Miscellaneous Settings. If you are using DHCP to set up the network interface, you do not need to change anything on this screen.

The Network Devices frame lists the network devices found by the installer. Normally you want network devices to become active when the system boots. Remove the tick from the check box at the left of a device if you do *not* want that device to become active when the system boots.

To configure a network device manually (not using DHCP), highlight the device and click **Edit** to the right of the list of devices. Anaconda displays the Edit Interface window. To set up IPv4 networking manually, click the radio button labeled **Manual**



**Figure 3-9** The Software Selection screen

**configuration** under **Enable IPv4 support** and enter the IP address and netmask of the system in the appropriate boxes. You can also set up or disable IPv6 networking on this screen. Click **OK**.

If you are not using DHCP, click the radio button labeled **manually** under **Set the hostname** in the network configuration screen and enter the name of the system. When you turn off DHCP configuration in the Network Devices frame, Anaconda allows you to specify a gateway address and one or more DNS (name-server) addresses. You do not have to specify more than one DNS address, although it can be useful to have two in case the first nameserver stops working. Click **Next**.

**Software Selection** (This screen does not appear when you install from a live CD.) As the Software Selection screen explains, by default Anaconda installs a basic Fedora system, including software that allows you to use the Internet. See Figure 3-9. Near the top of the screen are three check boxes that you can put ticks in to select categories of software to install: **Office and Productivity** (*FEDORA* only; selected by default), **Software Development**, and **Web Server**.

Fedora/RHEL software is kept in repositories (see Chapter 13). In the middle of the screen are check boxes (*FEDORA* only) you can put ticks in to select repositories that hold the following items:

- **Installation Repo**—Indicates Anaconda is to install from the repository included on the installation medium.
- **Fedora 12 - xxx**—Indicates Anaconda is to use the online Fedora 12 repository. The *xxx* indicates the system architecture (e.g., i386).
- **Fedora 12 - xxx - Updates**—Indicates Anaconda is to use the online Fedora 12 Updates repository. The *xxx* indicates the system architecture (e.g., i386).



**Figure 3-10** The Enable Network Interface window

Selecting either of the last two choices gives you more software packages to choose from later in the installation process if you decide to customize the software selection during installation.

Enable Network  
Interface

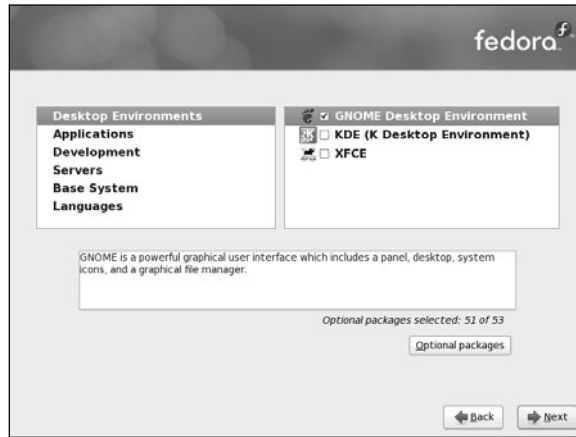
When you put a tick in either of the last two check boxes, Anaconda displays the Enable Network Interface window (Figure 3-10). By default, the check box labeled **Use dynamic IP configuration (DHCP)** has a tick in it. If the system is connected to the local network, and if that network is using DHCP, click **OK** and Anaconda will set up the network connection automatically. Otherwise, you must select the appropriate network from the Interface drop-down list, remove the tick from the check box labeled **Use dynamic IP configuration (DHCP)**, and specify an IP address for the local system, a gateway address, and a nameserver address. Your network administrator or ISP should be able to provide this information. Click **OK**; the Enable Network Interface window closes.

Below the repository selection frame in the Software Selection screen are buttons labeled **Add additional software repositories** and **Modify repository**. See Chapter 13 for information on software repositories.

Toward the bottom of the screen are two radio buttons:

- **Customize later**—Installs the default packages plus those required to perform the tasks selected from the list at the top of this screen.
- **Customize now**—Displays the package selection screen (discussed in the next section) after you click **Next** on this screen so you can select specific categories of software and package groups you want to install. If you want to set up servers as described in Part V of this book, select **Customize now** and install them in the next step.

In most cases it is a good idea to customize the software selection before installation. Regardless of which software groups and packages you select now, you can



**Figure 3-11** The package selection screen

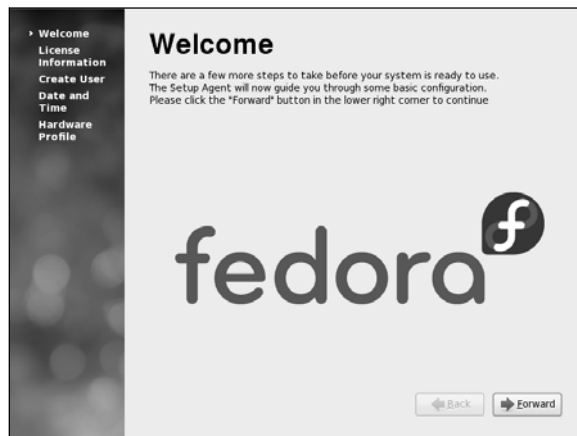
change which software groups and packages are installed on a system any time after the system is up and running (as long as the system can connect to the Internet).

**Package selection** If you selected **Customize now**, Anaconda displays a package selection screen that contains two adjacent frames near the top of the screen (Figure 3-11). If you added repositories in addition to the Installation repo, this screen will display more choices. Select a software category from the frame on the left and package groups from the frame on the right. Each package group comprises many software packages, some mandatory (the base packages) and some optional.

For example, to install KDE, which is not installed by default, click **Desktop Environments** in the left frame. Anaconda highlights your selection and displays a list of desktop environments you can install in the right frame. Put a tick in the check box labeled **KDE (K Desktop Environment)**; Anaconda highlights KDE, displays information about KDE in the frame toward the bottom of the window, displays the number of optional packages that are selected, and activates the button labeled **Optional packages**. Click this button to select which optional packages you want to install in addition to the base packages. To get started, accept the default optional packages. If you will be running servers on the system, click **Servers** on the left and select the servers you want to install from the list on the right. Select other package categories in the same manner. When you are done, click **Next**; Anaconda begins writing to the hard disk.

## BEGINNING INSTALLATION

After going through some preliminary steps, Anaconda installs Fedora/RHEL based on your choices in the preceding screens, placing a log of the installation in `/root/install.log` and a Kickstart file (page 82) in `/root/anaconda-ks.cfg`. To change the way you set up Fedora/RHEL, you can press **CONTROL-ALT-DEL** to reboot the system and start over. If you reboot the system, you will lose all the work you did up to this point.



**Figure 3-12** The Welcome screen

Installing Fedora/RHEL can take a while. The amount of time depends on the hardware you are installing the operating system on and the number of software packages you are installing.

**Installation Complete** When Anaconda is finished, it tells you that the installation is complete. An installation from a live CD ejects the CD. If you are using another installation technique, you must remove the CD/DVD (if that is the medium you installed from). Click **Reboot**.

## FIRSTBOOT: WHEN YOU REBOOT

When the system reboots, it is running Fedora/RHEL. The first time it boots, Fedora/RHEL runs Firstboot, which asks a few questions before allowing you to log in.

**Welcome** There is nothing to do on the Welcome screen (Figure 3-12). Click **Forward**.

**License Information** After the Welcome screen, Firstboot displays the License Information screen. If you understand the license information, click **Forward**.

**Firewall (RHEL)** Next RHEL gives you the opportunity to set up a very basic *firewall* (page 1082). First select **Enabled** or **Disabled** from the drop-down list labeled **Firewall**. If you enable the firewall, select which services the firewall will pass through to the system. These services are the ones the system is providing by means of servers you set up. For example, you do not need to enable WWW to browse the Web using Firefox; you need to enable WWW only if you want to set up an Apache (HTTP) Web server. Select **Secure WWW (HTTPS)**, which is used for secure browser connections, to allow secure HTTP to pass through the firewall. Click the triangle to the left of **Other ports** to open a frame in which you can add and remove additional protocols and ports that the firewall will pass. Use the buttons labeled **Add** and **Remove** to manipulate this list.

For more information on setting up a firewall, refer to “JumpStart: Building a Firewall Using `system-config-firewall`” on page 824. Chapter 25 on `iptables` has information on how to build a more complete and functional firewall. Click **Forward**.

**SELinux (RHEL)** SELinux (Security Enhanced Linux) enforces security policies that limit what a user or a program can do. On this screen RHEL allows you to choose one of two policies: **Enforcing** or **Permissive**. Alternatively, you can disable SELinux. If you enable SELinux, you can modify its policy. The policy defaults to Enforcing, which prevents any user or program from doing anything that is not permitted by the policy. If you will never want to use SELinux, disable it. If you do not want to use it now but may want to do so in the future, establish a Permissive policy—it issues warnings but does not enforce the policy. It can take a lot of time to turn on SELinux on a system where it has been disabled. For more information refer to “SELinux” on page 414. Click **Forward**.

**Create User** The next screen allows you to set up a user account. For more information refer to “Configuring User and Group Accounts” on page 556.

**Date and Time** The next screen allows you to set the system date and time. Running the Network Time Protocol (NTP) causes the system clock to reset itself periodically from a clock on the Internet. If the system is connected to the Internet, you can enable NTP by putting a tick in the check box labeled **Synchronize date and time over the network**. Click **Forward**.

When the Date and Time screen closes, the installation is complete. You can now use the system and set it up as you desire. For example, you may want to customize the desktop (as explained in Chapters 4 and 8) or set up servers (as discussed in Part V of this book).

## INITIALIZING DATABASES AND UPDATING THE SYSTEM

Updating the **whatis** database ensures that the **whatis** (page 168) and **apropos** (page 167) utilities will work properly. Similarly, updating the **locate** database ensures that **locate** will work properly. (The **locate** utility indexes and allows you to search for files on the system quickly and securely.) Instead of updating these databases when you install the system, you can wait for **cron** (page 565) to run them, but be aware that **whatis**, **apropos**, and **locate** will not work for a while. The best way to update these databases is via the cron scripts that run daily. Working with **root** privileges (Superuser; page 405), give the following commands:

```
# /etc/cron.daily/makewhatis.cron
# /etc/cron.daily/mlocate.cron
```

These utilities run for several minutes and may complain about not being able to find a file or two. When the system displays a prompt, the **whatis** and **locate** databases are up-to-date.



**Figure 3-13** The Welcome screen displaying boot parameters (options)

## INSTALLATION TASKS

This section details some common tasks you may need to perform during or after installation. It covers modifying the boot parameters, using Disk Druid to partition the disk during installation, using `palimpsest` to view and modify partitions, using logical volumes (LVs) to facilitate disk partitioning, using Kickstart to automate installation, and setting up a system that will boot either Windows or Linux (a dual-boot system).

## MODIFYING BOOT PARAMETERS (OPTIONS)

**FEDORA** To modify boot parameters, you must interrupt the automatic boot process by pressing a key such as the SPACE bar while Fedora is counting down when you first boot from a live CD (page 52) or install DVD (page 55). When you press a key, Fedora displays the Welcome menu (Figure 3-2 on page 53 or Figure 3-4 on page 56). Use the ARROW keys to highlight the selection you want *before* proceeding (page 56). With the desired selection highlighted, press the TAB key to display the boot command-line parameters (Figure 3-13).

**RHEL** RHEL presents a **boot:** prompt in place of the boot parameters line Fedora displays when you press TAB. You can enter any of the parameters described in this section in response to the **boot:** prompt; however, you must precede these parameters with the word **linux**. (See the examples in the next paragraphs.)



*RHEL+FEDORA* Type a **SPACE** before you enter any parameters. You can specify multiple parameters separated by **SPACES**. Press **RETURN** to boot the system. For more information on boot parameters, refer to [www.kernel.org/doc/Documentation/kernel-parameters.txt](http://www.kernel.org/doc/Documentation/kernel-parameters.txt), [www.kernel.org/pub/linux/kernel/people/gregkh/lkn/lkn\\_pdf/ch09.pdf](http://www.kernel.org/pub/linux/kernel/people/gregkh/lkn/lkn_pdf/ch09.pdf), or the Web page at [fedoraproject.org/wiki/Anaconda/Options](http://fedoraproject.org/wiki/Anaconda/Options). Alternatively, you can use Google to search on **linux boot parameters**.

## What to do if the installation does not work

**tip** On some hardware, the installation may pause for as long as ten minutes. Before experimenting with other fixes, try waiting for a while. If the installation hangs, try booting with one or more of the boot parameters described in this section. Try running the installer in pseudographical (textual) mode.

Following are some of the parameters you can add to the boot command line. If you encounter problems with the display during installation, supply the **nofb** parameter, which turns off video memory. If you are installing from a medium other than a DVD—that is, if you are installing from files on the local hard disk or from files on another system using FTP, NFS, or HTTP—supply the **askmethod** or **method** parameter.

Many of these parameters can be combined. For example, to install Linux in text mode using a terminal running at 115,200 baud, no parity, 8 bits, connected to the first serial device, supply the following parameters (the **,115200n8** is optional). The first line shows the parameters you enter while booting Fedora. The second line shows the parameters, including **linux**, you enter in response to the **boot:** prompt while booting RHEL.

```
text console=ttyS0,115200n8 FEDORA
boot: linux text console=ttyS0,115200n8 RHEL
```

The next set of parameters installs Fedora/RHEL on a monitor with a resolution of 1024 × 768, without probing for any devices. The installation program asks you to specify the source of the installation data (CD, DVD, FTP site, or other) and requests a video driver.

```
resolution=1024x768 noprobe askmethod FEDORA
boot: linux resolution=1024x768 noprobe askmethod RHEL
```

- noacpi** Disables ACPI (Advanced Configuration and Power Interface). This parameter is useful for systems that do not support ACPI or that have problems with their ACPI implementation. The default is to enable ACPI. Also **acpi=off**.
- noapic** Disables APIC (Advanced Programmable Interrupt Controller). The default is to enable APIC.
- noapm** Disables APM (Advanced Power Management). The default is to enable APM. Also **apm=off**.

**askmethod** Presents a choice of installation sources: local CD/DVD or hard disk, or over a network using NFS, FTP, or HTTP (first installation CD, Net Boot CD, and install DVD only).

- **Local CD/DVD**—Displays the Disc Found screen, which allows you to test the installation media (the same as if you had not entered any boot parameters).
- **Hard drive**—Prompts for the partition and directory that contain the installation tree or the ISO image of the install DVD. Do not include the name of the mount point when you specify the name of the directory. For example, if the ISO images are in the `/home/sam/FC12` directory and `/dev/sda6` holds the partition that is normally mounted on `/home`, you would specify the partition as `/dev/sda6` and the directory as `sam/FC12` (no leading slash).
- The next two selections display the Configure TCP/IP screen from which you can select DHCP or Manual configuration. Manual configuration requires you to enter the system's IP address and netmask as well as the IP addresses of the default gateway and primary nameserver.
  - ♦ **NFS directory**—Displays the NFS Setup screen, which requires you to enter the NFS server name and the name of the directory that contains the installation tree or the ISO image of the install DVD. Enter the server's IP address and the *name* of the exported directory, not its device name. The remote (server) system must export (page 739) the directory hierarchy that holds the installation tree or the ISO image of the install DVD.
  - ♦ **URL**—Displays the URL Setup screen, which requires you to enter the URL of the directory that contains the installation tree or the ISO image of the install DVD.

**nodma** Turns off direct memory access (DMA) for all disk controllers. This parameter may make buggy controllers (or controllers with buggy drivers) more reliable, but also causes them to perform very slowly because the connected devices have to run in PIO mode instead of DMA mode. It may facilitate testing CD/DVDs that were not written correctly. For more information refer to “The Disc Found Screen” on page 57.

**nofb** (**no framebuffer**) Turns off the framebuffer (video memory). This option is useful if problems arise when the graphical phase of the installation starts.

**irqpoll** Changes the way the kernel handles interrupts.

**ks=*URI*** Specifies the location of a Kickstart (page 82) file to use to control the installation process. The *URI* is the pathname or network location of the Kickstart file.

**nolapic** Disables local APIC. The default is to enable local APIC.

**lowres** Runs the installation program at a resolution of 640 × 480 pixels. See also **resolution**.

- `mem=xxxM` Overrides the detected memory size. Replace `xxx` with the number of megabytes of RAM in the computer.
- `method=URI` Specifies an installation method and location without prompting as `askmethod` does. For example, you can use the following parameter to start installing from the specified server:
- ```
method=ftp://download.fedora.redhat.com/pub/fedora/linux/releases/12/Fedora/i386/os
```
- `noprobe` Disables hardware probing for all devices, including network interface cards (NICs), graphics cards, and the monitor. This option forces you to select devices from a list. You must know exactly which cards or chips the system uses when you use this parameter. Use `noprobe` when probing causes the installation to hang or otherwise fail. This parameter allows you to supply arguments for each device driver you specify.
- `rescue` Puts the system in rescue mode; see page 411 for details.
- `resolution=WxH` Specifies the resolution of the monitor you are using for a graphical installation. For example, `resolution=1024x768` specifies a monitor with a resolution of 1024 × 768 pixels.
- `text` Installs Linux in pseudographical (page 28) mode. Although the images on the screen appear to be graphical, they are composed entirely of text characters.
- `vnc` Installs Linux via a VNC (virtual network computing) remote desktop session. After providing an IP address, you can control the installation remotely using a VNC client from a remote computer. You can download a VNC client, which runs on several platforms, from [www.realvnc.com](http://www.realvnc.com). Use `yum` (page 500) to install the `vnc` software package to run a VNC client on a Fedora/RHEL system.
- `vncpassword=passwd` Enables a password for a VNC connection. This option requires that you also use the `vnc` option.

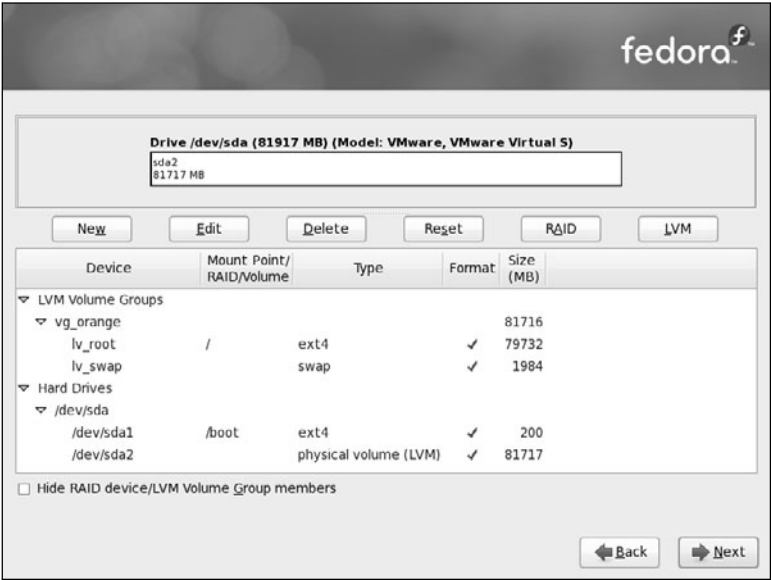
## PARTITIONING THE DISK

See page 30 for a discussion of partitions and setup of the hard disk.

### USING DISK DRUID TO PARTITION THE DISK

Disk Druid, a graphical disk-partitioning program that can add, delete, and modify partitions on a hard disk, is part of the Fedora/RHEL installation system. You can use Disk Druid only while you are installing a system; it cannot be run on its own. You can use `palimpsest` (page 78), `parted` (page 568), or `fdisk` to manipulate partitions and `system-config-lvm` to work with LVs after you install Fedora/RHEL. As explained earlier, if you want a basic set of partitions, you can allow Anaconda to partition the hard disk automatically.

Anaconda runs Disk Druid when you put a tick in the check box labeled **Review and modify partitioning layout** or when you select **Create custom layout** in the Disk Partitioning screen (Figure 3-7, page 61).



**Figure 3-14** Disk Druid: main screen, default layout

**Clone and RAID** Disk Druid includes Clone, a tool that copies the partitioning scheme from a single drive to other drives. Clone is useful for making multiple copies of a RAID partition/drive when you are creating a large RAID array of identical partitions or identically partitioned drives. Click the **RAID** button to access the Clone tool, which is active only when at least one unallocated RAID partition exists. For more information on RAID, see page 37.

**Default layout** Figure 3-14 shows the Disk Druid main screen as it appears when you have chosen the default layout for the hard disk (see “Disk Partitioning” on page 60). This screen has three sections (from top to bottom): a graphical representation of the disk drives showing how each is partitioned, a row of buttons, and a table listing one partition or LV per line. In the figure, the graphical depiction of the `/boot` partition is so small that its descriptive text is covered by the other partition.

The following buttons appear near the top of the screen:

- **New**—Adds a new partition to the disk (page 76)
- **Edit**—Edits the highlighted partition or LV (both on page 73)
- **Delete**—Deletes the highlighted partition or LV
- **Reset**—Cancels the changes you have made and causes the Disk Druid table to revert so it matches the layout of the disk

- **RAID**—Enables you to create software RAID partitions and to join two or more RAID partitions into a RAID device (page 37)
- **LVM**—Enables you to create physical volumes (PVs), which you can then use to create LVs (page 38)

The Disk Druid table contains the following columns:

- **Device**—The name of the device in the `/dev` directory (for example, `/dev/sda1` or the name of the LV).
- **Mount Point/RAID/Volume**—Specifies where the partition will be mounted when the system is brought up (for example, `/usr`). It is also used to specify the RAID device or LVM volume the partition is part of.
- **Type**—The type of the partition, such as `ext4`, `swap`, or **physical volume** (LVM).
- **Format**—A tick in this column indicates the partition will be formatted as part of the installation process. All data on the partition will be lost.
- **Size (MB)**—The size of the partition or LV in megabytes.
- **Start**—The number of the block the partition starts on. (*RHEL*)
- **End**—The number of the block the partition ends on. (*RHEL*)

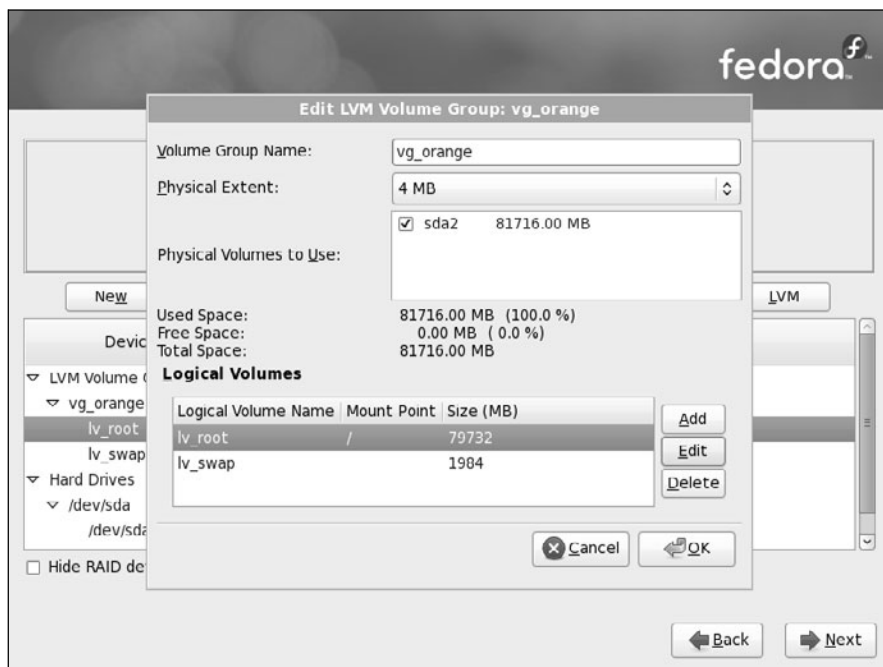
At the bottom of the screen is a check box that allows you to hide RAID device and LVM volume group members. Do not put a tick in this check box if you want to see all information about the disk drives.

## LVs: LOGICAL VOLUMES

When you instruct Anaconda to partition the hard disk with a default layout (see “Disk Partitioning” on page 60), it uses LVM (page 38) to set up most of the hard disk, creating LVs (logical volumes) instead of partitions. It places `/boot` on the first partition on the drive, not under the control of LVM. LVM creates a VG (volume group) named `vg_xxx`, where `xxx` is the name of the system. Within this VG it creates two LVs: root (`/`, `lv_root`) and swap (`lv_swap`). The swap LV occupies up to a few gigabytes; the root LV takes up the rest of the drive. This section explains how to make the root LV smaller so you can add additional LVs to `vg_xxx`.

If you click the Disk Druid **LVM** button with the default setup (with the root LV occupying all of the disk that is not occupied by the swap LV and the `/boot` partition), Disk Druid displays a dialog box that advises you that there are not enough physical volumes and suggests that you create a new partition. Because the existing partitions occupy the whole disk, you cannot create a new partition.

To make the root LV smaller and make room for additional partitions, first highlight the root partition (`lv_root`) and then click **Edit**. Disk Druid displays the Edit

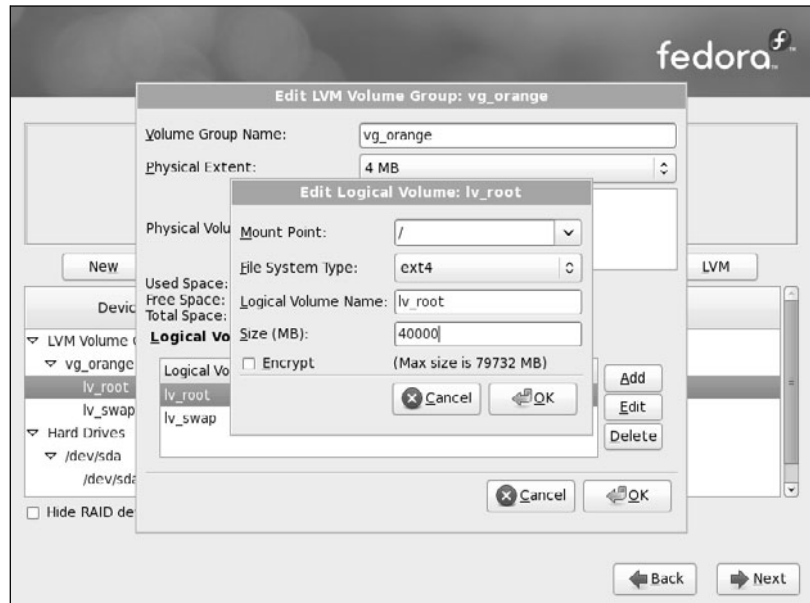


**Figure 3-15** Disk Druid: Edit LVM Volume Group window

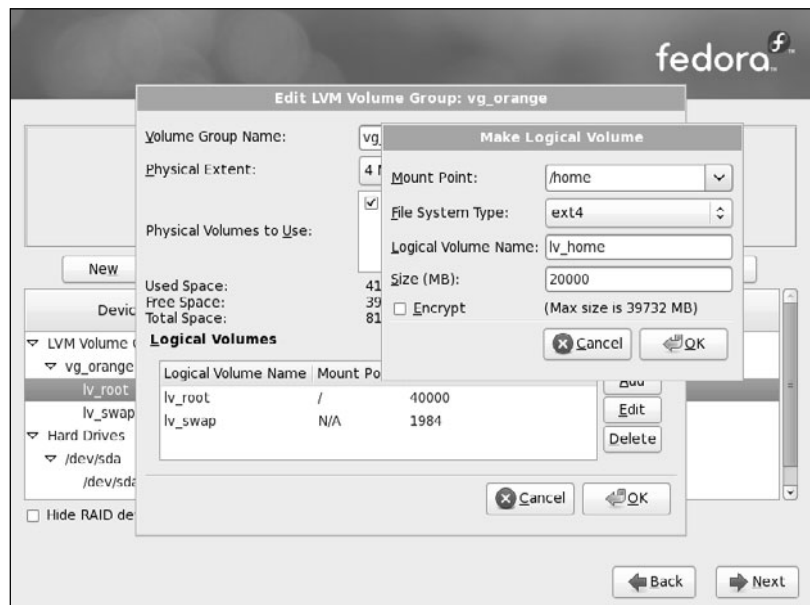
LVM Volume Group window (Figure 3-15). The figure shows that **vg\_orange** (the system is named **orange**) has no free space (see the line in the middle of the window). There are two LVs on this system: swap, which does not have a mount point, and root, which has a mount point of **/**.

Highlight the root LV (**lv\_root**) in the frame labeled **Logical Volumes** and click **Edit**. Disk Druid displays the Edit Logical Volume window (Figure 3-16), which allows you to change the size of the root LV. Replace the numbers in the text box labeled **Size (MB)** with the number of megabytes you want to assign to the root LV. Figure 3-16 shows the size of the root partition being changed to 40 gigabytes (40,000 megabytes). Click **OK**.

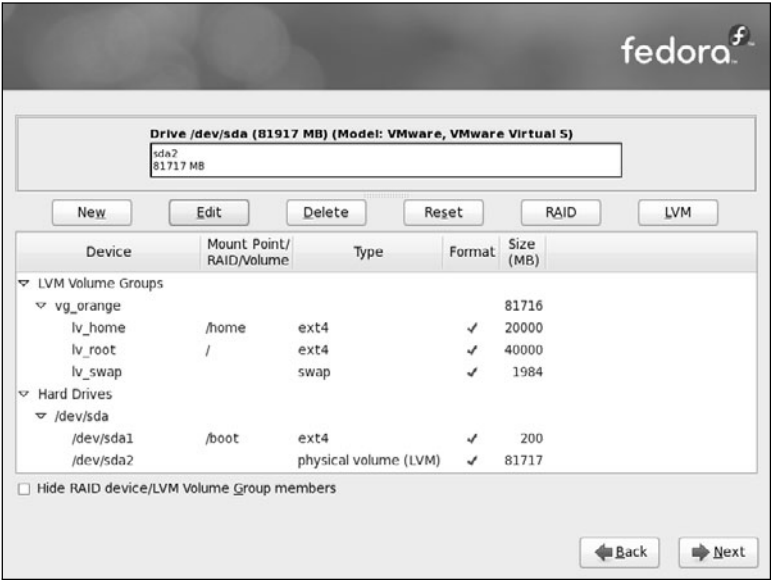
Once you decrease the size of the root partition, the Edit LVM Volume Group window shows that the VG has free space. You can now add another LV to the VG. Click **Add** in the Edit LVM Volume Group window to display the Make Logical Volume window (Figure 3-17). Select a mount point, filesystem type, and size for the LV. You can change the LV name if you like, although Disk Druid assigns logical, sequential names that are easy to use. Figure 3-17 shows a **/home** LV with a name of **lv\_home** and a filesystem type of **ext4** being created with a size of 20 gigabytes. Click **OK** when the LV is set up the way you want.



**Figure 3-16** Disk Druid: Edit Logical Volume window



**Figure 3-17** Disk Druid: Make Logical Volume window



**Figure 3-18** Disk Druid: main screen with the new `/home` LV

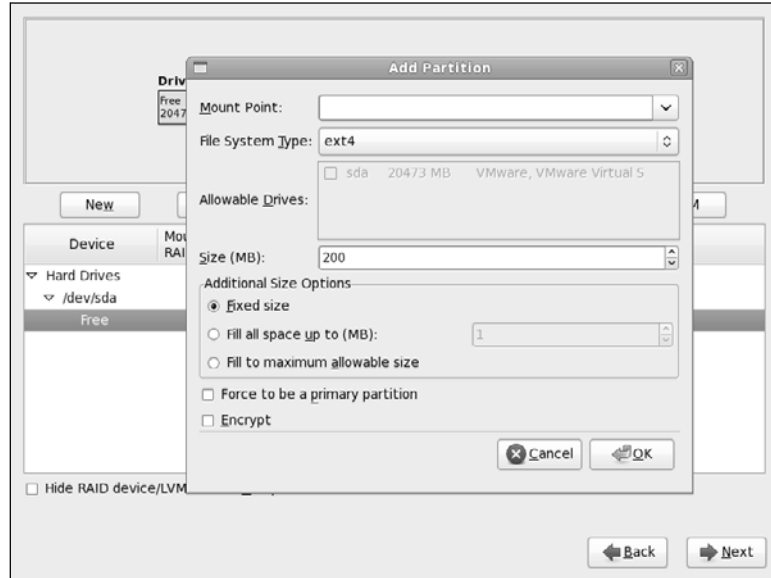
Figure 3-18 shows the modified Disk Druid main screen with the new `/home` LV.

**PARTITIONS**

**Add a new partition** To add a new partition to a hard disk, *the hard disk must have enough free space to accommodate the partition*; see “Resizing a partition” on page 77. Click the **New** button to add a partition. In response, Disk Druid displays the Add Partition window (Figure 3-19). Specify the mount point (the name of the directory the partition will be mounted on; page 32) and the filesystem type; use the arrow buttons at the right ends of these boxes to display drop-down lists.

If more than one drive is available, put a tick in the check box next to the drive you want the partition to be created on in the Allowable Drives frame. Specify the size of the partition and, in the Additional Size Options frame, click the radio button labeled **Fixed size** to create the partition close to the size you specify. Because of block-size constraints, the final partitions are not usually exactly the size you specify. Click the radio button labeled **Fill all space up to (MB)** and fill in the maximum size you want the partition to be to create a partition that takes up the existing free space, up to the maximum size you specify. In other words, Disk Druid will not complain if it cannot create the partition as large as you would like. Click the radio button labeled **Fill to maximum allowable size** to cause the partition to occupy all of the remaining free space on the disk, regardless of size. (If you create another partition after creating a **Fill to maximum allowable size** partition, the new partition will pull blocks from the existing maximum size partition.)





**Figure 3-19** Disk Druid: Add Partition window, **ext4** filesystem

Put a tick in the check box labeled **Encrypt** to encrypt the partition. Put a tick in the check box labeled **Force to be a primary partition** to create a primary partition (page 31). Click **OK**, and Disk Druid adds the partition to its table (but does not write the changes to the hard disk).

Edit an existing  
partition

To modify an existing partition, highlight the partition in the Disk Druid table or the graphical representation of the hard disk and click the **Edit** button; Disk Druid displays the Edit Partition window. Using this window, you can change the mount point or size of a partition, or format the partition as another type (**ext3**, **vfat**, **swap**, and so on).

### Always back up the data on a hard disk

**caution** If you are installing Fedora/RHEL on a disk that holds data that is important to you, always back up the data before you start the installation process. Things can and do go wrong. The power might go out in the middle of an installation, corrupting the data on the hard disk. A bug in the partitioning software might destroy a filesystem. Although it is unlikely, you might make a mistake and format a partition holding data you want to keep.

Resizing a partition

If you have a hard disk with a single partition that occupies the entire disk, such as when you are setting up a dual-boot system by adding Fedora/RHEL to a Windows system (page 82), you may be able to resize the partition to install Fedora/RHEL. The process of resizing a partition is the same regardless of the type of partition: You can use the following technique to resize Windows, Linux, or other types of partitions.

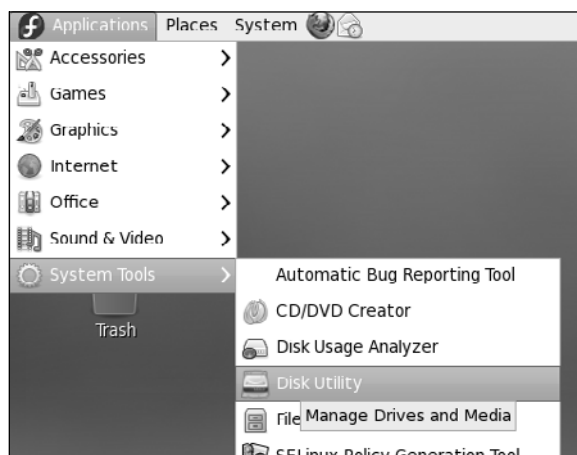
To install Fedora/RHEL on this system, you must resize (shrink) the partition to make room for Fedora/RHEL. Before you resize a Windows partition, you must boot Windows and defragment the partition using the Windows defragmenter; see the tip on page 83. To resize the partition, highlight the partition in the Disk Druid table or the graphical representation of the hard disk and click the **Edit** button; Disk Druid displays the Edit Partition window.

In the Edit Partition window, put a tick in the check box labeled **Resize**. Then enter the size, in megabytes, you want to shrink the filesystem to. Make sure that the size you specify is larger than the amount of space the data on the filesystem occupies. When you click **OK**, Disk Druid shrinks the partition.

## palimpsest: THE GNOME DISK UTILITY (*FEDORA*)

Unless you are certain the hard disk where you are installing Fedora/RHEL has nothing on it (it is a new disk) or you are sure the disk holds no information of value, it is a good idea to examine the contents of the disk before you start the installation. The **palimpsest** disk utility, which is available from a live session, is a good tool for this job. It is part of the **gnome-disk-utility** package. Open the Palimpsest Disk Utility window by selecting **Main menu: Applications⇒System Tools⇒Disk Utility** as shown in Figure 3-20. Alternatively, you can give the command **palimpsest** in a terminal emulator window (page 118).

The **palimpsest** utility displays the layout of the hard disk (Figure 3-21). From this window you can create and delete partitions. Although you can create partitions using **palimpsest**, you cannot specify the mount point (page 32) for a partition—this step must wait until you are installing Fedora/RHEL and using the Disk Druid partitioner. You can save time if you use **palimpsest** to examine a hard disk and Disk Druid to set up the partitions you install Fedora/RHEL on.



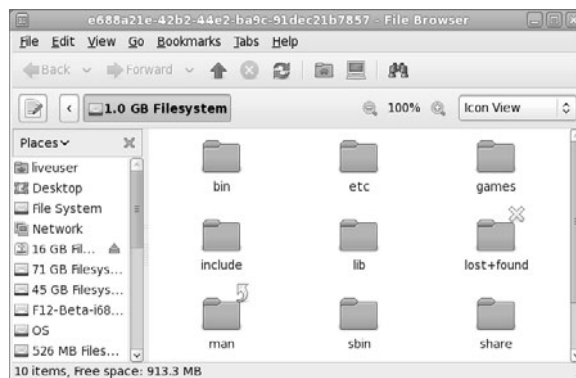
**Figure 3-20** Selecting the **palimpsest** disk utility from the Main menu



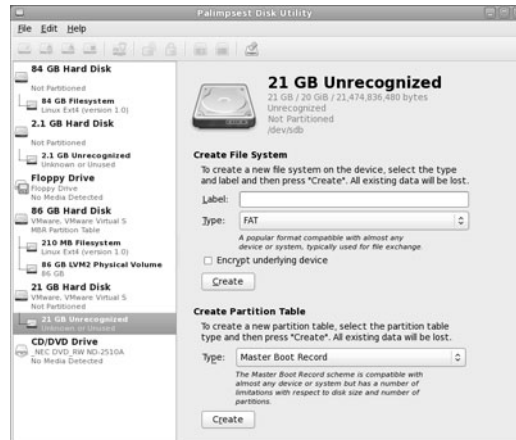
**Figure 3-21** The palimpsest utility displaying information about a filesystem

## DISPLAYING THE CONTENTS OF A FILESYSTEM

To display the contents of a filesystem, highlight the filesystem in the Palimpsest Disk Utility window and click the mount icon (far left) in the palimpsest toolbar near the top of the window. The palimpsest utility mounts the highlighted filesystem and displays the mount location (Figure 3-21) as a link. Right-click the mount location and select Open Link from the drop-down menu. Nautilus displays the filesystem in a window (Figure 3-22). Unless you instruct Nautilus to always open File Browser windows as explained under “The Two Faces of Nautilus” on page 99, Nautilus will display the filesystem in a Spatial view (page 270). A Spatial view should not be a problem in this situation. When you have finished examining the contents of the filesystem, click the unmount icon (second from left) to unmount the filesystem.



**Figure 3-22** Browsing a partition using palimpsest



**Figure 3-23** A disk without a partition table

## DELETING A PARTITION

Before deleting a partition, make sure it does not contain any data you need. To use the palimpsest utility to delete a partition, highlight the partition you want to delete and click the button labeled **Delete**. After checking with you, palimpsest deletes the partition.

## WRITING A PARTITION TABLE

A new disk does not have a partition table (page 30) and looks similar to the disk highlighted in Figure 3-23. It will be marked as **Unrecognized**. Make sure you highlight the entry that says **Unrecognized** and not the one that says **Hard Disk**. If the disk you are working with already has a partition table, skip to the next section.

Typically you will want to create a partition table of type **Master Boot Record**. With this type of partition selected, click the button below the Create Partition Table heading labeled **Create**. After checking that you really want to create a partition table, which makes data on the disk inaccessible, palimpsest creates the table.

## CREATING A PARTITION AND FILESYSTEM

Once you have created a partition table, the disk will be marked as **Free** (free space; page 30) and you will be able to create a partition that holds a filesystem in the free space (Figure 3-24). Using the slider labeled **Size**, or the adjacent spin box, specify the desired size of the new partition. You can enter a label if you like. Next specify a filesystem type; under Fedora, **ext4** filesystems are the most common. Typically you will want to own the filesystem, so allow the tick to remain in the check box labeled **Take ownership of file system**. If you want the filesystem to be encrypted, put a tick in the check box labeled **Encrypt underlying filesystem**. Finally, click **Create**. After checking with you, palimpsest will create the filesystem. If you did not use all of the free space, you can create additional partitions/filesystems in the same manner.



Figure 3-24 An empty disk with a partition table

USING SMART TO DISPLAY DISK PERFORMANCE INFORMATION

SMART (Self-Monitoring, Analysis, and Reporting Technology) monitors hard disks and attempts to predict hard disk failures. To see a SMART report for a disk on the system, highlight the disk (the entry that says **Hard Disk**) and click **More Information** on the right side of the Palimpsest Disk Utility window; palimpsest displays a window similar to the one shown in Figure 3-25. From this window you can run various self-tests and scroll through the information at the bottom of the window.

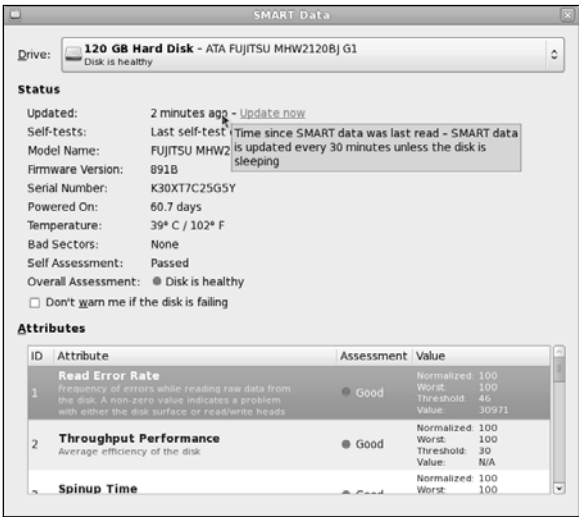
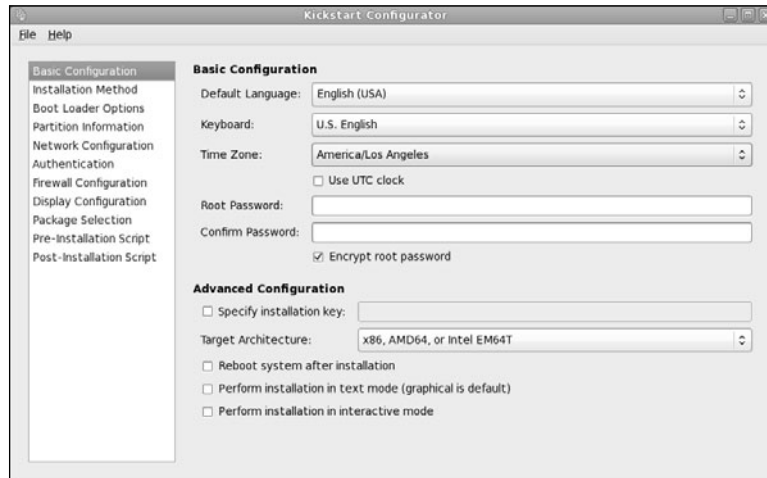


Figure 3-25 SMART data as displayed by palimpsest



**Figure 3-26** The Kickstart Configurator window

## USING THE KICKSTART CONFIGURATOR

Kickstart is a Fedora/RHEL program that completely or partially automates the same installation and post-installation configuration on one or more machines. To use Kickstart, you create a single file that answers all the questions that are normally asked during an installation. Anaconda then refers to this file instead of asking you questions during installation. See the `ks` boot parameter on page 70. Using Kickstart, you can automate language selection, network configuration, keyboard selection, boot loader installation, disk partitioning, X Window System configuration, and more.

The `system-config-kickstart` utility displays the Kickstart Configurator window (Figure 3-26), which creates a Kickstart installation script. This utility is part of the `system-config-kickstart` software package but is not installed by default. You can install this package using `yum`; see page 500. To run this utility, enter `system-config-kickstart` on a command line or select **Main menu: Applications⇒System tools⇒Kickstart**.

Figure 3-26 shows the first window the Kickstart Configurator displays. To generate a Kickstart file (`ks.cfg` by default), go through each section of this window (the items along the left side) and fill in the answers and put ticks in the appropriate check boxes. It may be helpful to start with the Kickstart installation script that Anaconda generated when you installed the system (`/root/anaconda.cfg`). Click **Help** on the menubar for instructions on completing these tasks. When you are finished, click **File⇒Save**. The Kickstart Configurator gives you a chance to review the generated script before it saves the file.

## SETTING UP A DUAL-BOOT SYSTEM

A *dual-boot* system is one that can boot one of two (or more) operating systems. This section describes how to add Fedora/RHEL to a system that can boot Windows,

thereby creating a system that can boot Windows or Linux. You can use the same technique for adding Fedora/RHEL to a system that runs a different version or distribution of Linux.

One issue that arises when you are setting up a dual-boot system is the need to find disk space for the new Fedora/RHEL system. The next section discusses several ways to create the needed space.

## CREATING FREE SPACE ON A WINDOWS SYSTEM

Typically you install Fedora/RHEL in free space on a hard disk. To add Fedora/RHEL to a Windows system, you must have enough free space on a hard disk that already holds Windows. There are several ways to provide or create this free space. The following paragraphs discuss these options in order from easiest to most difficult.

**Add a new hard disk.** Add another hard disk to the system and install Linux on the new disk, which contains only free space. This technique is very easy and clean but requires a new hard disk.

**Use existing free space.** If there is sufficient free space on the Windows disk, you can install Linux there. This technique is the optimal choice, but there is rarely enough free space on an installed hard disk.

**Resize Windows partitions.** Windows partitions often occupy the entire disk, which explains why resizing a Windows partition is the technique most commonly used to free up space. Windows systems typically use NTFS, FAT32, and/or FAT16 filesystems. You can resize an existing Windows partition when you install Fedora/RHEL. Alternatively, you can use the `palimpsest` utility to examine and resize a partition to open up free space in which to install Linux (page 77).

### Always defragment before resizing

**caution** You must boot Windows and defragment a Windows partition before you resize it. Sometimes you may need to run the Windows defragmenter several times to consolidate most file fragments. Not only will defragmenting give you more space for a Linux partition, but it may also keep the process of setting up a dual-boot system from failing.

**Remove a Windows partition.** If you can delete a big enough Windows partition, you can install Linux in its place. To delete a Windows partition, you must have multiple partitions under Windows and be willing to lose the data in the partition you delete. In many cases, you can save this data by moving it from the partition you will delete to another Windows partition.

Once you are sure a partition contains no useful information, you can delete it when you install Fedora/RHEL. Alternatively, you can use `palimpsest` to delete it (page 80). After deleting the partition, you can install Fedora/RHEL in the free space formerly occupied by the partition you removed.

## INSTALLING FEDORA/RHEL AS THE SECOND OPERATING SYSTEM

After you have created enough free space on a Windows system (see the previous section), you can begin installing Fedora/RHEL. When you get to the Disk Partitioning

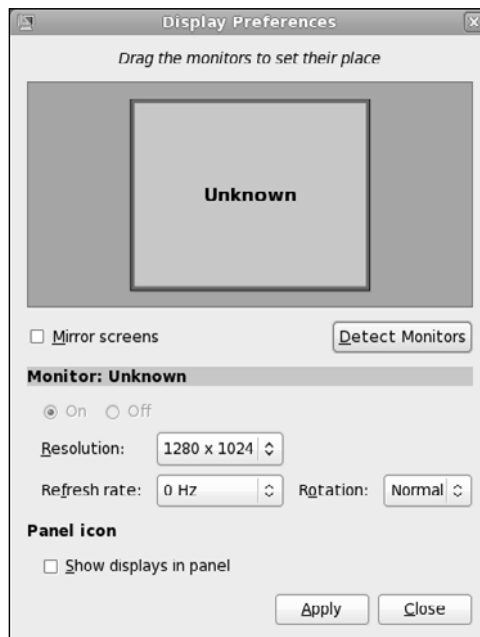
screen (Figure 3-7, page 61), choose **Use free space** to have Anaconda partition the free space on the hard disk automatically. If you need to delete a Windows partition, you must choose **Create custom layout**; this selection calls Disk Druid (page 71) so you can delete the appropriate Windows partition and create Linux partitions in the free space. When you boot the system, you will be able to choose which operating system you want to run.

## THE X WINDOW SYSTEM

If you specified a graphical desktop environment such as GNOME or KDE, you installed the X.org (x.org/wiki) implementation of the X Window System when you installed Linux. The X Window System release X11R7.2 comprises almost 50 software packages. The X configuration files are kept in `/etc/X11`.

### gnome-display-properties: CONFIGURES THE DISPLAY

You can use the `gnome-display-properties` (*FEDORA*) or `system-config-display` (*RHEL*) utility to display the Display Preferences window (Figure 3-27), which allows you to configure the monitor. Most users never need to run this utility: In almost all cases, Fedora/RHEL autoconfiguration sets up X.org to work properly. To run this utility, enter `gnome-display-properties` (*FEDORA*) or `gnome-config-display` (*RHEL*) on a



**Figure 3-27** The Display Preferences window



command line or select **Main menu: System**⇒**Preferences**⇒**Display** (*FEDORA*) or **Main menu: System**⇒**Administration**⇒**Display** (*RHEL*).

Figure 3-27 shows the Display Preferences window, which allows you to specify the resolution for the monitor. Normally the system probes the monitor and fills in these values. If these values are missing, check the specifications for the monitor and select the appropriate values from the drop-down lists.

## MORE INFORMATION

Web X.org: [www.x.org/wiki](http://www.x.org/wiki), [www.freedesktop.org](http://www.freedesktop.org)  
X.org FAQ: [www.x.org/wiki/FAQ](http://www.x.org/wiki/FAQ)

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## CHAPTER SUMMARY

Most installations of Fedora/RHEL begin by booting from the live CD or the install DVD. When the system boots from the CD/DVD, it displays a message saying when it will boot automatically. During the time it displays this message, you can give various commands and then have the system continue booting.

The program that installs Fedora/RHEL is named Anaconda. Anaconda identifies the hardware, builds the necessary filesystems, and installs or upgrades the Fedora/RHEL operating system. It can run in textual or graphical (default) interactive mode or in batch mode using Kickstart.

The Disk Druid graphical disk-partitioning program can add, delete, and modify partitions and logical volumes (LVs) on a hard disk during installation. The *palimpsest* utility reports on and manipulates hard disk partitions before or after installation. The *system-config-lvm* utility works with logical volumes after installation.

A dual-boot system can boot one of two or more operating systems, frequently Windows and Linux. The biggest task in setting up a dual-boot system, assuming you want to add Linux to a Windows system, is finding enough disk space to hold Linux.

Fedora/RHEL uses the X.org X Window System version X11R7.2. Fedora/RHEL uses the GNOME display manager (*gdm*) to provide a graphical login.

---

## EXERCISES

1. What is a live system? What advantages does it have over an installed system?
2. Which boot parameter would you use to begin an FTP installation?
3. Describe the Anaconda installer.

4. Where on the disk should you put your **/boot** partition or the root (**/**) partition if you do not use a **/boot** partition?
5. If the graphical installer does not work, what three steps should you try?
6. When should you specify an **ext2** filesystem instead of **ext4**?
7. Describe Disk Druid.

---

## ADVANCED EXERCISES

8. When does a Fedora/RHEL system start X by default?
9. If you do not install grub on the master boot record of the hard disk, how can you boot Linux?
10. Why would you place **/var** at the beginning of the disk?
11. How does Anaconda set up a hard disk by default?

## PART II

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# GETTING STARTED WITH FEDORA AND RED HAT ENTERPRISE LINUX

### CHAPTER 4

INTRODUCTION TO FEDORA AND RED HAT  
ENTERPRISE LINUX 89

### CHAPTER 5

THE LINUX UTILITIES 147

### CHAPTER 6

THE LINUX FILESYSTEM 187

### CHAPTER 7

THE SHELL 223

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# INTRODUCTION TO FEDORA AND RED HAT ENTERPRISE LINUX

## IN THIS CHAPTER

|                                                               |     |
|---------------------------------------------------------------|-----|
| Curbing Your Power (Super-<br>user/root Privileges) . . . . . | 90  |
| A Tour of the Fedora/RHEL<br>Desktop . . . . .                | 90  |
| Mouse Preferences . . . . .                                   | 97  |
| Using Nautilus to Work<br>with Files . . . . .                | 98  |
| The Update Applet . . . . .                                   | 104 |
| Updating, Installing, and<br>Removing Software Packages . .   | 122 |
| Where to Find Documentation . .                               | 124 |
| More About Logging In . . . . .                               | 132 |
| What to Do If You Cannot Log In .                             | 134 |
| Working from the<br>Command Line . . . . .                    | 138 |
| Controlling Windows: Advanced<br>Operations . . . . .         | 141 |

One way or another you are sitting in front of a computer that is running Fedora or Red Hat Enterprise Linux. After describing **root** (Superuser) privileges, this chapter takes you on a tour of the system to give you some ideas about what you can do with it. The tour does not go into depth about choices, options, menus, and so on; that is left for you to experiment with and to explore in greater detail in Chapter 8 and throughout later chapters of this book. Instead, this chapter presents a cook's tour of the Linux kitchen: As you read it, you will have a chance to sample the dishes that you will enjoy more fully as you read the rest of this book.

Following the tour is a section that describes where to find Linux documentation (page 124). The next section offers more about logging in on the system, including information about passwords (page 132). The chapter concludes with a more advanced, optional section about working with Linux windows (page 141).

Be sure to read the warning about the dangers of misusing the powers of **root** (Superuser) in the next section. While heeding that warning, feel free to experiment with the system: Give commands, create files, click objects, choose items from menus, follow the examples in this book, and have fun.

## CURBING YOUR POWER (SUPERUSER/root PRIVILEGES)

While you are logged in as the user named **root**, you are referred to as *Superuser* or *administrator*; you are working with **root** privileges and have extraordinary systemwide powers. Running the `su` or `sudo` utility can give you similar privileges. When working with **root** privileges, you can read from or write to almost any file on the system, execute programs that ordinary users cannot, and more. On a multiuser system you may not be permitted to know the **root** password and so may not be able to run certain programs. Nevertheless, someone—the *system administrator*—knows the **root** password, and that person maintains the system. When you are running Linux on your own computer, you will assign a password to **root** when you install Linux. Refer to “System Administrator and Superuser” on page 405 for more information.

### Do not experiment while you are working with root privileges

---

**caution** Feel free to experiment when you are *not* working with **root** privileges. When you *are* working with **root** privileges, do only what you have to do and make sure you know exactly what you are doing. After you have completed the task at hand, revert to working as yourself. When working with **root** privileges, you can damage the system to such an extent that you will need to reinstall Linux to get it working again.

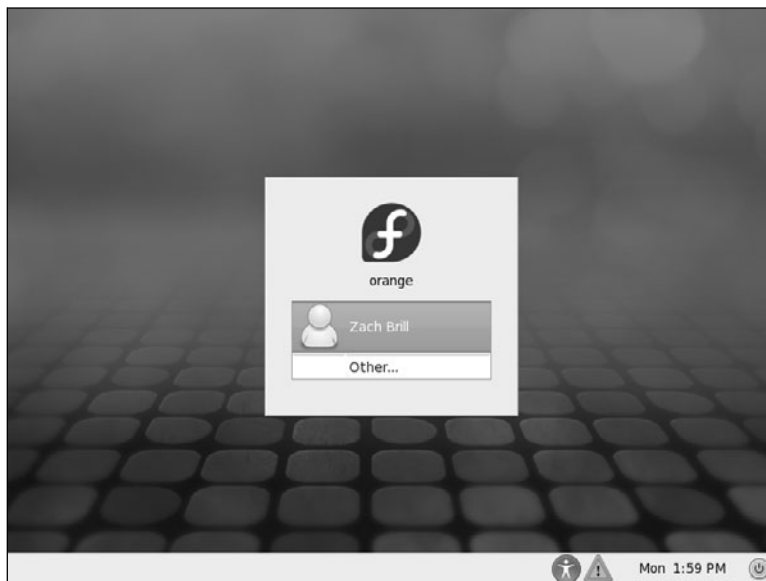
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## A TOUR OF THE FEDORA/RHEL DESKTOP

This section presents new words (for some readers) in a context that explains the terms well enough to get you started with the Linux desktop. If you would like exact definitions as you read this section, refer to “GNOME Desktop Terminology” on page 110 and to the Glossary. The Glossary also describes the data entry *widgets* (page 1115), such as the *combo box* (page 1075), *drop-down list* (page 1080), *list box* (page 1091), and *text box* (page 1110).

**GNOME** GNOME ([www.gnome.org](http://www.gnome.org)), a product of the GNU project (page 4), is the user-friendly default desktop manager under Fedora/RHEL. KDE ([www.kde.org/whatiskde](http://www.kde.org/whatiskde)), the K Desktop Environment, is a powerful desktop manager and complete set of tools you can use in place of GNOME.

This tour describes GNOME, a full-featured, mature desktop environment that boasts a rich assortment of configurable tools. After discussing logging in, this section covers desktop features—including panels, objects, and workspaces—and explains how to move easily from one workspace to another. It describes several ways to launch objects (run programs) from the desktop, how to set up the desktop to meet your needs and please your senses, and how to manipulate windows. As the tour continues, it explains how to work with files and folders using the Nautilus File Browser window, one of the most important GNOME tools. The tour concludes with a discussion of the Update applet, the object that allows you to keep a system up-to-date with the click of a button; getting help; and logging out.



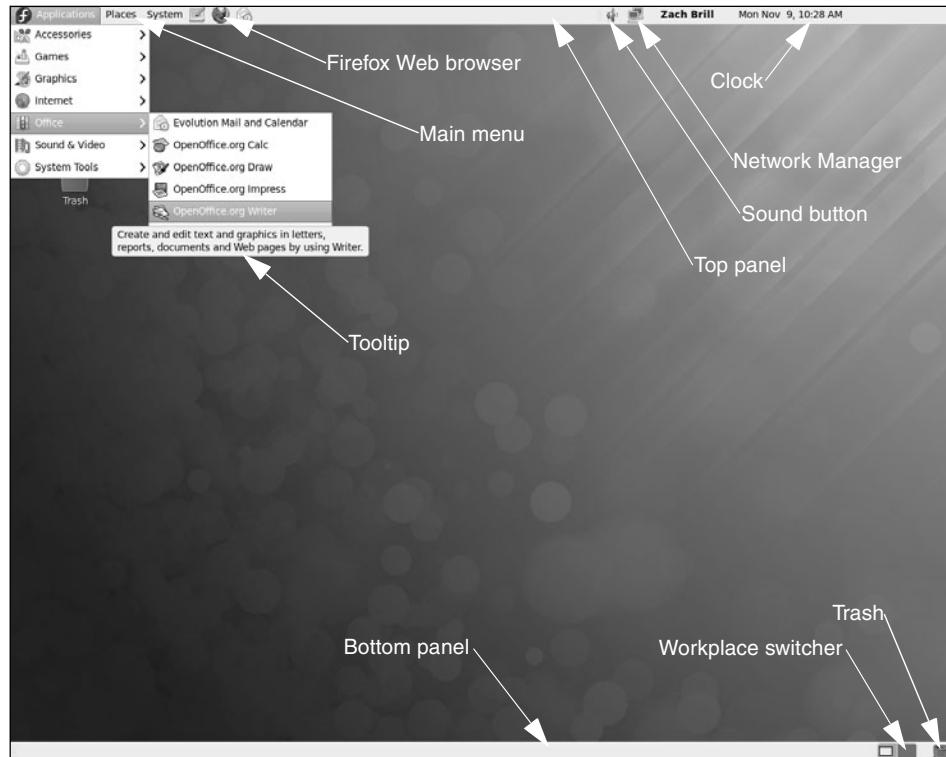
**Figure 4-1** The Fedora GNOME Login screen

## LOGGING IN ON THE SYSTEM

*FEDORA* When you boot a standard Fedora system, it displays a Login screen (Figure 4-1) on the system console. In the middle of the screen is a window that holds a list of usernames. Once you click your username, Fedora displays a text box labeled **Password**. In addition, at the bottom of the screen is a panel whose icons allow you to work in a different language, select a different keyboard layout, change your access preferences (e.g., make the text larger and easier to read), view boot messages, and restart or shut down the system. For more information refer to “The Login Screen” on page 133.

*RHEL* When you boot a standard RHEL system, it displays a Login screen on the system console. This screen includes a text box labeled **Username**. At the bottom of the screen are buttons that allow you to work in a different language, change the session you are logging in to, and restart or shut down the system. Press F10 for a complete menu of login options. For more information refer to “The Login Screen” on page 133.

To log in, click your username (*FEDORA*) or enter your username in the text box labeled **Username** and press RETURN (*RHEL*). A text box labeled **Password** appears (*FEDORA*) or the label changes to **Password** (*RHEL*). Enter your password and press RETURN. If Fedora/RHEL displays an error message, try entering your username and password again. Make sure the CAPS LOCK key is not on (Fedora/RHEL displays a message if it is)—the routine that verifies your entries is case sensitive. See page 134 if you need help with logging in and page 136 if you want to change your



**Figure 4-2** The initial workspace

password. The system takes a moment to set things up and then displays a workspace (Figure 4-2).

## INTRODUCTION

You can use the desktop as is or you can customize it until it looks and functions nothing like the initial desktop. If you have a computer of your own, you may want to add a user (page 556) and work as that user while you experiment with the desktop. When you figure out which features you like, you can log in as yourself and implement those features. That way you need not concern yourself with “ruining” your desktop and not being able to get it back to a satisfactory configuration.

**Panels and objects** When you log in, GNOME displays a workspace that includes Top and Bottom panels (bars) that are essential to getting your work done easily and efficiently (Figure 4-2). Each of the panels holds several icons and words called objects. (Buttons, applets, and menus are all types of objects.) When you click an object, something happens.

A panel does not allow you to do anything you could not do otherwise, but rather collects objects in one place and makes your work with the system easier. Because



the panels are easy to configure, you can set them up to hold those tools you use frequently. You can create additional panels to hold different groups of tools.

Workspaces and  
the desktop

What you see displayed on the screen is a *workspace*. Initially Fedora/RHEL configures GNOME with four workspaces. The desktop, which is not displayed all at once, is the collection of all workspaces. “Switching Workspaces” on page 95 describes some of the things you can do with workspaces.

### Do not remove objects or panels yet

**caution**

You can add and remove panels and objects as you please. Until you are comfortable working with the desktop and have finished reading this section, however, it is best not to remove any panels or objects from the desktop.

### Click and right-click

**tip**

This book uses the term **click** when you need to click the *left* mouse button and **right-click** when you need to click the *right* mouse button. See page 97 for instructions on adapting the mouse for left-handed use.

## LAUNCHING PROGRAMS FROM THE DESKTOP

This section describes three of the many ways you can start a program running from the desktop.

Click an object

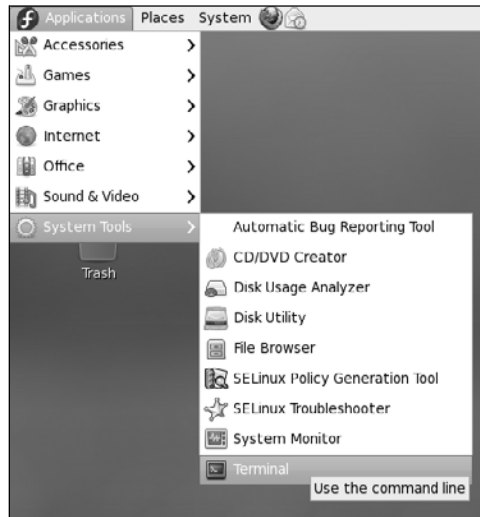
The effect of clicking an object depends on what the object is designed to do. Clicking an object may, for example, start a program; display a menu or a folder; or open a file, a window, or a dialog box.

For example, to start the Firefox Web browser, (left-) click the Firefox object (the blue and orange globe on the Top panel; see Figure 4-2. GNOME opens a window running Firefox. When you are done using Firefox, click the small **x** at the right end of the titlebar at the top of the window. GNOME closes the window.

When you (left-) click the date and time near the right end of the Top panel, the Clock applet displays a calendar for the current month. (Under Fedora, if you double-click a date on the calendar, the object opens the Evolution calendar to the date you clicked—but first you have to set up Evolution.) Click the date and time again to close the calendar.

Select from the  
Main menu

The second way to start a program is by selecting it from a menu. The Main menu is the object at the left end of the Top panel that includes the words **Applications**, **Places**, and **System**. Click one of these words to display the corresponding menu. Each menu selection that holds a submenu displays a triangle (pointing to the right) to the right of the name of the menu (Figure 4-3, next page). When you move the mouse pointer over one of these selections and leave it there for a moment (this action is called *hovering*), the menu displays the submenu. When you allow the mouse cursor to hover over one of the submenu selections, GNOME displays a *tooltip* (page 110).



**Figure 4-3** Main menu: Applications⇒Accessories⇒Terminal

Experiment with the Main menu. Start Sudoku (Main menu: Applications⇒Games⇒Sudoku [*FEDORA*; *RHEL* does not include games by default]), a terminal emulator (Main menu: Applications⇒System Tools⇒Terminal [*FEDORA*] or Main menu: Applications⇒Accessories⇒Terminal [*RHEL*]), and other programs from the Applications menu. The Places and System menus are discussed on page 114.

Use the Run Application window

You can also start a program by pressing ALT-F2 to display the Run Application window (Figure 4-4). As you start to type **firefox** in the text box at the top of the window, for example, the window recognizes what you are typing and displays the Firefox logo and the rest of the word **firefox**. Click **Run** to start Firefox.

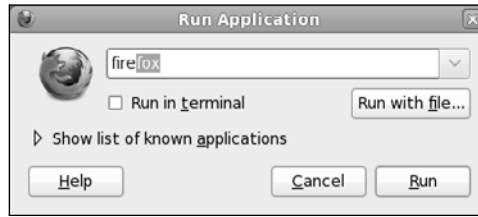
### optional

Running textual applications

You can run command-line utilities, which are textual (not graphical), from the Run Applications window. When you run a textual utility from this window, you must put a tick in the check box labeled **Run in terminal** (click the check box to put a tick in it; click it again to remove the tick). The tick tells GNOME to run the command in a terminal emulator window. When the utility finishes running, GNOME closes the window.

For example, type **vim** (the name of a text-based editor) in the text box, put a tick in the check box labeled **Run in terminal**, and click **Run**. GNOME opens a Terminal (emulator) window and runs the **vim** text editor in that window. When you exit from **vim** (press **ESCAPE:q!** sequentially to do so), GNOME closes the Terminal window.

You can run a command-line utility that only displays output and then terminates. Because the window closes as soon as the utility is finished running, and because most utilities run quickly, you will probably not see the output. Type the following



**Figure 4-4** The Run Application window

command in the text box to run the `df` (disk free; page 729) utility and keep the window open until you press RETURN (remember to put a tick in the check box labeled **Run in terminal**):

```
bash -c "df -h ; read"
```

This command starts a `bash` shell (Chapter 7) that executes the command line following the `-c` option. The command line holds two commands separated by a semicolon. The second command, `read` (page 937), waits for you to press RETURN before terminating. Thus the output from the `df -h` command remains on the screen until you press RETURN. Replace `read` with `sleep 10` to have the window remain open for ten seconds.

## SWITCHING WORKSPACES

**Workplace Switcher** Each rectangle in the *Workplace Switcher applet* (or just *Switcher*)—the group of rectangles near the right end of the Bottom panel—represents a workspace (Figure 4-2, page 92). When you click a rectangle, the Switcher displays the corresponding workspace and highlights the rectangle to indicate which workspace is displayed. You can also press CONTROL-ALT-RIGHT ARROW to display the workspace to the right of the current workspace; pressing CONTROL-ALT-LEFT ARROW works in the opposite direction.

Click the rightmost rectangle in the Switcher (not the Trash applet to its right) and then select **Main menu: System⇒Preferences⇒Mouse**. GNOME opens the Mouse Preferences window. The Switcher rectangle that corresponds to the workspace you are working in displays a small colored rectangle. This small rectangle corresponds in size and location within the Switcher rectangle to the window within the workspace. Click and hold the left mouse button with the mouse pointer on the titlebar at the top of the window and drag the window to the edge of the desktop. The small rectangle within the Switcher moves to the corresponding location within the Switcher rectangle.

Now click a different rectangle in the Switcher and open another application—for example, the GNOME Help Browser (select **Main menu: System⇒Help**). With the GNOME Help Browser window in one workspace and the Mouse Preferences window in another, you can click the corresponding rectangles in the Switcher to switch back and forth between the workspaces (and applications).

## Right-click to display an Object context menu

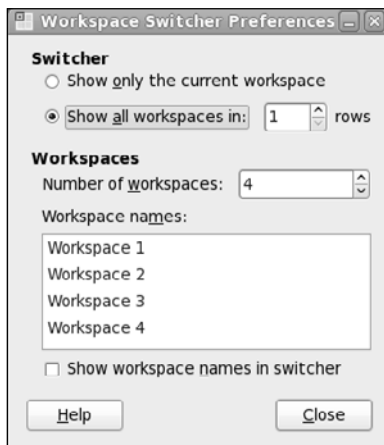
**tip** A *context menu* is one that is appropriate to its context. When you right-click an object, it displays an Object context menu. Each object displays its own context menu, although similar objects have similar context menus. Most Object context menus have either a Preferences or Properties selection. See the adjacent section, “Setting Personal Preferences,” and page 119 for more information on Object context menus.

## SETTING PERSONAL PREFERENCES

You can set preferences for many objects on the desktop, including those on the panels.

**Workspace Switcher** To display the Workspace Switcher Preferences window (Figure 4-5), first *right-click* anywhere on the Switcher to display the Switcher menu and then select **Preferences**. Specify the number of workspaces you want in the spin box labeled **Number of workspaces**. (The window looks different when you have Desktop Effects [page 108] enabled [*FEDORA*].) The number of workspaces the Switcher displays changes as you change the number in the spin box—you can see the result of your actions before you close the Preferences window. Four workspaces is typically a good number to start with. Click **Close**.

**Clock applet** The Clock applet has an interesting Preferences window. Right-click the Clock applet (Figure 4-2, page 92) and select **Preferences**. GNOME displays the General tab of the Clock Preferences window (under *RHEL* this window has no tabs). This tab enables you to customize the date and time displayed on the Top panel. The clock immediately reflects the changes you make in this window. Click the **Location** tab and then the **Add** button and enter the name of the city you are in or near to cause the Clock applet to display weather information.



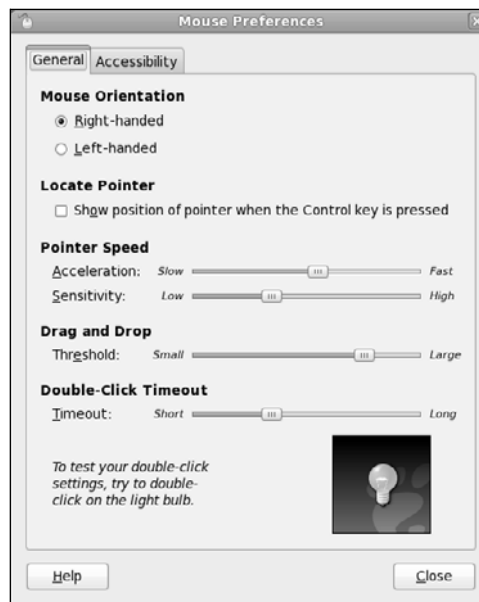
**Figure 4-5** The Workspace Switcher Preferences window

Different objects display different Preferences windows. In contrast, objects that launch programs display Properties windows and do not have Preferences windows. Experiment with different Preferences and Properties windows and see what happens.

## MOUSE PREFERENCES

The Mouse Preferences window (Figure 4-6) enables you to change the characteristics of the mouse to suit your needs. To display this window, select **Main menu: System⇒Preferences⇒Mouse** or give the command `gnome-mouse-properties` from a terminal emulator or Run Application window (ALT-F2). Under Fedora, the Mouse Preferences window has two tabs: General and Accessibility (and a third, Touchpad, on a laptop). Under RHEL, this window has three tabs.

- Left-handed mouse** Select the General or Buttons tab. To change the orientation of the mouse buttons for use by a left-handed person, click the radio button labeled **Left-handed**. If you change the setup of the mouse buttons, remember to reinterpret the descriptions in this book accordingly. That is, when this book asks you to click the left button or does not specify a button to click, click the right button, and vice versa. See “Remapping Mouse Buttons” on page 262 for information on changing the orientation of the mouse buttons from the command line.
- Double-click timeout** Use the Double-Click Timeout slider to change the speed with which you must double-click a mouse button to have the system recognize your action as a double-



**Figure 4-6** The Mouse Preferences window, General tab

click rather than as two single clicks. You can also control the acceleration and sensitivity of the mouse. The Drag and Drop Threshold specifies how far you must drag an object before the system considers the action to be the drag part of a drag-and-drop operation.

From the Accessibility tab, you can control different aspects of mouse clicks.

## WORKING WITH WINDOWS

To resize a window, position the mouse pointer over an edge of the window; the pointer turns into a double arrow. When the pointer is a double arrow, you can click and drag the side of a window. When you position the mouse pointer over a corner of the window, you can resize both the height and the width of the window simultaneously.

To move a window, click and drag the titlebar (the bar across the top of the window with the name of the window in it). For fun, try moving the window past either side of the workspace. What happens? The result depends on how Desktop Effects (page 108) is set.

**Titlebar** At the right of the titlebar are three icons that control the window (Figure 4-18, page 115). Clicking the underscore, which usually appears at the left of the set of icons, minimizes (iconifies) the window so the only indication of the window is the object with the window's name in it on the Bottom panel (a Window List applet; page 113). Click the Window List applet to toggle the window between visible and minimized. Clicking the box icon, which usually appears as the middle of the three icons, toggles the window between its maximum size (maximizes the window) and its normal size. Double-clicking the titlebar does the same thing.

**Terminating a program** Clicking the **x** closes the window and usually terminates the program running in the window. In some cases you may need to click several times. Some programs, such as Empathy IM Client, do not terminate, but rather continue to run in the background. When in this state, the program displays an icon near the right end of the Top panel. Right-click the icon and select **Quit** from the drop-down menu to terminate the program.

## USING NAUTILUS TO WORK WITH FILES

Nautilus, the GNOME file manager, is a simple, powerful file manager. You can use it to create, open, view, move, and copy files and folders as well as to execute programs and scripts. One of its most basic and important functions is to create and manage the desktop. This section introduces Nautilus and demonstrates the correspondence between Nautilus and the desktop. See page 264 for more detailed information on Nautilus.

**Terms: folder and directory** Nautilus displays the File Browser window, which displays the contents of a folder. The terms *folder* and *directory* are synonymous; “folder” is frequently used in

graphical contexts, whereas “directory” may be used in textual or command-line contexts. This book uses these terms interchangeably.

**Term: File Browser** This book sometimes uses the terms *File Browser window* and *File Browser* when referring to the Nautilus File Browser window.

Double-clicking an object in a File Browser window has the same effect as double-clicking an object on the desktop: Nautilus takes an action appropriate to the object. For example, when you double-click a text file, Nautilus opens the file with a text editor. When you double-click an OpenOffice.org document, Nautilus opens the file with OpenOffice.org. If the file is executable, Nautilus runs it. If the file is a folder, Nautilus opens the folder and displays its contents in place of what had previously been in the window.

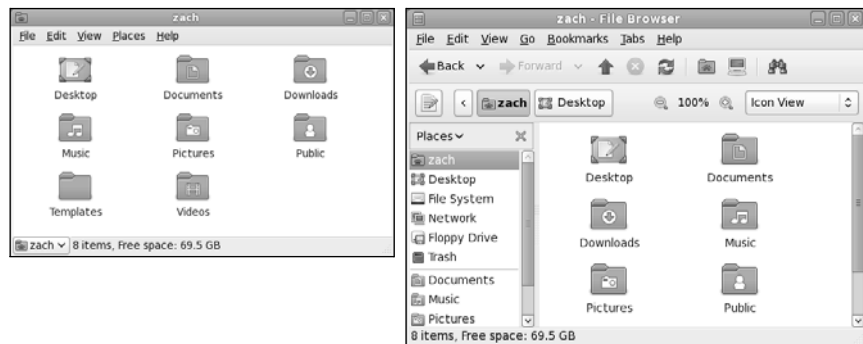
**FEDORA** From within a Nautilus File Browser window, you can open a folder in a new tab. To do so, middle-click the folder or right-click the folder and select **Open in New Tab** from the drop-down menu; Nautilus displays a new tab named for the directory you clicked. Click the tab to display contents of the directory.

### Nautilus: To follow examples, turn off Spatial view, turn on File Browser windows

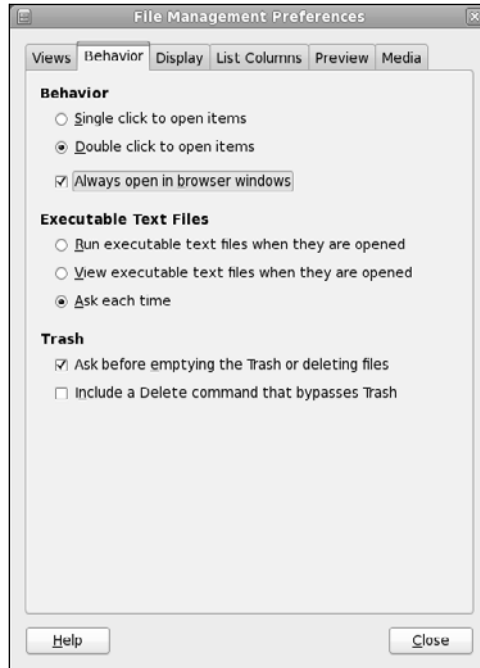
**tip** By default, Fedora/RHEL display the Nautilus Spatial view. The examples in this book show Nautilus displaying File Browser windows. To make the Nautilus windows on your desktop correspond to the windows in the figures in this book, turn on Nautilus File Browser windows by following the instructions under “The Two Faces of Nautilus.”

## THE TWO FACES OF NAUTILUS

The appearance of Nautilus differs depending on how it is set up. Namely, it can display a *Spatial view* or a *File Browser window*. See Figure 4-7 for an example of each. By default, Fedora/RHEL is set up to display the Spatial view. Because the Spatial view is less conventional, this book uses the Nautilus File Browser window in examples. The following steps make File Browser windows the Nautilus default



**Figure 4-7** The Nautilus Spatial view (left) and File Browser window (right)



**Figure 4-8** The File Management Preferences window, Behavior tab

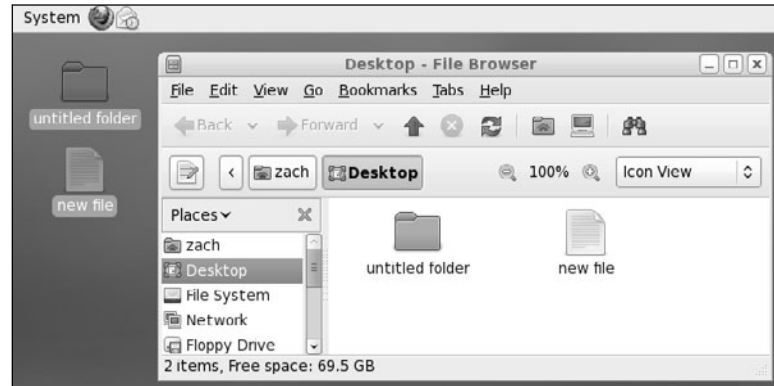
and ensure that Nautilus windows on the screen look similar to those in this book. See page 270 for more information on the Nautilus Spatial view.

To turn off the Nautilus Spatial view and turn on File Browser windows:

1. Select **Main menu: Places⇒Home folder**. Nautilus opens a window that displays a Spatial view of the contents of your home folder (also called your home directory; page 192). It appears similar to the left side of Figure 4-7.
2. From the menubar of the new window, select **Edit⇒Preferences**. Nautilus displays the File Management Preferences window.
3. Click the tab labeled **Behavior**. See Figure 4-8.
4. Click the check box labeled **Always open in browser windows**. A tick will appear in the check box.
5. Click the button labeled **Close** at the lower-right corner of the File Management Preferences window to close the window.
6. Click the **x** at the upper-right corner of the home folder window to close the window.

After following these steps, Nautilus will always display File Browser windows as shown in this book.





**Figure 4-9** Part of a workspace with a Nautilus File Browser window

## THE Desktop DIRECTORY

The files on the desktop are held in a directory that has a pathname (page 193) of `/home/username/Desktop`, where *username* is your login name or, if you are logged in on a live session, `liveuser`. The simple directory name is **Desktop**. See the tip on page 99 to turn off the Nautilus Spatial view before continuing. When you select **Main menu: Places⇒Desktop**, GNOME opens a File Browser window showing the files on the desktop (Figure 4-9). Initially there are no files. (Nautilus does not show the Computer, home directory, and Trash files in the browser window; see the adjacent optional section for an explanation.) If you click the pencil-and-paper object at the left edge near the top of the File Browser window, the Location text box shows the pathname of the directory Nautilus is displaying.

**optional** Although icons for the Computer, home directory, and Trash files appear on the desktop, these files are not stored in the `/home/username/Desktop` directory. Because they are not in the **Desktop** directory, they do not appear in a Nautilus window that displays the contents of the **Desktop** directory. These icons appear on the desktop because of the way the GNOME configuration files are set up. The GNOME configuration files are XML (page 1116) files that reside in the directory hierarchy with its root at `/home/username/gconf`. Although it is not recommended, you can edit these files with `gconf-editor`. You must install the `gconf-editor` package to use this editor. See [projects.gnome.org/gconf](http://projects.gnome.org/gconf) for more information.

To see the correspondence between the graphical desktop and the **Desktop** directory, right-click anywhere within the large clear area of the Desktop File Browser window. Select **Create Document⇒Empty File**. Nautilus creates a new file on the desktop and displays its object in this window. When you create this file, GNOME highlights the name **new file** under the file: You can type any name you like at this point. Press RETURN when you are finished entering the name. If you double-click the new file, Nautilus assumes it is a text file and opens the file in a `gedit` window. (The

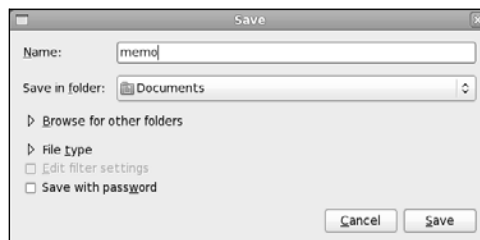
gedit utility is a simple text editor.) Type some text and click **Save** on the toolbar. Close the window either by using the File menu or by clicking the x at the right end of the titlebar. You have created a text document on the desktop. You can now double-click the document object on the desktop or in the File Browser window to open and edit it.

Next, create a folder by right-clicking the root window (any empty part of the workspace) and selecting **Create Folder**. You can name this folder in the same way you named the file you created previously. The folder object appears on the desktop and within the Desktop File Browser window.

On the desktop, drag the file until it is over the folder; the folder opens. Release the mouse button to drop the file into the folder; GNOME moves the file to the folder. Again on the desktop, double-click the folder you just moved the file to. GNOME opens another File Browser window, this one displaying the contents of the folder. The file you moved to the folder appears in the new window. Now drag the file from the window to the previously opened Desktop File Browser window. The file is back on the desktop, although it may be hidden by one of the File Browser windows.

Next, open a word processing document by selecting **Main menu: Applications⇒Office⇒OpenOffice.org Writer**. If that program is not available, select **Main menu: Applications⇒Accessories⇒gedit Text Editor**. Type some text and click the Save (floppy disk) icon or select **menubar: File⇒Save** to save the document. The editor displays a Save or Save As window (Figure 4-10). Type the name you want to save the document as (use **memo** for now) in the text box labeled **Name**. You can specify the directory in which you want to save the document in one of two ways: by using the drop-down list labeled **Save in folder** or by using the **Browse for other folders** section of the Save window.

Click the triangle to the left of **Browse for other folders** to open and close this section of the window. Figure 4-10 shows the Save window with this section closed. With the **Browse for other folders** section closed, you can select a directory from the drop-down list labeled **Save in folder**. This technique is quick and easy, but presents a limited number of choices of folders. By default, it saves the document in your home folder (**/home/username**). If you want to save the document to the desktop, click **Desktop** in this drop-down list and then click **Save**. OpenOffice.org saves the document with a filename extension of **.odt**, which indicates it is an OpenOffice.org word processing document. The object for this type of file has some text and a picture in it.



**Figure 4-10** The Save window

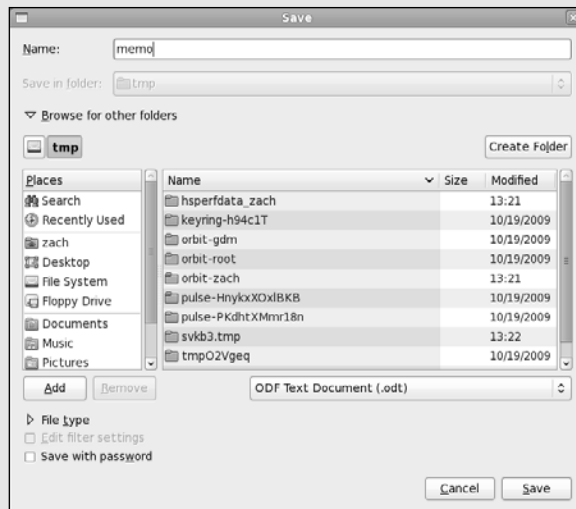
**optional**Browse/Save  
window

With the **Browse for other folders** section opened (click the triangle to the left of **Browse for other folders**), the Save window grays out the drop-down list labeled **Save in folder** and expands the **Browse for other folders** section, as shown in Figure 4-11. This expanded section holds two large side-by-side list boxes: **Places** and **Name**. The list box labeled **Places** displays directories and locations on the system, including **File System**. The list box labeled **Name** lists the files within the directory highlighted in **Places**.

The **Browse for other folders** section of the Browse/Save window allows you to look through the filesystem and select a directory or file. GNOME utilities and many applications use this window, although sometimes applications call it a Browse window. In this example, the text editor calls it a Save window and uses it to locate the directory where the document will be saved.

Assume you want to save a file in the **/tmp** directory. Click **File System** in the list box on the left; the list box on the right displays the files and directories in the root directory (represented by **/**; see “Absolute Pathnames” on page 193 for more information). Next, double-click **tmp** in the list box on the right. The buttons above the list box on the left change to reflect the directory displayed in the list box on the right. Click **Save**.

The buttons above the left-side list box represent directories. The right-side list box displays the directories found within the directory named in the highlighted (darker) button. This directory is the one you would save the file to if you clicked **Save** at this point. Click one of these buttons to display the corresponding directory in the list box on the right and then click **Save** to save the file in that directory.



**Figure 4-11** A Save window with Browse for other folders open

When you have finished editing the document, close the window. If you have made any changes since you last saved it, the text editor asks if you want to save the document. If you choose to save it, the text editor saves the revised version over (in the same file as) the version you saved previously. Now the **memo** object appears on the desktop and in the Desktop File Browser window. Double-click either object to open it.

The **Desktop** directory is special

In summary, the **Desktop** directory is like any other directory, except that GNOME displays its contents on the desktop (in every workspace). It is as though the desktop is a large, plain Desktop File Browser window. You can work with the **Desktop** directory because it is always displayed. Within the GUI, you must use a utility, such as Nautilus, to display and work with the contents of any other directory.

## SELECTING OBJECTS

The same techniques can be used to select one or more objects in a File Browser window or on the desktop. Select an object by clicking it once; GNOME highlights the object. Select additional objects by holding down the **CONTROL** key while you click each object. You can select a group of adjacent objects by highlighting the first object and then, while holding down the **SHIFT** key, clicking the last object; GNOME highlights all objects between the two objects you clicked. Alternatively, you can use the mouse pointer to drag a box around a group of objects.

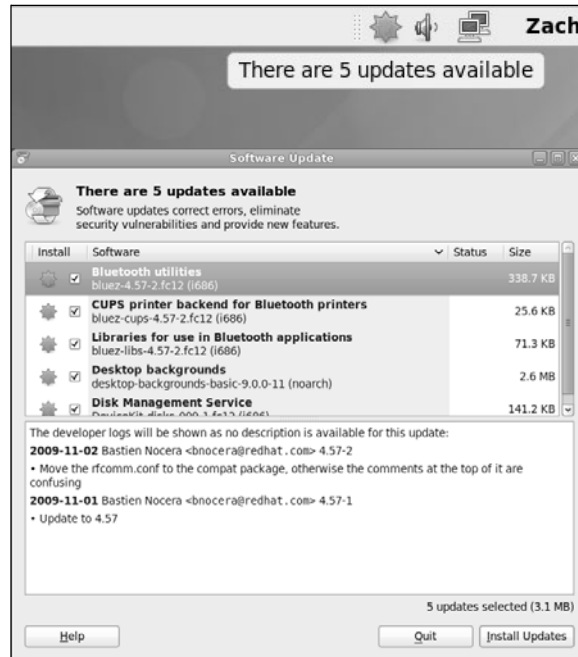
To experiment with these techniques, open a File Browser window displaying your home folder. Select a few objects, right-click, and select **Copy**. Now move the mouse pointer over an empty part of the desktop, right-click, and select **Paste**. You have copied the selected objects from your home folder to the desktop. You can drag and drop objects to move them, although you cannot move the **Desktop** folder on top of itself.

## EMPTYING THE TRASH

Selecting **File Browser menubar: Edit⇒Move to Trash** moves the selected (highlighted) object to the **Trash** directory. Because files in the trash take up space on the hard disk (just as any files do), it is a good idea to remove them periodically. All File Browser windows allow you to permanently delete all files in the **Trash** directory by selecting **File Browser menubar: File⇒Empty Trash**. To view the files in the trash, click the Trash applet at the right end of the Bottom panel (Figure 4-2, page 92). Nautilus displays the Trash File Browser window. Select **Empty Trash** from the Trash applet context menu to permanently remove all files from the trash. (This selection does not appear if there are no files in the trash.) Alternatively, you can open the **Trash** directory, right-click an object, and select **Permanently** to remove only that object (file). You can drag and drop files to and from the trash just as you can with any other folder.

## THE UPDATE APPLET

On systems connected to the Internet, Fedora/RHEL is initially set up to automatically search for and notify you when software updates are available. GNOME



**Figure 4-12** The Update applet and the Software Update window

places the Update applet (Figure 4-12) toward the right end of the Top panel when updates are available. Clicking this object opens the Software Update window (Figure 4-12). You can also open this window by selecting **Main menu: System⇒Administration⇒Software Update (FEDORA)** or **Main menu: Applications⇒System Tools⇒Software Updater (RHEL)** or by giving the command **gpk-update-viewer (FEDORA)** or **pup (RHEL)** from a terminal emulator or Run Application window (ALT-F2).

Software Update  
window

When the Software Update window opens, it displays the message **Checking for updates**; after a moment it displays the number of available updates. If no updates are available, the window displays the message **All software is up to date**. If updates are available, click **Install Updates**. As it downloads and installs the software packages, the Software Update window displays messages and a progress bar. When it is finished, the Software Update window closes. If the updates require you to reboot the system or restart a program, an object appears on the Top panel. Click this object and take the required action as soon as you are ready. For more information refer to “Updating, Installing, and Removing Software Packages” on page 122.

## CHANGING APPEARANCE (THEMES)

One of the most exciting aspects of a Linux desktop is the flexibility it offers in allowing you to change its appearance. You can change not only the backgrounds, but also window borders (including the titlebar), icons, the buttons applications use, and more. To see some examples of what you can do, visit [art.gnome.org](http://art.gnome.org).

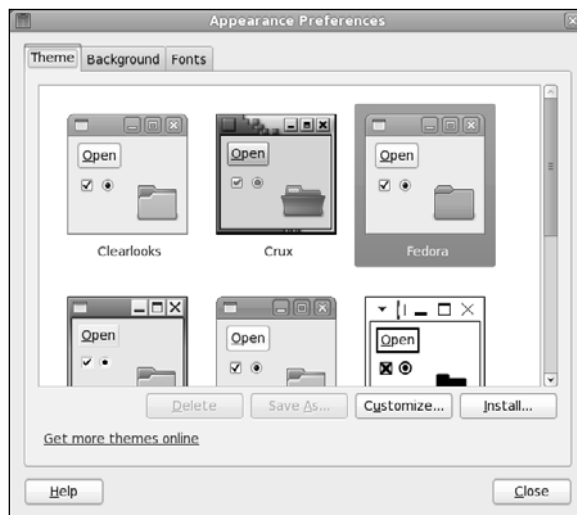
**Themes** In a GUI, a *theme* is a recurring pattern and overall look that (ideally) pleases the eye and is easy to interpret and use. You can work with desktop themes at several levels. The first and easiest choice is to leave well enough alone. Fedora comes with a good-looking theme named Fedora; RHEL uses Clearlooks. If you are not interested in changing the way the desktop looks, continue with the next section.

The next choice, which is almost as easy, is to select one of the alternative themes that comes with Fedora/RHEL. You can also modify one of these themes, changing the background, fonts, or interface. In addition, you can download themes from many sites on the Internet and change them in the same ways.

The next level is customizing a theme, which changes the way the theme looks—for example, changing the icons used by a theme. At an even higher level, you can design and code your own theme. For more information see the tutorials at [art.gnome.org](http://art.gnome.org).

**Appearance Preferences window (FEDORA)** The key to changing the appearance of the desktop is the Appearance Preferences window. Display this window by choosing **Main menu: System⇒Preferences⇒Appearance** or by right-clicking the root window (any empty space on a workspace) and selecting **Change Desktop Background**. The Appearance Preferences window has three tabs:

- The **Theme** tab (Figure 4-13) enables you to select one of several themes. Click a theme and the workspace immediately reflects the use of that theme. Fedora is the default Fedora theme; select this theme to make the workspace appear as it did when you installed the system. RHEL uses Clearlooks. Once you select a theme, you can either click **Close** if you are satisfied with your choice or click the other tabs to modify the theme.



**Figure 4-13** The Appearance Preferences window, Theme tab

- The **Background** tab enables you to specify a wallpaper or color for the desktop background. To specify a wallpaper, click one of the samples in the Wallpaper frame or click **Add** and choose a file—perhaps a picture—you want to use as wallpaper. (Clicking **Add** displays the Add Wallpaper window; see “Browse/Save window” on page 103 for instructions on selecting a file using this window.) Then choose the style you want GNOME to use to apply the wallpaper. For example, Zoom makes the picture you chose fit the workspace.

You can also specify a color for the background: either solid or a gradient between two colors. To use a color, you must first select **No Desktop Background** from the Wallpaper frame: Allow the mouse pointer to hover over each of the wallpapers displayed in the Wallpaper frame until you find one that displays the tooltip **No Desktop Background**. Select that (non)wallpaper. (Initially the icon for this wallpaper appears at the upper-left corner of the wallpaper icons.) Next select **Solid color** from the drop-down list labeled **Colors** and click the colored box to the right of this list. GNOME displays the Pick a Color window. Click a color you like from the ring and adjust the color by dragging the little circle within the triangle. Click **OK** when you are done. The color you chose becomes the background color of the desktop. See page 273 for more information on the Pick a Color window.

- The **Fonts** tab (Figure 8-8, page 272) enables you to specify which fonts you want GNOME to use in different places on the desktop. You can also change how GNOME renders the fonts (page 272).

The changes you make in the Background and Fonts tabs are used by any theme you select, including ones you customize. When you have finished making changes in the Appearance Preferences window tabs, you can either click **Close** to use the theme as you have modified it or return to the Theme tab to customize the theme.

Customizing  
a theme

From the Theme tab of the Appearance Preferences window, select the theme you want to customize or continue with the theme you modified in the preceding section. Click **Customize** to open the Customize Theme window. Go through each tab in this window; choose entries and watch how each choice changes the workspace. Not all tabs work with all themes. When you are satisfied with the result, click **Close**.

After you customize a theme, it is named Custom. When you customize another theme, those changes overwrite the Custom theme. For this reason it is best to save a customized theme by clicking **Save As** and specifying a unique name for the theme. After saving a theme, it appears among the themes in the Theme tab.

*RHEL* In place of the Appearance Preferences window, RHEL uses the Theme Preferences and Desktop Background Preferences windows. The Theme Preferences window takes the place of Fedora’s Theme tab and the Desktop Background Preferences window takes the place of Fedora’s Background tab.

## DESKTOP EFFECTS (*FEDORA*)

Open the Desktop Effects window by selecting **Main menu: System⇒Preferences⇒Desktop Effects** or by giving the command **desktop-effects** from a terminal emulator or Run Application window (ALT-F2). This window enables you to turn on Desktop Effects and to select from two options. Turning on Desktop Effects replaces the Metacity window manager with Compiz (compiz.org), which implements a 3D-accelerated desktop. One of the most dramatic desktop effects is wiggly windows: To see this effect, turn on Desktop Effects, select **Windows Wobble when Moved**, and drag a window around using its titlebar. If you experience problems with the system, turn off Desktop Effects.

### Desktop Effects can cause problems

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**caution** Turning on Desktop Effects can cause unexpected graphical artifacts, shorten battery life, and reduce performance in 3D applications and video playback. If you are having problems with a system, try turning off Desktop Effects and see if the problem goes away.

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## SESSION MANAGEMENT

A session starts when you log in and ends when you log out or reset the session. With fully GNOME-compliant applications, GNOME can manage sessions so the desktop looks the same when you log in as it did when you saved a session or logged out: The same windows will be positioned as they were on the same workspaces and programs will be as you left them.

The Startup Applications Preferences window allows you to select which applications you want to run each time you log in. It also allows you to save automatically those applications that were running and those windows that were open when you logged out; they will start running when you log on again. To open the Startup Applications Preferences (*FEDORA*) or Sessions (*RHEL*) window, select **Main menu: System⇒Preferences⇒Startup Applications** (*FEDORA*) or **Main menu: System⇒Preferences⇒More Preferences⇒Sessions** (*RHEL*) or give the command **gnome-session-properties** from a terminal emulator or Run Application window (ALT-F2). You must give this command while logged in as yourself (not while working with root privileges).

To save a session, display the Startup Applications Preferences window. Click the **Options** tab and then put a tick in the check box labeled **Automatically remember running applications when logging out**. Each time you log in, the same windows will appear as when you logged out.

## GETTING HELP

Fedora/RHEL provides help in many forms. Selecting **Main menu: System⇒Help** displays the GNOME Help Browser, which provides information on the desktop.



To display other information, click a topic in the list on the left side of this window. You can also enter text to search for in the text box labeled **Search** and press RETURN. In addition, most windows provide a Help object or menu. See “Where to Find Documentation” on page 124 for more resources.

## FEEL FREE TO EXPERIMENT

Try selecting different items from the Main menu and see what you discover. Following are some applications you may want to explore:

- The **gedit** text editor is a simple text editor. Select **Main menu: Applications⇒Accessories⇒gedit Text Editor** to access it.
- OpenOffice.org’s Writer is a full-featured word processor that can import and export Microsoft Word documents. Select **Main menu: Applications⇒Office⇒OpenOffice.org Writer**. The **Office** menu also offers a database, presentation manager, and spreadsheet. If this application is not available on the system, install the **openoffice.org-writer** software package as explained on page 501.
- Firefox is a powerful, full-featured Web browser. Click the blue and orange globe object on the Top panel to start Firefox. You can also select **Main menu: Applications⇒Internet⇒Firefox Web Browser**.
- Empathy is a graphical IM (instant messaging) client that allows you to chat on the Internet with people who are using IM clients such as AOL, MSN, and Yahoo! To start Empathy, select **Main menu: Applications⇒Internet⇒Empathy IM Client**.

The first time you start Empathy, it opens a window that says **Welcome to Empathy**. Follow the instructions to access an existing IM account or open a new one. Visit [live.gnome.org/Empathy](http://live.gnome.org/Empathy) for more information.

## LOGGING OUT

To log out, select **Main Menu: System⇒Logout *username***. You can also choose to shut down the system. From a textual environment, press CONTROL-D or give the command **exit** in response to the shell prompt.

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## GETTING THE MOST OUT OF THE DESKTOP

The GNOME desktop is a powerful tool with many features. This section covers many aspects of its panels, the Main menu, windows, terminal emulation, and ways to update, install, and remove software. Chapter 8 continues where this chapter leaves off, discussing the X Window System, covering Nautilus in more detail, and describing a few of the GNOME utilities.

## GNOME DESKTOP TERMINOLOGY

The following terminology, which is taken from the GNOME Users Guide, establishes a foundation for discussing the GNOME desktop. Figure 4-2 on page 92 shows the initial Fedora GNOME desktop.

- Desktop The *desktop* comprises all aspects of the GNOME GUI. While you are working with GNOME, you are working on the desktop. There is always exactly one desktop.
- Panels Panels are bars that appear on the desktop and hold (panel) objects. Initially there are two gray panels: one along the top of the screen (the Top Edge panel, or just Top panel) and one along the bottom (the Bottom Edge panel, or just Bottom panel). You can add and remove panels. You can place panels at the top, bottom, and both sides of the desktop, and you can stack more than one panel at any of these locations. The desktop can have no panels, one panel, or several panels. See page 111 for more information on panels.
- Panel objects Panel objects appear as words or icons on panels. You can click these objects to display menus, run applets, or launch programs. The five types of panel objects are applets, launchers, buttons, menus, and drawers. See page 113 for more information on panel objects.
- Windows A graphical application typically runs within and displays a window. At the top of most windows is a titlebar you can use to move, resize, and close the window. The *root window* is the unoccupied area of the workspace and is frequently obscured. The desktop can have no windows, one window, or many windows. Although most windows have decorations (page 142), some, such as the Logout window, do not.
- Workspaces Workspaces divide the desktop into one or more areas, with one such area filling the screen at any given time. Initially there are two workspaces. Because panels and objects on the desktop are features of the desktop, all workspaces display the same panels and objects. By default, a window appears in a single workspace. The Switcher (page 95) enables you to display any one of several workspaces.
- Tooltips Tooltips (Figure 4-2, page 92) is a minicontext help system that you activate by moving the mouse pointer over a button, icon, window border, or applet (such as those on a panel) and allowing it to hover there. When the mouse pointer hovers over an object, GNOME displays a brief explanation of the object.

## OPENING FILES

By default, you double-click an object to open it; alternatively, you can right-click the object and select **Open** from the drop-down menu. When you open a file, GNOME figures out the appropriate tool to use by determining the file's *MIME* (page 1094) type. GNOME associates each filename extension with a MIME type and each MIME type with a program. Initially GNOME uses the filename extension to try to determine a file's MIME type. If it does not recognize the filename extension, it examines the file's *magic number* (page 1092).

For example, when you open a file with a filename extension of **ps**, GNOME calls the Evince document viewer, which displays the PostScript file in a readable format.

When you open a text file, GNOME uses `gedit` to display and allow you to edit the file. When you open a directory, GNOME displays its contents in a File Browser window. When you open an executable file such as Firefox, GNOME runs the executable. When GNOME uses the wrong tool to open a file, the tool generally issues an error message. See “Open With” on page 121 for information on how to use a tool other than the default tool to open a file.

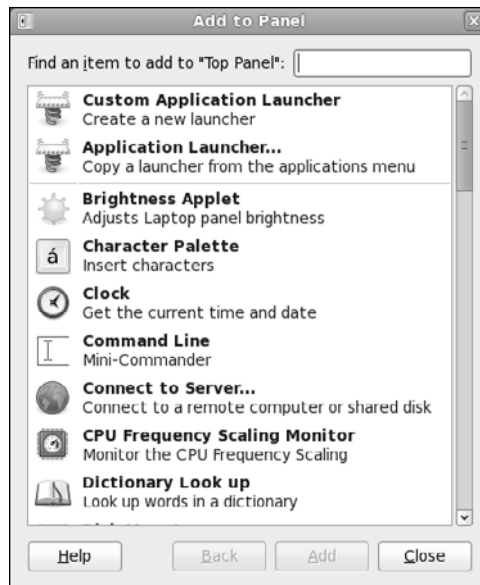
## PANELS

As explained earlier, panels are the bars that initially appear at the top and bottom of the desktop. They are part of the desktop, so they remain consistent across workspaces.

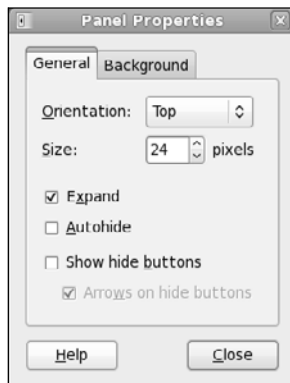
### THE PANEL (CONTEXT) MENU

Right-clicking an empty part of a panel displays the Panel (Context) menu. Aside from help and informational selections, this menu has four selections.

**Add to Panel** Selecting **Add to Panel** displays the Add to Panel window (Figure 4-14). You can drag an object from this window to a panel, giving you the choice of which panel the object appears on. You can also highlight an object and click **Add** to add the object to the panel whose menu you used to display this window. Many objects in this window are whimsical: Try **Eyes** and select **Bloodshot** from its preferences window, or try **Fish**. One of the more useful objects is **Search for Files**. When you click this object on the panel, it displays the **Search for Files** window (page 274).



**Figure 4-14** The Add to Panel window



**Figure 4-15** The Panel Properties window, General tab

**Properties** Selecting **Properties** displays the Panel Properties window (Figure 4-15). This window has two tabs: General and Background.

In the General tab, Orientation selects which side of the desktop the panel appears on; Size adjusts the width of the panel. Expand causes the panel to span the width or height of the workspace; without a tick in this check box, the panel is centered and just wide enough to hold its objects. Autohide causes the panel to disappear until you bump the mouse pointer against the side of the workspace. Hide buttons work differently from autohide: Show hide buttons displays buttons at each end of the panel. When you click one of these buttons, the panel slides out of view, leaving only a button remaining. When you click that button, the panel slides back into place.

If you want to see what stacked panels look like, use the Orientation drop-down list to change the location of the panel you are working with. If you are working with the Top panel, select **Bottom**, and vice versa. Like Preferences windows, Properties windows lack Apply and Cancel buttons; they implement changes immediately. Use the same procedure to put the panel back where it was.

The Background tab of the Panel Properties window enables you to specify a color and transparency or an image for the panel. See “Pick a Color Window” on page 273 for instructions on changing the color of the panel. Once you have changed the color, move the slider labeled **Style** to make the color of the panel more or less transparent. If you do not like the effect, click the radio button labeled **None (use system theme)** to return the panel to its default appearance. Click **Close**.

**Delete This Panel** Selecting **Delete This Panel** does what you might expect. Be careful with this selection: When it removes a panel, it removes all the objects on the panel and you will need to reconstruct the panel if you want it back as it was.

**New Panel** Selecting **New Panel** adds a new panel to the desktop. GNOME decides where it goes. You can then move the panel to somewhere else using Orientation in the General tab of the Panel Properties window for the new panel.



**Figure 4-16** Window List applets

## PANEL OBJECTS

The icons and words on a panel, called *panel objects*, display menus, launch programs, and present information. The panel object with the blue and orange globe starts Firefox. The email button (the open envelope icon) starts Evolution, an email and calendaring application ([www.gnome.org/projects/evolution](http://www.gnome.org/projects/evolution)). You can start almost any utility or program on the system using a panel object. This section describes the various types of panel objects.

- Applets An applet is a small program that displays its user interface on or adjacent to the panel. You interact with the applet using its Applet panel object. The Clock (date and time) and Workspace Switcher (both shown in Figure 4-2 on page 92) are applets.
- Window List applet Although not a distinct type of object, the Window List applet is a unique and important tool. One Window List applet (Figure 4-16) appears on the Bottom panel for each open or iconified window on the displayed workspace. Left-clicking this object minimizes its window or restores the window if it is minimized. Right-click this object to display the Window Operations menu (page 116). If a window is buried under other windows, click its Window List applet to make it visible.
- Launchers When you open a launcher, it can execute a command, start an application, display the contents of a folder or file, open a URI in a Web browser, and so on. In addition to appearing on panels, launchers can appear on the desktop. The Firefox object is a launcher: It starts the Firefox application. Under **Main menu: Applications**, you can find launchers that start applications. Under **Main menu: Places**, the Home Folder, Documents, Desktop, and Computer objects are launchers that open File Browser windows to display folders.
- Buttons A button performs a single, simple action. The Sound button (Figure 4-2, page 92) displays a volume control. The Show Desktop button, which may appear at the left end of the Bottom panel, minimizes all windows on the workspace.
- Menus A menu displays a list of selections you can choose from. Some of the selections can be submenus with more selections. All other selections are launchers. The next section discusses the Main menu.
- Drawers A drawer is an extension of a panel. You can put the same objects in a drawer that you can put on a panel, including another drawer. When you click a drawer object, the drawer opens; you can then click an object in the drawer the same way you click an object on a panel.

## THE PANEL OBJECT CONTEXT MENUS

Three selections are unique to Panel Object context menus (right-click a panel object to display this menu). The Remove from Panel selection does just that. The

Move selection allows you to move the object within the panel and to other panels; you can also move an object by dragging it with the middle mouse button. The Lock to Panel selection locks the object in position so it cannot be moved. When you move an object on a panel, it can move through other objects. If the other object is not locked, it can displace the object if necessary. The Move selection is grayed out when the object is locked.

## THE MAIN MENU

The Main menu appears at the left of the Top panel and includes **Applications**, **Places**, and **System**. Click one of these words to display the corresponding menu.

**Applications** The **Applications** menu holds several submenus, each named for a category of applications (e.g., Games, Graphics, Internet, Office—the list varies depending on the software installed on the system). Selections from the submenus launch applications—peruse these selections, hovering over those you are unsure of to display the associated tooltips.

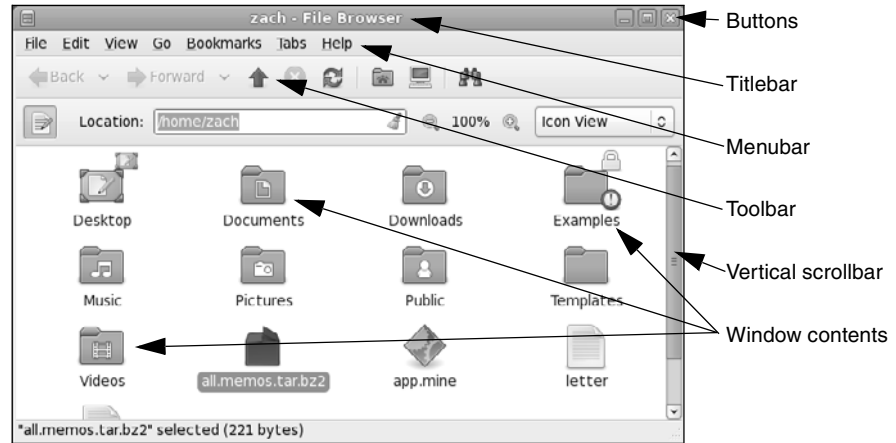
**Places** The **Places** menu holds a variety of launchers, most of which open a File Browser window. The Home Folder, Desktop, and Documents objects display your directories with corresponding names. The Computer, CD/DVD Creator, and Network objects display special locations. Each of these locations enables you to access file manager functions. For example, the CD/DVD Creator selection enables you to burn a CD or DVD. The Connect to Server selection opens a window that allows you to connect to various types of servers, including SSH and FTP servers (see “File” on page 268). Below these selections are mounted filesystems; click one of them to display the top-level directory of that filesystem. The Search for Files selection enables you to search for files (page 274).

**System** The **System** menu holds two submenus as well as selections that provide support and allow you to log out. The two submenus are key to configuring your account and setting up and maintaining the system.

The Preferences submenu establishes the characteristics of your account; each user can establish her own preferences. Click some of these selections to become familiar with the various ways you can customize your account on a Fedora/RHEL system.

The Administration submenu controls the way the system works. For example, **Administration**⇒**Printing** (page 522) sets up and configures printers you can use from the system and **Administration**⇒**Add/Remove Software** allows you to add and remove software packages (page 123). Most of these selections require you to enter the **root** password to make changes. These menu selections are discussed throughout this book.

**Copying launchers to a panel** You can copy any launcher from the Main menu to the Top panel or the desktop. Instead of left-clicking the menu selection, right-click it. GNOME displays a drop-down menu that enables you to add the launcher to the Top panel or desktop.



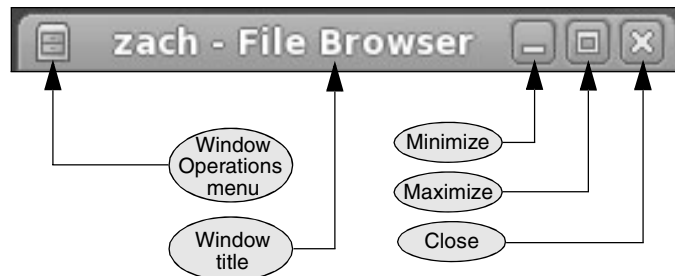
**Figure 4-17** A typical window

## WINDOWS

In a workspace, a *window* is a region that runs, or is controlled by, a particular program (Figure 4-17). Because you can control the look and feel of windows—even the buttons they display—your windows may not look like the ones shown in this book. Each window in a workspace has a Window List applet (page 113) on the Bottom panel.

**Titlebar** A titlebar (Figures 4-17 and 4-18) appears at the top of most windows and controls the window it is attached to. You can change the appearance and function of a titlebar, but it will usually have at least the functionality of the buttons shown in Figure 4-18.

The minimize (iconify) button collapses the window so the only indication of its presence is its Window List applet on the Bottom panel; click this applet to restore the window. Click the maximize button to expand the window so it occupies the



**Figure 4-18** A window titlebar

whole workspace; click the same button on the titlebar of a maximized window to restore the window to its former size. You can also double-click the titlebar to maximize and restore a window. Clicking the close button closes the window and usually terminates the program running in it. To reposition the window, left-click the titlebar and drag the window to the desired location.

**Window Operations menu** The Window Operations menu contains most common operations you need to perform on any window. Click the Window Operations menu button or right-click either the titlebar or the Window List applet (page 113) to display this menu. You can use this menu to move a window to another workspace, keep the window on top of or below other windows, and cause the window to always be visible on the displayed workspace.

**Toolbar** A *toolbar* (Figure 4-17, preceding page) usually appears near the top of a window and contains icons, text, applets, menus, and more. Many kinds of toolbars exist. The titlebar is not a toolbar; rather, it is part of the window decorations placed there by the window manager (page 142).

### CHANGING THE INPUT FOCUS (WINDOW CYCLING)

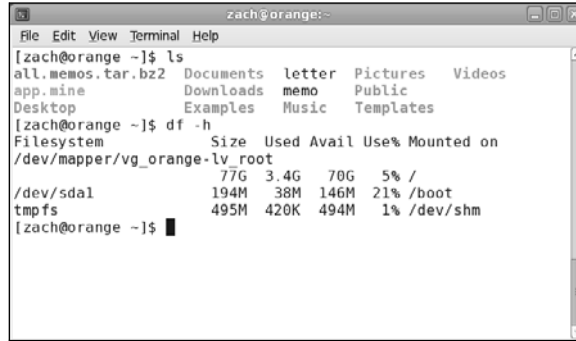
The window with the input focus is the one that receives keyboard characters and commands you type. In addition to using the Window List applet (page 113), you can change which window on the current workspace has the input focus by using the keyboard; this process is called *window cycling*. When you press ALT-TAB, GNOME displays in the center of the workspace a box that holds icons representing the programs running in the windows in the workspace. It also shifts the input focus to the window that was active just before the currently active window, making it easy to switch back and forth between two windows. When you hold ALT and press TAB multiple times, the focus moves from window to window. Holding ALT and SHIFT and repeatedly pressing TAB cycles in the other direction. See page 141 for more information on input focus.

### CUTTING AND PASTING OBJECTS USING THE CLIPBOARD

There are two similar ways to cut/copy and paste objects and text on the desktop and both within and between windows. First you can use the clipboard, technically called the *copy buffer*, to copy or move objects or text. To do so, you explicitly copy an object or text to the buffer and then paste it somewhere else. Applications that follow the user interface guidelines use CONTROL-X to cut, CONTROL-C to copy, and CONTROL-V to paste. Application context menus frequently provide these same options.

You may not be familiar with the second method to copy and paste text—using the *selection* or *primary* buffer, which always contains the text you most recently selected (highlighted). You cannot use this method to copy objects. Clicking the middle mouse button (click the scroll wheel on a mouse that has one) pastes the contents of the selection buffer at the location of the mouse pointer (if you are using a two-button mouse, click both buttons at the same time to simulate clicking the middle button).





**Figure 4-19** A Terminal (emulator) window

With both these techniques, start by highlighting an object or text to select it. You can drag a box around multiple objects to select them or drag the mouse pointer over text to select it. Double-click to select a word or triple-click to select a line or a paragraph.

Next, to use the clipboard, explicitly copy (CONTROL-C) or cut (CONTROL-X) the objects or text.<sup>1</sup> If you want to use the selection buffer, skip this step.

To paste the selected objects or text, position the mouse pointer where you want to put it and then either press CONTROL-V (clipboard method) or press the middle mouse button (selection buffer method).

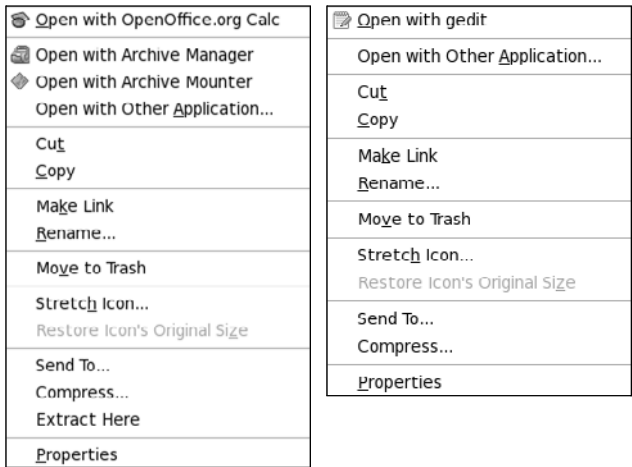
When using the clipboard, you can give as many commands as you like between the CONTROL-C or CONTROL-X and CONTROL-V, as long as you do not press CONTROL-C or CONTROL-X again. When using the selection buffer, you can give other commands after selecting text and before pasting it, as long as you do not select (highlight) other text.

## USING THE ROOT WINDOW

The *root window* is any part of a workspace that is not occupied by a window, panel, or object. It is the part of the workspace where you can see the background. To view the root window when it is obscured, click the Show Desktop button (if it is displayed) at the left end of the Bottom panel to minimize the windows in the workspace.

**Desktop menu** Right-click the root window to display the Desktop menu, which enables you to create a folder, launcher, or document. The Change Desktop Background selection opens the Appearance Preferences window (page 106) to its Background tab.

1. These control characters do not work in a terminal emulator window because the shell running in the window intercepts them before the terminal emulator can receive them. You must either use the selection buffer in this environment or use copy/paste from the **Edit** selection on the menubar or from the context menu (right-click).



**Figure 4-20**    The Object context menus for a spreadsheet (left) and a text file (right)

**RUNNING COMMANDS FROM A TERMINAL EMULATOR/SHELL**

A *terminal emulator* is a window that presents a command-line interface (CLI); it functions as a textual (character-based) terminal and is displayed in a graphical environment.

To display the GNOME terminal emulator named Terminal (Figure 4-19, preceding page), select **Main menu: Applications⇒System Tools⇒Terminal (FEDORA)**, **Main menu: Applications⇒Accessories⇒Terminal (RHEL)**, or enter the command **gnome-terminal** from a Run Application window (ALT-F2). Because you are already logged in and are creating a subshell in a desktop environment, you do not need to log in again. Once you have opened a terminal emulator window, try giving the command **man man** to read about the man utility (page 125), which displays Linux manual pages. Chapter 5 describes utilities you can run from a terminal emulator.

You can run character-based programs that would normally run on a terminal or from the console in a terminal emulator window. You can also start graphical programs from this window. A graphical program opens its own window.

When you are typing in a terminal emulator window, several characters, including \*, ?, |, [, and ], have special meanings. Avoid using these characters until you have read “Special Characters” on page 148.

The shell    Once you open a terminal emulator window, you are communicating with the command interpreter called the *shell*. The shell plays an important part in much of your communication with Linux. When you enter a command at the keyboard in response to the shell prompt on the screen, the shell interprets the command and initiates the appropriate action—for example, executing a program; calling a compiler, a Linux utility, or another standard program; or displaying an error message indicating you entered a command incorrectly. When you are working on a GUI, you bypass the shell and execute a program by clicking an object or a name. Refer to Chapter 7 for more information on the shell.

## THE OBJECT CONTEXT MENU

When you right-click an object or group of objects either on the desktop or in a File Browser window, GNOME displays an Object context menu. Different types of objects display different context menus, but most context menus share common selections. Figure 4-20 shows context menus for an OpenOffice.org spreadsheet file and for a plain text file. Table 4-1 lists some common Object context menu selections.

**Table 4-1** Object context menu selections

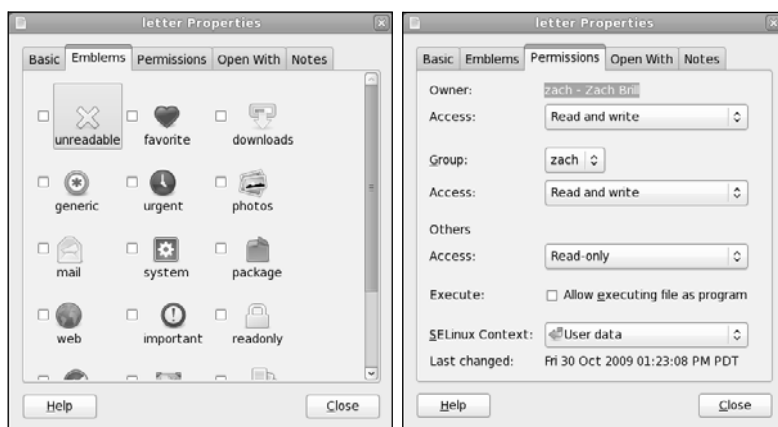
|                             |                                                                                                                                                                                                                                                                                                                                                                                                    |
|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Open                        | Runs an executable file. Opens a file with an appropriate application. Opens a folder in a File Browser window. Same as double-clicking the object.                                                                                                                                                                                                                                                |
| Open in New Window          | (From a File Browser window only.) Opens a folder in a new File Browser window instead of replacing the contents of the current window. Same as holding down SHIFT while double-clicking a folder in a Browser window.                                                                                                                                                                             |
| Open with " <i>App</i> "    | Opens the file using the application named <i>App</i> . When this selection appears as the first selection in the menu, <i>App</i> is the default application that GNOME uses to open this type of file. See page 121 for information on changing this default.                                                                                                                                    |
| Open with ►                 | A triangle appearing to the right of a selection indicates the selection is a menu. Allow the mouse pointer to hover over the selection to display the submenu. Each submenu selection is an Open with " <i>App</i> " selection (above). The last selection in the submenu is Open with Other Application (below).                                                                                 |
| Browse Folder               | (On the desktop only.) Opens a folder in a File Browser window. Same as double-clicking a folder on the desktop.                                                                                                                                                                                                                                                                                   |
| Open with Other Application | Displays the Open With menu, which allows you to select an application to open this type of file. The next time you use the Object context menu to open this type of file, the application you selected appears as an Open with " <i>App</i> " selection (above). Does not change the default application for this type of file. See page 121 for information on changing the default application. |
| Cut                         | Removes the object and places it on the clipboard (page 116).                                                                                                                                                                                                                                                                                                                                      |
| Copy                        | Copies the object to the clipboard (page 116).                                                                                                                                                                                                                                                                                                                                                     |
| Extract Here                | Extracts the contents of an archive and some other types of files, such as some documents, to a directory with the same name as the original file plus <b>_FILES</b> .                                                                                                                                                                                                                             |
| Make Link                   | Creates a symbolic link to the object in the same directory as the object. You can then move the link to a different directory where it may be more useful. For more information refer to "Symbolic Links" on page 216.                                                                                                                                                                            |
| Move to Trash               | Moves the object to the trash (page 104).                                                                                                                                                                                                                                                                                                                                                          |
| Send to                     | Opens a Send To window that allows you to email the object.                                                                                                                                                                                                                                                                                                                                        |
| Create Archive              | Opens the Create Archive window, which allows you to specify a format and a name for an archive of one or more objects (page 268).                                                                                                                                                                                                                                                                 |
| Properties                  | Displays the Object Properties window (see the next section).                                                                                                                                                                                                                                                                                                                                      |

## THE OBJECT PROPERTIES WINDOW

The Object Properties window displays information about a file, such as who owns it, permissions, size, location, MIME type, ways to work with it, and so on. This window is titled *filename Properties*, where *filename* is the name of the file you clicked to open the window. To display this window, right-click an object and select **Properties** from the drop-down menu. The Properties window initially displays some basic information. Click the tabs at the top of the window to display additional information. Different types of files are associated with different sets of tabs. You can modify the settings in this window only if you have permission to do so. This section describes the five tabs most commonly found in Object Properties windows.

**Basic** The Basic tab displays information about the file, including its MIME type, and enables you to select a custom icon for the file and change its name. Change the name of the file in the text box labeled **Name**. If the filename is not listed in a text box, you do not have permission to change it. An easy way to change the icon is to open a File Browser window at `/usr/share/icons`. Work your way down through the directories until you find an icon you like, and then drag and drop it on the icon to the left of **Name** in the Basic tab of the Object Properties window. This technique does not work for files that are links (indicated by the arrow emblem at the upper right of the object).

**Emblems** The Emblems tab (Figure 4-21, left) allows you to add and remove emblems associated with the file by placing or removing a tick in the check box next to an emblem. Figure 4-17 on page 115 shows some emblems on file objects. Nautilus displays emblems in both its Icon and List views, although there may not be room for more than one emblem in the List view. Emblems are displayed on the desktop as well. You can also place an emblem on an object by dragging the emblem from the Side pane/Emblems and dropping it on an object in the View pane (page 265) of a File Browser window. Drag the Erase emblem to an object to remove most emblems from the object.



**Figure 4-21** The Object Properties window: Emblems tab (left); Permissions tab (right)

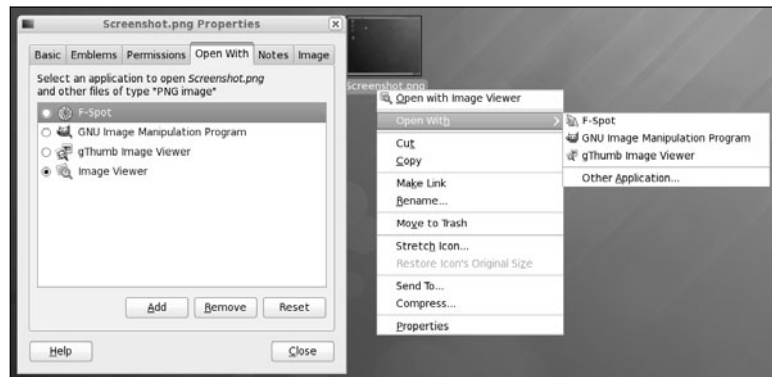
**Permissions** The Permissions tab (Figure 4-21, right) allows the owner of a file to change the file's permissions (page 203) and to change the group (see `/etc/group` on page 472) the file is associated with to any group the owner is associated with. When running with **root** privileges, you can also change the owner of the file. The command `su -RETURN` followed by the command **nautilus**, when given from a terminal emulator window, opens a File Browser window running with **root** privileges (but read the caution on page 90). Nautilus grays out items you are not allowed to change.

Using the drop-down lists, you can give the owner (called *user* elsewhere; see the tip about `chmod` on page 205), group, and others read or read and write permission for a file. You can prohibit the group and others from accessing the file by specifying permissions as **None**. Put a tick in the check box labeled **Execute** to give all users permission to execute the file. This tab does not give you as fine-grained control over assigning permissions as `chmod` (page 204) does.

Permissions for a directory work as explained on page 206. Owner, group, and others can be allowed to list files in a directory, access (read and—with the proper permissions—execute) files, or create and delete files. Group and others permissions can be set to **None**. The tri-state check box labeled **Execute** does not apply to the directory, but rather applies to the files in the directory. A tick in this check box gives everyone execute access to these files; a hyphen does not change execute permissions of the files; and an empty check box removes execute access for everyone from these files.

**Open With** When you ask GNOME to open a file that is not executable (by double-clicking its icon or right-clicking and selecting the first **Open with** selection), GNOME determines which application or utility it will use to open the file. GNOME uses several techniques to determine the *MIME* (page 1094) type of a file and selects the default application based on that determination.

The Open With tab (Figure 4-22) enables you to change which applications GNOME can use to open the file and other files of the same MIME type (typically files with the same filename extension). Click the **Add** button to add to the list of



**Figure 4-22** The Object Properties window, Open With tab, and the Object context menu, Open With submenu for the same file

applications. Highlight an application and click **Remove** to remove an application from the list. You cannot remove the default application.

When you add an application, GNOME adds that application to the Open With list, but does not change the default application it uses to open that type of file. Click the radio button next to an application to cause that application to become the default application that GNOME uses to open this type of file.

When a file has fewer than four applications in the Open With tab, the Object context menu displays all applications in that menu. With four or more applications, the Object context menu provides an Open With submenu (Figure 4-22).

**Notes** The Notes tab provides a place to keep notes about the file.

## UPDATING, INSTALLING, AND REMOVING SOFTWARE PACKAGES

Fedora/RHEL software comes in packages that include all necessary files, instructions so a program can automatically install and remove the software, and a list of other packages the package depends on. There are many ways to search for and install software packages. The Update applet (page 104) prompts you each time updates are available for software on the system. The Add/Remove Software window (discussed on the next page) is an easy way to install popular software. Chapter 13 explains how to work with software packages from the command line.

### UPDATES (*FEDORA*)

Open the Software Update Preferences window (Figure 4-23) by selecting **Main menu: System⇒Preferences⇒Software Updates**. This window allows you to choose how often you want the system to check for updates, which updates you want the system to automatically install (otherwise it prompts you to install the updates), and how often you want the system to check for major upgrades (new releases of Fedora).



**Figure 4-23** The Software Update Preferences window

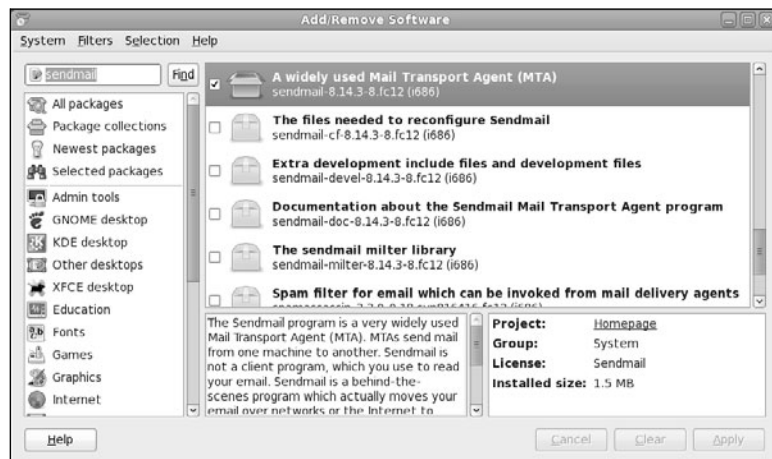
## ADD/REMOVE SOFTWARE

Under Fedora, you can use the Add/Remove Software window (Figure 4-24) to add and remove applications from the system. You can open this window by selecting **Main menu: System⇒Administration⇒Add/Remove Software** or by giving the command **gpk-application** from a terminal emulator or Run Application window (ALT-F2). Maximizing this window may make it easier to use. Under RHEL, select **Main menu: System⇒Applications⇒Add/Remove Software** to open the Package Manager window (page 505); it may be easier to use RHN (page 516) to add or remove software.

The text box at the upper-left corner of the Add/Remove Software window (adjacent to the grayed-out button labeled **Find**) is the key to finding the package you want to add or remove. Initially, the icon at the left of this text box is a pencil and paper, indicating that you will search for software packages by description. Click this icon to select other types of searches from a drop-down list.

Enter the name or part of the name of an application in the text box at the upper-left corner of the window and click **Find** to search for an application. The Add/Remove Software window displays a list of matching software packages in the frame on the right side of the window. Alternatively, you can select one of the entries from the list on the left side of the window to display a list of packages. Select **All packages** to display a list of all available software packages. An icon and text at the lower-left corner of the window keeps you informed of the utility's progress.

Scroll through the packages displayed in the frame on the right side of the window. When you click/highlight an application, the window displays a summary of the application in the frame at the lower-right corner of the window. Put a tick in the check box next to each application you want to install. Remove ticks from any

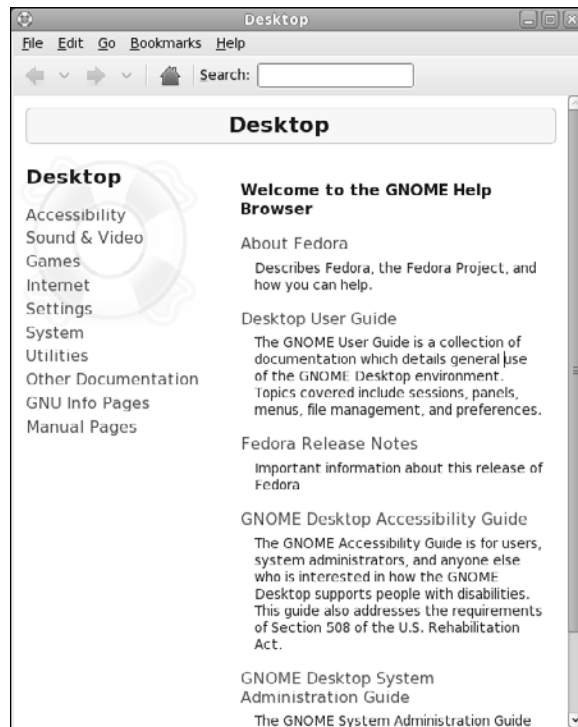


**Figure 4-24** The Add/Remove Software window

applications you want to remove. Click **Apply** to implement the changes you have marked. If a package you want to install depends on other packages that are not installed, the utility will ask for permission to install the dependent packages. Because you need to work with **root** privileges to install and remove software, the utility may ask for the **root** password. When it is finished, the utility may ask if you want to run the new application. Close the Add/Remove Software window when you are finished. Packages you installed may be available on the Main menu.

## WHERE TO FIND DOCUMENTATION

Distributions of Linux, including Fedora/RHEL, typically do not come with hard-copy reference manuals. However, its online documentation has always been one of Linux's strengths. The **man** (or manual) and **info** pages have been available via the **man** and **info** utilities since early releases of the operating system. The GNOME desktop provides a graphical Help Browser. Not surprisingly, with the ongoing growth of Linux and the Internet, the sources of documentation have expanded as well. This section discusses some of the places you can look for information on Linux in general and Fedora/RHEL in particular. See also Appendix B.



**Figure 4-25** The GNOME Help Browser



## GNOME HELP BROWSER

To display the GNOME Help Browser (Figure 4-25), select **Main menu: System**⇒**Help**. Click topics in this window until you find the information you are looking for. Click **Manual Pages** to display man pages. Click **GNU Info Pages** to display info pages. You can also search for a topic using the text box labeled **Search**.

## man: DISPLAYS THE SYSTEM MANUAL

In addition to the graphical GNOME Help Browser, the textual man utility displays (man) pages from the system documentation. This documentation is helpful when you know which utility you want to use but have forgotten exactly how to use it. You can also refer to the man pages to get more information about specific topics or to determine which features are available with Linux. Because the descriptions in the system documentation are often terse, they are most helpful if you already understand the basic functions of a utility.

Because man is a character-based utility, you need to open a terminal emulator window (page 118) to run it. You can also log in on a virtual terminal (page 137) and run man from there.

To find out more about a utility, give the command **man**, followed by the name of the utility. Figure 4-26 shows man displaying information about itself; the user entered a **man man** command.

less (pager) The man utility automatically sends its output through a *pager*—usually less (page 150), which displays one screen at a time. When you access a manual page in this manner, less displays a colon (:) prompt at the bottom of the screen after it displays each screen of text and waits for you to request another screen of text by pressing the SPACE bar. Pressing **h** (help) displays a list of less commands. Pressing **q**

```

zach@orange:~
File Edit View Terminal Help
man(1) man(1)

NAME
  man - format and display the on-line manual pages

SYNOPSIS
  man [-acdfFhkKtWw] [--path] [-m system] [-p string] [-C con-
  fig file] [-M pathlist] [-P pager] [-B browser] [-H helpager]
  [-S section_list] [section] name ...

DESCRIPTION
  man formats and displays the on-line manual pages. If you
  specify section, man only looks in that section of the manual.
  name is normally the name of the manual page, which is typi-
  cally the name of a command, function, or file. However, if
  name contains a slash (/) then man interprets it as a file
  specification, so that you can do man ./foo.5 or even man
  /cd/foo/bar.1.gz.

  See below for a description of where man looks for the manual
  page files.

MANUAL SECTIONS
  The standard sections of the manual include:
  :
  
```

**Figure 4-26** The man utility displaying information about itself

(quit) stops `less` and causes the shell to display a prompt. You can search for topics covered by `man` pages using the `apropos` utility (page 127).

Based on the FHS (Filesystem Hierarchy Standard; page 198), the Linux system manual and the `man` pages are divided into ten sections, where each section describes related tools:

1. User Commands
2. System Calls
3. Subroutines
4. Devices
5. File Formats
6. Games
7. Miscellaneous
8. System Administration
9. Kernel
10. New

This layout closely mimics the way the set of UNIX manuals has always been divided. Unless you specify a manual section, `man` displays the earliest occurrence in the manual of the word you specify on the command line. Most users find the information they need in sections 1, 6, and 7; programmers and system administrators frequently need to consult the other sections.

In some cases the manual contains entries for different tools with the same name. For example, the following command displays the `man` page for the `passwd` utility from section 1 of the system manual:

```
$ man passwd
```

To see the `man` page for the `passwd` file from section 5, enter this command:

```
$ man 5 passwd
```

The preceding command instructs `man` to look only in section 5 for the `man` page. In documentation you may see this `man` page referred to as `passwd(5)`. Use the `-a` option (see the adjacent tip) to view all `man` pages for a given subject (press `qRETURN` to display each subsequent `man` page). For example, give the command `man -a passwd` to view all `man` pages for `passwd`.

## Options

---

**tip** An option modifies the way a utility or command works. Options are usually specified as one or more letters that are preceded by one or two hyphens. An option typically appears following the name of the utility you are calling and a `SPACE`. Other *arguments* (page 1069) to the command follow the option and a `SPACE`. For more information refer to “Options” on page 225.

---

## apropos: SEARCHES FOR A KEYWORD

When you do not know the name of the command you need to carry out a particular task, you can use `apropos` with a keyword to search for it. This utility searches for the keyword in the short description line (the top line) of all `man` pages and displays those that contain a match. The `man` utility, when called with the `-k` (keyword) option, provides the same output as `apropos` (it is the same command).

The database `apropos` uses, named **whatis**, is not available on Fedora/RHEL systems when they are first installed, but is built automatically by `crond` (page 565) using `makewhatis`. (The `cron` utility runs the `/etc/cron.daily/makewhatis.cron` script to build the **whatis** database.) If you turn the system off periodically (as with a laptop), the script may not be run. If `apropos` does not produce any output, run the command `makewhatis -w` while working with `root` privileges.

The following example shows the output of `apropos` when you call it with the **who** keyword. The output includes the name of each command, the section of the manual that contains it, and the brief description from the top of the `man` page. This list includes the utility that you need (`who`) and identifies other, related tools that you might find useful:

```
$ apropos who
at.allow (5)      - determine who can submit jobs via at or batch
at.deny (5)      - determine who can submit jobs via at or batch
from (1)         - print names of those who have sent mail
w (1)            - Show who is logged on and what they are doing.
w.procps (1)     - Show who is logged on and what they are doing.
who (1)          - show who is logged on
whoami (1)       - print effective userid
whois (1)        - client for the whois directory service
```

`whatis` The `whatis` utility is similar to `apropos` but finds only complete word matches for the name of the utility:

```
$ whatis who
who (1) - show who is logged on
```

## info: DISPLAYS INFORMATION ABOUT UTILITIES

The textual `info` utility is a menu-based hypertext system developed by the GNU project (page 2) and distributed with Fedora/RHEL. The `info` utility includes a tutorial

### man and info display different information

**tip** The `info` utility displays more complete and up-to-date information on GNU utilities than does `man`. When a `man` page displays abbreviated information on a utility that is covered by `info`, the `man` page refers to `info`. The `man` utility frequently displays the only information available on non-GNU utilities. When `info` displays information on non-GNU utilities, it is frequently a copy of the `man` page.

```

zach@orange:~
File Edit View Terminal Help
File: coreutils.info, Node: Top, Next: Introduction, Up: (dir)

GNU Coreutils
*****

This manual documents version 7.6 of the GNU core utilities, including
the standard programs for text and file manipulation.

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document under the terms of the GNU Free Documentation License,
Version 1.3 or any later version published by the Free Software
Foundation; with no Invariant Sections, with no Front-Cover Texts,
and with no Back-Cover Texts. A copy of the license is included
in the section entitled "GNU Free Documentation License".

* Menu:

* Introduction::          Caveats, overview, and authors.
* Common options::       Common options.
* Output of entire files:: cat tac nl od
* Formatting file contents:: fmt pr fold
zz-Info: (coreutils.info.gz)Top, 339 lines Top
Welcome to Info version 4.13. type h for help, m for menu item.

```

**Figure 4-27** The initial screen displayed by `info coreutils`

on itself ([www.gnu.org/software/texinfo/manual/info](http://www.gnu.org/software/texinfo/manual/info)) and documentation on many Linux shells, utilities, and programs developed by the GNU project. Figure 4-27 shows the screen that `info` displays when you give the command `info coreutils` (the `coreutils` software package holds the Linux core utilities).

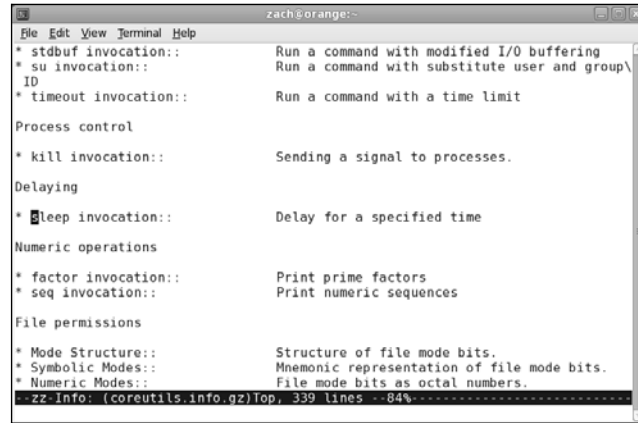
Because the information on this screen is drawn from an editable file, your display may differ from the screens shown in this section. When you see the initial `info` screen, you can press any of the following keys:

- **h** to go through an interactive tutorial on `info`
- **?** to list `info` commands
- **SPACE** to scroll through the menu of items for which information is available
- **m** followed by the name of the menu you want to display or a **SPACE** to display a list of menus
- **q** or **CONTROL-C** to quit

The notation `info` uses to describe keyboard keys may not be familiar to you. The notation **C-h** is the same as **CONTROL-H**. Similarly, **M-x** means hold down the **META** or **ALT** key and press **x**. (On some systems you need to press **ESCAPE** and then **x** to duplicate the function of **META-X**.)

### You may find `pinfo` easier to use than `info`

**tip** The `pinfo` utility is similar to `info` but is more intuitive if you are not familiar with the `emacs` editor. This utility runs in a textual environment, as does `info`. When it is available, `pinfo` uses color to make its interface easier to use. If `pinfo` is not installed on the system, use the Add/Remove Software window (page 123) to install the **pinfo** package. Run `pinfo` from a terminal emulator or Run Application window (**ALT-F2**) and select **Run in terminal**.



**Figure 4-28** The screen displayed by `info coreutils` after you type `/sleep` RETURN twice

After giving the command `info coreutils`, press the SPACE bar a few times to scroll through the display. Type `/sleep` RETURN to search for the string `sleep`. When you type `/`, the cursor moves to the bottom line of the window and displays **Search for string** *[string]*:, where *string* is the last string you searched for. Press RETURN to search for *string* or enter the string you want to search for. Typing `sleep` displays `sleep` on that line, and pressing RETURN displays the next occurrence of `sleep`.

Now type `/` RETURN (or `/sleep` RETURN) to search for the next occurrence of `sleep` as shown in Figure 4-28. The asterisk at the left end of the line indicates that this entry is a menu item. Following the asterisk is the name of the menu item and a description of the item.

Each menu item is a link to the info page that describes the item. To jump to that page, search for or use the ARROW keys to move the cursor to the line containing the menu item and press RETURN. With the cursor positioned as it is in Figure 4-28, press RETURN to display information on `sleep`. Alternatively, you can type the name of the menu item in a menu command to view the information: To display information on `sleep`, for example, you can give the command `m sleep`, followed by RETURN. When you type `m` (for *menu*), the cursor moves to the bottom line of the window (as it did when you typed `/`) and displays **Menu item:**. Typing `sleep` displays `sleep` on that line, and pressing RETURN displays information about the menu item you have chosen.

Figure 4-29 (on the next page) shows the *top node* of information on `sleep`. A node groups a set of information you can scroll through with the SPACE bar. To display the next node, press `n`. Press `p` to display the previous node.

As you read through this book and learn about new utilities, you can use `man` or `info` to find out more about those utilities. If you can print PostScript documents, you can print a manual page by using the `man` utility with the `-t` option (for example, `man -t cat | lpr` prints information about the `cat` utility). You can also use a Web browser to display the documentation at [www.tldp.org](http://www.tldp.org), [docs.fedoraproject.org](http://docs.fedoraproject.org), or [www.redhat.com/docs](http://www.redhat.com/docs) and then print the desired information from the browser.

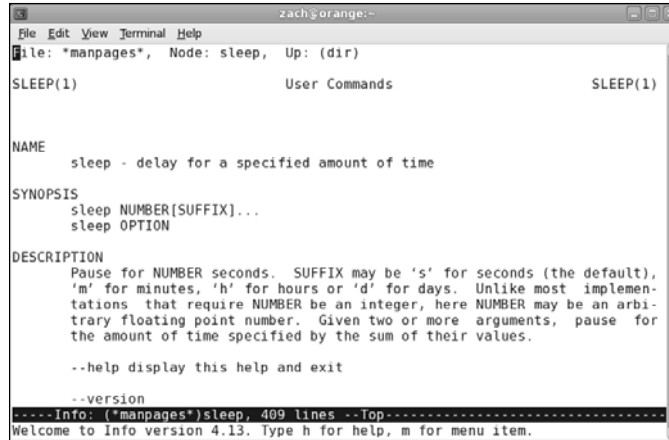


Figure 4-29 The info page on the sleep utility

## THE `--help` OPTION

Another tool you can use in a textual environment is the `--help` option. Most GNU utilities provide a `--help` option that displays information about the utility. Non-GNU utilities may use a `-h` or `-help` option to display help information.

```
$ cat --help
Usage: cat [OPTION] [FILE]...
Concatenate FILE(s), or standard input, to standard output.

-A, --show-all           equivalent to -vET
-b, --number-nonblank     number nonblank output lines
-e                        equivalent to -vE
-E, --show-ends           display $ at end of each line
...
```

If the information that `--help` displays runs off the screen, send the output through the `less` pager (page 125) using a pipe (page 158):

```
$ ls --help | less
```

## HOWTOs: FINDING OUT HOW THINGS WORK

A HOWTO document explains in detail how to do something related to Linux—from setting up a specialized piece of hardware to performing a system administration task to setting up specific networking software. Mini-HOWTOs offer shorter explanations. As with Linux software, one person or a few people generally are responsible for writing and maintaining a HOWTO document, but many people may contribute to it.

The Linux Documentation Project (LDP, page 132) site houses most HOWTO and mini-HOWTO documents. Use a Web browser to visit [www.tldp.org](http://www.tldp.org), click **HOWTOs**, and pick the index you want to use to find a HOWTO or mini-HOWTO. You can also use the LDP search feature on its home page to find HOWTOs and other documents.

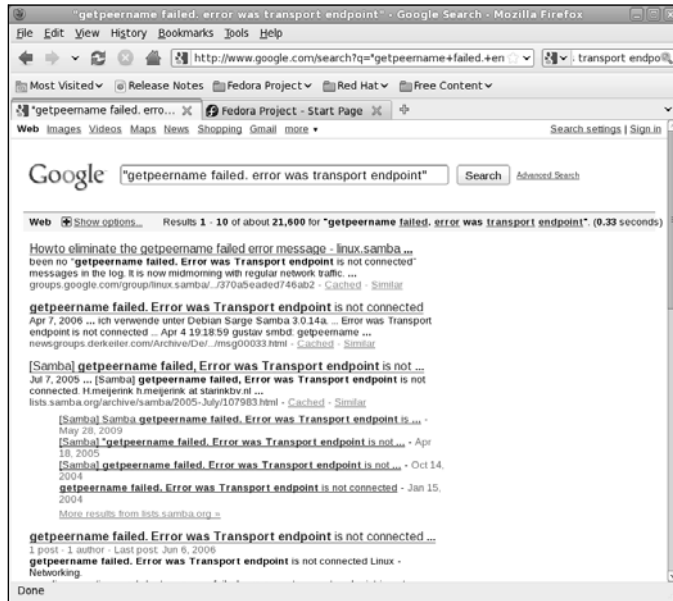


Figure 4-30 Google reporting on an error message

## GETTING HELP WITH THE SYSTEM

GNOME provides tooltips (page 110), a context-sensitive Help system, and the Help Browser discussed on page 125.

### FINDING HELP LOCALLY

The `/usr/src/linux/Documentation` (present only if you install the kernel source code, as explained in Chapter 15) and `/usr/share/doc` directories often contain more detailed and different information about a utility than `man` or `info` provides. Frequently this information is meant for people who will be compiling and modifying the utility, not just using it. These directories hold thousands of files, each containing information on a separate topic.

### USING THE INTERNET TO GET HELP

The Internet provides many helpful sites related to Linux. Aside from sites that offer various forms of documentation, you can enter an error message from a program you are having a problem with in a search engine such as Google ([www.google.com](http://www.google.com), or its Linux-specific version at [www.google.com/linux](http://www.google.com/linux)). Enclose the error message within double quotation marks to improve the quality of the results. The search will likely yield a post concerning your problem and suggestions about how to solve it. See Figure 4-30.

The Red Hat and Fedora Web sites are rich sources of information. The following list identifies locations that may be of interest:

- Fedora documentation is available at [docs.fedoraproject.org](http://docs.fedoraproject.org).

- Manuals for Red Hat Linux through Linux 9 and RHEL are available at [www.redhat.com/docs](http://www.redhat.com/docs).
- Various types of support documents and support are available at [www.redhat.com/apps/support](http://www.redhat.com/apps/support) (requires free registration).
- You can query the Red Hat Knowledgebase at [kbase.redhat.com](http://kbase.redhat.com).
- The home pages for Fedora ([fedoraproject.org](http://fedoraproject.org)) and RHEL ([www.redhat.com](http://www.redhat.com)) have a wealth of information.
- Fedora/RHEL support forums are online discussions about any Red Hat–related issues that people want to raise. One forum is dedicated to new users; others to Apache, the X Window System, and so on. Go to [www.redhat.com/mailman/listinfo](http://www.redhat.com/mailman/listinfo) to browse the lists. Another site that has similar, useful information is [fedoraforum.org](http://fedoraforum.org).
- The Fedora/RHEL bugs database is available at [bugzilla.redhat.com](http://bugzilla.redhat.com). Anyone can search the database. To submit new bugs or append to existing bugs, you need to sign up for a free account.
- Fedora weekly news is available at [fedoraproject.org/wiki/FWN](http://fedoraproject.org/wiki/FWN).
- RHEL hardware help is available from the Red Hat hardware catalog at [hardware.redhat.com](http://hardware.redhat.com). The hardware that Fedora supports is mostly a superset of that supported by RHEL.

GNU GNU manuals are available at [www.gnu.org/manual](http://www.gnu.org/manual). In addition, you can visit the GNU home page ([www.gnu.org](http://www.gnu.org)) to obtain additional documentation and other GNU resources. Many of the GNU pages and resources are available in a variety of languages.

The Linux  
Documentation  
Project

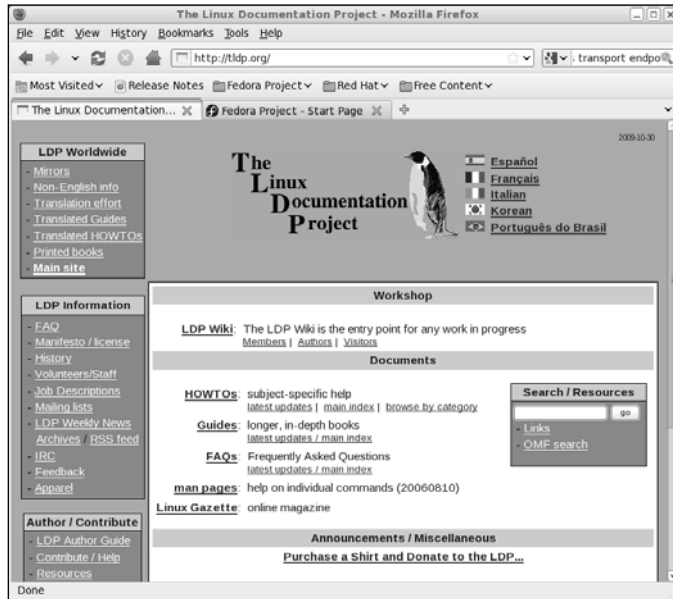
The Linux Documentation Project ([www.tldp.org](http://www.tldp.org); Figure 4-31), which has been around for almost as long as Linux, houses a complete collection of guides, HOW-TOs, FAQs, man pages, and Linux magazines. The home page is available in English, Portuguese, Spanish, Italian, Korean, and French. It is easy to use and supports local text searches. It also provides a complete set of links you can use to find almost anything you want related to Linux (click **Links** in the Search box or go to [www.tldp.org/links](http://www.tldp.org/links)). The links page includes sections on general information, events, getting started, user groups, mailing lists, and newsgroups, with each section containing many subsections.

---

## MORE ABOUT LOGGING IN

Refer to “Logging In on the System” on page 91 for information about logging in. This section covers options you can choose from the Login screen and solutions to common login problems. It also describes how to log in from a terminal and from a remote system.





**Figure 4-31** The Linux Documentation Project home page

## Always use a password

### security

Unless you are the only user of a system; the system is not connected to any other systems, the Internet, or a modem; and you are the only one with physical access to the system, it is poor practice to maintain a user account without a password.

## THE LOGIN SCREEN

**FEDORA** The Login screen (Figure 4-1, page 91) presents a list of users who are allowed to log in on the system. On a panel at the bottom of the screen are three buttons. Click the round blue button depicting a person to select from a list of access preferences that may make it easier for some people to use the system. Click the triangular yellow button holding an exclamation point to display a list of boot messages. Click the gray round button at the right end of the panel to restart or shut down the system. Click your name from the list of users to log in.

Once you have clicked your name, the login screen displays a text box labeled **Password**. In addition, to the panel at the bottom of the screen, it adds buttons labeled **Language** and **Keyboard**. If multiple window managers or desktops are installed, a button labeled **Sessions** also appears. Enter your password in the text box and press RETURN to log in.

Before you log in, the button labeled **Language** displays the name of the language the upcoming session will use. To change the language of the upcoming session, click this button and select a language from the drop-down list. If the language you

want is not listed, select **Other** from the drop-down list; Fedora displays the Languages window. Select the language you want from this window and click **OK**. Then log in. Fedora asks if you want to change the names of standard folders (directories) so they appear in the new language.

You can change the keyboard layout the upcoming session expects by using the button labeled **Keyboard** on the login screen in the same manner as you use for the Language button. With multiple window managers or desktops installed, you can use the button labeled **Sessions** to choose between them.

*RHEL* The procedure for logging in under *RHEL* is similar to that for *FEDORA* except you are presented with a text box labeled **Username** in which to enter your username, the button labeled **Language** appears on the initial screen, and there is no button labeled **Keyboard**.

## WHAT TO DO IF YOU CANNOT LOG IN

If you enter either your username or your password incorrectly, the system displays an error message after you enter *both* your username *and* your password. This message indicates that you have entered either the username or the password incorrectly or that they are not valid. It does not differentiate between an unacceptable username and an unacceptable password—a strategy meant to discourage unauthorized people from guessing names and passwords to gain access to the system.

Following are some common reasons why logins fail:

- **The username and password are case sensitive.** Make sure the **CAPS LOCK** key is off and enter your username and password exactly as specified or as you set them up.
- **You are not logging in on the right machine.** The login/password combination may not be valid if you are trying to log in on the wrong machine. On a larger, networked system, you may have to specify the machine you want to connect to before you can log in.
- **Your username is not valid.** The login/password combination may not be valid if you have not been set up as a user. If you are the system administrator, refer to “Configuring User and Group Accounts” on page 556. Otherwise, check with the system administrator.
- **A filesystem is full.** When a filesystem critical to the login process is full, it may appear as though you have logged in successfully, but after a moment the Login screen reappears. You must boot the system in rescue mode (page 411) and delete some files.
- **The account may be disabled.** The **root** account is disabled from a GUI login by default. An administrator may disable other accounts. Often the **root** account is not allowed to log in over a network. You must use **su** or **sudo** (page 405) if you need to work with root privileges from a remote system.

Refer to “Changing Your Password” on page 136 if you want to change your password.

## LOGGING IN REMOTELY: TERMINAL EMULATORS, ssh, AND DIAL-UP CONNECTIONS

When you are not using a console, terminal, or other device connected directly to the Linux system you are logging in on, you are probably connected to the Linux system using terminal emulation software on another system. Running on the local system, this software connects to the remote Linux system via a network (Ethernet, asynchronous phone line, PPP, or other type) and allows you to log in.

### Make sure **TERM** is set correctly

**tip** No matter how you connect, make sure you have the **TERM** variable set to the type of terminal your emulator is emulating. For more information refer to “Specifying a Terminal” on page 1040.

When you log in via a dial-up line, the connection is straightforward: You instruct the local emulator program to contact the remote Linux system, it dials the phone, and the remote system displays a login prompt. When you log in via a directly connected network, you use **ssh** (secure; page 627) or **telnet** (not secure; page 377) to connect to the remote system. The **ssh** program has been implemented on many operating systems, not just Linux. Many user interfaces to **ssh** include a terminal emulator. From an Apple, Windows, or UNIX machine, open the program that runs **ssh** and give it the name or IP address (refer to “Host Address” on page 367) of the system you want to log in on. For examples and more details on working with a terminal emulator, refer to “Running Commands from a Terminal Emulator/Shell” on page 118. The next section provides more information about logging in from a terminal emulator.

## LOGGING IN FROM A TERMINAL (EMULATOR)

Before you log in on a terminal, terminal emulator, or other textual device, the system displays a message called *issue* (stored in the `/etc/issue` file) that identifies the version of Fedora/RHEL running on the system. A sample *issue* message follows:

```
Fedora release 12 (Constantine)
Kernel 2.6.31.5-127.fc12.i686.PAE on an i686 (tty2)
```

This message is followed by a prompt to log in. Enter your username and password in response to the system prompts. If you are using a *terminal* (page 1110) and the screen does not display the **login:** prompt, check whether the terminal is plugged in and turned on, and then press the RETURN key a few times. If **login:** still does not appear, try pressing CONTROL-Q (Xoff). If you are using a *workstation* (page 1116), run **ssh** (page 627), **telnet** (page 377), or whatever communications/emulation software you use to log in on the system.

Once the *shell prompt* (or just *prompt*) appears, you have successfully logged in; this prompt shows the system is ready for you to give a command. The first shell prompt line may be preceded by a short message called the *message of the day*, or **motd** (page 474), which is stored in the `/etc/motd` file. Fedora/RHEL establishes a prompt of `[user@host directory]$`, where *user* is your username, *host* is the name of

the system, and *directory* is the name of the directory you are working in. A tilde (~) represents your home directory. For information on how to change the prompt, refer to page 307.

### Did you log in last?

**security** As you are logging in to a textual environment, after you enter your username and password, the system displays information about the last login on this account, showing when it took place and where it originated. You can use this information to determine whether anyone has accessed the account since you last used it. If someone has, perhaps an unauthorized user has learned your password and logged in as you. In the interest of maintaining security, advise the system administrator of any circumstances that make you suspicious—and change your password.

---

## CHANGING YOUR PASSWORD

If someone else assigned you a password, it is a good idea to give yourself a new one. For security reasons, none of the passwords you enter is displayed by any utility.

### Protect your password

**security** Do not allow someone to find out your password: *Do not* put your password in a file that is not encrypted, allow someone to watch you type your password, or give your password to someone you do not know (a system administrator never needs to know your password). You can always write your password down and keep it in a safe, private place.

---

### Choose a password that is difficult to guess

**security** Do not use phone numbers, names of pets or kids, birthdays, words from a dictionary (not even a foreign language), and so forth. Do not use permutations of these items or a l33t-speak variation of a word: Modern dictionary crackers may also try these permutations.

---

### Differentiate between important and less important passwords

**security** It is a good idea to differentiate between important and less important passwords. For example, Web site passwords for blogs or download access are not very important; it is acceptable to use the same password for these types of sites. However, your login, mail server, and bank account Web site passwords are critical: Never use these passwords for an unimportant Web site.

---

To change your password, select **Main menu: System⇒Preferences⇒About Me** and click **Change Password**. From a command line, give the command **passwd**.

The first item the system asks for is your current (old) password. This password is verified to ensure that an unauthorized user is not trying to alter your password. Then the system requests a new password.

To be relatively secure, a password should contain a combination of numbers, uppercase and lowercase letters, and punctuation characters and meet the following criteria:

- Must be at least six characters long (or longer if the system administrator sets it up that way). Seven or eight characters is a good compromise between length and security.
- Should not be a word in a dictionary of any language, no matter how seemingly obscure.
- Should not be the name of a person, place, pet, or other thing that might be discovered easily.
- Should contain at least two letters and one digit or punctuation character.
- Should not be your username, the reverse of your username, or your username shifted by one or more characters.

Only the first item is mandatory. Avoid using control characters (such as CONTROL-H) because they may have a special meaning to the system, making it impossible for you to log in. If you are changing your password, the new password should differ from the old one by at least three characters. Changing the case of a character does not make it count as a different character. Refer to “Keeping the System Secure” on page 577 for more information about choosing a password.

### **pwgen helps you pick a password**

**security** The **pwgen** utility (install the **pwgen** package) generates a list of almost random passwords. With a little imagination, you can pronounce, and therefore remember, some of these passwords.

After you enter your new password, the system asks you to retype it to make sure you did not make a mistake when you entered it the first time. If the new password is the same both times you enter it, your password is changed. If the passwords differ, you made an error in one of them. In this situation the system displays an error message or does not allow you to click the **OK** button. If the password you enter is not long enough, the system displays a message similar to **The password is too short.**

When you successfully change your password, you change the way you log in. If you forget your password, a user running with **root** privileges can change it and tell you the new password.

## **USING VIRTUAL CONSOLES**

When running Linux on a personal computer, you will frequently work with the display and keyboard attached to the computer. Using this physical console, you can access as many as 63 *virtual consoles* (also called *virtual terminals*). Some are set up to allow logins; others act as graphical displays. To switch between virtual consoles, hold the **CONTROL** and **ALT** keys down and press the function key that corresponds to the console you want to view. For example, **CONTROL-ALT-F5** displays the fifth virtual console. This book refers to the console you see when you press **CONTROL-ALT-F1** as the *system console*, or just *console*.

By default, five or six virtual consoles are active and have textual login sessions running. When you want to use both textual and graphical interfaces, you can set up a textual session on one virtual console and a graphical session on another. By default, under Fedora a graphical session runs on virtual console number one and under RHEL a graphical session runs on virtual console six or seven.

---

## WORKING FROM THE COMMAND LINE

Before the introduction of the graphical user interface (GUI), UNIX and then Linux provided only a command-line (textual) interface (CLI). Today, a CLI is available when you log in from a terminal, a terminal emulator, or a textual virtual console, or when you use `ssh` (page 625) or `telnet` (insecure, page 377) to log in on a system.

This section introduces the Linux CLI. Chapter 5 describes some of the more important utilities you can use from the command line. Most of the examples in Parts IV and V of this book use the CLI, adding examples of graphical tools where available.

**Advantages of the CLI** Although the concept may seem antiquated, the CLI has a place in modern computing. In some cases an administrator may use a command-line tool either because a graphical equivalent does not exist or because the graphical tool is not as powerful or flexible as the textual one. Frequently, on a server system, a graphical interface may not even be installed. The first reason for this omission is that a GUI consumes a lot of system resources; on a server, those resources are better dedicated to the main task of the server. Additionally, security considerations mandate that a server system run as few tasks as possible because each additional task can make the system more vulnerable to attack.

You can also write scripts using the CLI. Using scripts, you can easily reproduce tasks on multiple systems, enabling you to scale the tasks to larger environments. When you are the administrator of only a single system, using a GUI is often the easiest way to configure the system. When you act as administrator for many systems, all of which need the same configuration installed or updated, a script can make the task go more quickly. Writing a script using command-line tools is frequently easy, whereas it can be difficult to impossible using graphical tools.

**Pseudographical interface** Before the introduction of GUIs, resourceful programmers created textual interfaces that included graphical elements such as boxes, borders outlining rudimentary windows, highlights, and, more recently, color. These textual interfaces, called pseudographical interfaces, bridge the gap between textual and graphical interfaces.

## CORRECTING MISTAKES

This section explains how to correct typographical and other errors you may make while you are logged in on a textual display. Because the shell and most other utilities

do not interpret the command line or other text until after you press RETURN, you can readily correct your typing mistakes before you press RETURN.

You can correct such mistakes in several ways: erase one character at a time, back up a word at a time, or back up to the beginning of the command line in one step. After you press RETURN, it is too late to correct a mistake: At that point, you must either wait for the command to run to completion or abort execution of the program (page 140).

## ERASING A CHARACTER

While entering characters from the keyboard, you can back up and erase a mistake by pressing the *erase key* once for each character you want to delete. The erase key backs over as many characters as you wish. It does not, in general, back up past the beginning of the line.

The default erase key is BACKSPACE. If this key does not work, try pressing DEL or CONTROL-H. If these keys do not work, give the following `stty`<sup>2</sup> command to set the erase and line kill (see “Deleting a Line”) keys to their default values:

```
$ stty ek
```

## DELETING A WORD

You can delete a word you entered by pressing CONTROL-W. A *word* is any sequence of characters that does not contain a SPACE or TAB. When you press CONTROL-W, the cursor moves left to the beginning of the current word (as you are entering a word) or the previous word (when you have just entered a SPACE or TAB), removing the word.

### CONTROL-Z suspends a program

**tip** Although it is not a way of correcting a mistake, you may press the suspend key (typically CONTROL-Z) by mistake and wonder what happened. If you see a message containing the word **Stopped**, you have just stopped your job using job control (page 241). If you give the command **fg** to continue your job in the foreground, you should return to where you were before you pressed the suspend key. For more information refer to “bg: Sends a Job to the Background” on page 295.

## DELETING A LINE

Any time before you press RETURN, you can delete the line you are entering by pressing the (*line*) *kill key*. When you press this key, the cursor moves to the left, erasing characters as it goes, back to the beginning of the line. The default line kill key is CONTROL-U. If this key does not work, try CONTROL-X. If these keys do not work, give the `stty` command described under “Erasing a Character.”

---

2. The command `stty` is an abbreviation for *set teletypewriter*, the first terminal UNIX was run on. Today `stty` is commonly thought of as *set terminal*.

## ABORTING EXECUTION

Sometimes you may want to terminate a running program. For example, you may want to stop a program that is performing a lengthy task such as displaying the contents of a file that is several hundred pages long or copying a large file that is not the one you meant to copy.

To terminate a program from a textual display, press the *interrupt key* (CONTROL-C or sometimes DELETE or DEL). When you press this key, the Linux operating system sends a terminal interrupt signal to the program you are running and to the shell. Exactly what effect this signal has depends on the program. Some programs stop execution immediately, some ignore the signal, and some take other actions. When the shell receives a terminal interrupt signal, it displays a prompt and waits for another command.

If these methods do not terminate the program, try stopping the program with the suspend key (typically CONTROL-Z), giving a **jobs** command to verify the number of the job running the program, and using **kill** to abort the job. The job number is the number within the brackets at the left end of the line that **jobs** displays ([1]). In the next example, the **kill** command (page 409) uses **-TERM** to send a termination signal<sup>3</sup> to the job specified by the job number, which is preceded by a percent sign (%1). You can omit **-TERM** from the command, as **kill** sends a termination signal by default.

```
$ bigjob
^Z
[1]+  Stopped                  bigjob
$ jobs
[1]+  Stopped                  bigjob
$ kill -TERM %1
$ RETURN
[1]+  Killed                   bigjob
```

The **kill** command returns a prompt; press RETURN again to see the confirmation message. For more information refer to “Running a Program in the Background” on page 241.

## REPEATING/EDITING COMMAND LINES

To repeat a previous command, press the UP ARROW key. Each time you press this key, the shell displays an earlier command line. To reexecute the displayed command line, press RETURN. Press the DOWN ARROW key to browse through the command lines in the other direction.

The RIGHT and LEFT ARROW keys move the cursor back and forth along the displayed command line. At any point along the command line, you can add characters by typing them. Use the erase key to remove characters from the command line. For information about more complex command-line editing, see page 318.

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3. When the termination signal does not work, use the **kill (-KILL)** signal. A running program cannot ignore a kill signal; it is sure to abort the program (page 409).



optional

## CONTROLLING WINDOWS: ADVANCED OPERATIONS

Refer to “Windows” on page 115 for an introduction to working with windows under Fedora/RHEL. This section explores the following topics: changing the input focus on the workspace, changing the resolution of the display, and understanding more about the window manager.

### CHANGING THE INPUT FOCUS

When you type on the keyboard, the window manager (page 142) directs the characters you type somewhere, usually to a window. The *active window* is the window accepting input from the keyboard; it is said to have the *input focus*. Depending on how you set up your account, you can use the mouse in one of three ways to change the input focus (you can also use the keyboard; see page 116):

- **Click-to-focus** (*explicit focus*)—Gives the input focus to a window when you click the window. That window continues to accept input from the keyboard regardless of the location of the mouse pointer. The window loses the focus when you click another window. Although clicking the middle or right mouse button also activates a window, use only the left mouse button for this purpose; other buttons may have unexpected effects when you use them to activate a window.
- **Focus-follows-mouse** (*sloppy focus*, *enter-only*, or *focus-under-mouse*)—Gives the input focus to a window when you move the mouse pointer onto the window. That window maintains the input focus until you move the mouse pointer onto another window, at which point the new window gets the focus. When you move the mouse pointer off a window and onto the root window, the window that had the input focus does not lose it.
- **Focus-strictly-under-mouse** (*enter-exit focus*)—Gives the input focus to a window when you move the mouse pointer onto the window. That window maintains the input focus until you move the mouse pointer off the window, at which point no window has the focus. When you move the mouse pointer off a window and onto the root window, the window that had the input focus loses it, and input from the keyboard is lost.

You can use the Window Preferences window to change the focus policy. Under Fedora, you must install the **control-center-extra** package as explained on page 501 before you can display this window. To display this window, select **Main menu: System**⇒**Preferences**⇒**Windows** or give the command **gnome-window-properties** from a terminal emulator or Run Application window (ALT-F2). Put a tick in the check box next to **Select windows when the mouse moves over them** to select the focus-follows-mouse policy. When there is no tick in this check box, click-to-focus is in effect. Click **Close**. Focus-strictly-under-mouse is not available from this window.

To determine which window has the input focus, compare the window borders. The border color of the active window is different from the others or, on a monochrome display, is darker. Another indication that a window is active is that the keyboard cursor is a solid rectangle; in windows that are not active, the cursor is an outline of a rectangle.

Use the following tests to determine which keyboard focus method you are using. If you position the mouse pointer in a window and that window does not get the input focus, your window manager is configured to use the click-to-focus method. If the border of the window changes, you are using the focus-follows-mouse or focus-strictly-under-mouse method. To determine which of the latter methods you are using, start typing something, with the mouse pointer positioned on the active window. Then move the mouse pointer over the root window and continue typing. If characters continue to appear within the window, you are using focus-follows-mouse; otherwise, you are using focus-strictly-under-mouse.

## CHANGING THE RESOLUTION OF THE DISPLAY

The X server (the basis for the Linux graphical interface; see page 256) starts at a specific display resolution and *color depth* (page 1075). Although you can change the color depth only when you start an X server, you can change the resolution while the X server is running. The number of resolutions available depends both on the display hardware and on the configuration of the X server. Many users prefer to do most of their work at a higher resolution but might want to switch to a lower resolution for some tasks, such as playing games. You can switch between display resolutions by pressing either `CONTROL-ALT-KEYPAD-+` or `CONTROL-ALT-KEYPAD-`, using the `+` and `-` on the keyboard's numeric keypad. You can also use the Monitor Resolution Settings window (**Main menu: System**⇒**Preferences**⇒**Display**) to change the resolution of the display.

Changing to a lower resolution has the effect of zooming in on the display; as a result, you may no longer be able to view the entire workspace at once. You can scroll the display by pushing the mouse pointer against the edge of the screen.

## THE WINDOW MANAGER

A *window manager*—the program that controls the look and feel of the basic GUI—runs under a desktop manager (such as GNOME or KDE) and controls all aspects of the windows in the X Window System environment. The window manager defines the appearance of the windows on the desktop and controls how you operate and position them: open, close, move, resize, minimize, and so on. It may also handle some session management functions, such as how a session is paused, resumed, restarted, or ended (page 108).

**Window decorations** A window manager controls *window decorations*—that is, the titlebar and border of a window. Aside from the aesthetic aspects of changing window decorations, you

can alter their functionality by modifying the number and placement of buttons on the titlebar.

The window manager takes care of window manipulation so client programs do not need to do so. This setup is very different from that of many other operating systems, and the way that GNOME deals with window managers is different from how other desktop environments work. Window managers do more than simply manage windows—they provide a useful, good-looking, graphical shell to work from. Their open design allows users to define their own policies, down to the fine details.

Theoretically GNOME is not dependent on any particular window manager and can work with any of several window managers. Because of their flexibility, you would not see major parts of the desktop environment change if you were to switch from one window manager to another. A desktop manager collaborates with the window manager to make your work environment intuitive and easy to use. Although the desktop manager does not control window placement, it does get information from the window manager about window placement.

### FEDORA/RHEL WINDOW MANAGERS

Metacity and Compiz—the default window managers for GNOME—provide window management and start many components through GNOME panel objects. They also communicate with and facilitate access to other components in the environment. The Desktop Effects window (page 108) allows you to switch between Metacity and Compiz.

Using the standard X libraries, programmers have created other window managers, including **blackbox**, **fluxbox**, and **WindowMaker**. You can use yum (page 501) to install any of these packages.

## CHAPTER SUMMARY

As with many operating systems, your access to a Linux system is authorized when you log in. To do so, you enter your username and password on the Login screen. You can change your password at any time while you are logged in. Choose a password that is difficult to guess and that conforms to the criteria imposed by the utility that changes your password.

The system administrator is responsible for maintaining the system. On a single-user system, you are the system administrator. On a small, multiuser system, you or another user may act as the system administrator, or this job may be shared. On a large, multiuser system or a network of systems, there is frequently a full-time system administrator. When extra privileges are required to perform certain system

tasks, the system administrator logs in as the **root** user by entering the username **root** and the **root** password; this user is called Superuser or administrator. On a multiuser system, several trusted users may be given the **root** password.

Do not work with **root** privileges (as Superuser) as a matter of course. When you have to do something that requires **root** privileges, work with **root** privileges for only as long as absolutely necessary; revert to working as yourself as soon as possible.

Understanding the desktop and its components is essential to getting the most out of the Fedora/RHEL GUI. The panels offer a convenient way to launch applications, either by clicking objects or by using the Main menu. The Main menu is a multilevel menu you can work with to customize and maintain the system and to start many commonly used applications. A window is the graphical manifestation of an application. You can control its size, location, and appearance by clicking buttons on the window's titlebar. A terminal emulator allows you to use the Linux command-line interface from a graphical environment. You can use a terminal emulator to launch both textual and graphical programs.

Panels and menus enable you to select an object (which can be just about anything on the system). On a panel, you generally click an object; on a menu, you typically click text in a list.

The GNOME environment provides the casual user, the office worker, the power user, and the programmer/system designer a space to work in and a set of tools to work with. GNOME also provides off-the-shelf productivity and many ways to customize its look, feel, and response.

Nautilus is GNOME's simple, yet powerful file manager. It can create, open, display, move, and copy files and directories as well as execute programs and scripts. One of its most basic and important functions is to create and manage the desktop.

The **man** utility provides online documentation for system utilities. This utility is helpful both to new Linux users and to experienced users, who must often delve into system documentation for information on the finer points of a utility's behavior. The **info** utility also helps the beginner and the expert alike. It provides a tutorial on its use and documentation on many Linux utilities.

The textual or command-line interface (CLI) continues to have a place in modern computing. For example, sometimes a graphical tool does not exist or may not be as powerful or flexible as its textual counterpart. Security concerns on a server system mandate that the system run as few tasks as possible. Because each additional task can make a server more vulnerable to attack, frequently these systems do not have GUIs installed.

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## EXERCISES

1. The system displays the following message when you attempt to log in with an incorrect username *or* an incorrect password:

Incorrect username or password. Letters must be typed in the correct case.

- a. This message does not indicate whether your username, your password, or both are invalid. Why does it not reveal this information?
- b. Why does the system wait for a couple of seconds after you supply an incorrect username or password?
2. Give three examples of poor password choices. What is wrong with each?
3. Is **fido** an acceptable password? Give several reasons why or why not.
4. What is a context menu? How does a context menu differ from other menus?
5. What appears when you right-click the root window? How can you use this object?
6. How would you swap the effects of the right and left buttons on a mouse? What is the drag and drop threshold? How would you change it?
7. What are the primary functions of the Main menu?
8. What is the input focus? When no window has the input focus, what happens to the letters you type on the keyboard? Which type of input focus would you prefer to work with? Why?
9. What are the functions of a Window Operations menu? How do you display this menu?
10. What is a panel? Name a few objects on the panels and explain what you can use them for. What do the Workspace Switcher applet and the Window List applet do?
11. What are tooltips? How are they useful?

---

## ADVANCED EXERCISES

12. What change does the mouse pointer undergo when you move it to the edge of a window? What happens when you left-click and drag the mouse pointer when it looks like this? Repeat this experiment with the mouse pointer at the corner of a window.
13. Assume you have started a window manager without a desktop manager. What would be missing from the screen? Describe what a window manager does. How does a desktop manager make it easier to work with a GUI?
14. When the characters you type do not appear on the screen, what might be wrong? How can you fix this problem?
15. What happens when you run `vim` from the Run Application window without specifying that it be run in a terminal? Where does the output go?

16. The example on page 126 shows that the man pages for `passwd` appear in sections 1 and 5 of the system manual. Explain how you can use `man` to determine which sections of the system manual contain a manual page with a given name.
17. How many man pages are in the Devices subsection of the system manual? (*Hint: Devices is a subsection of Special Files.*)

# 5

## THE LINUX UTILITIES

### IN THIS CHAPTER

|                                                                 |     |
|-----------------------------------------------------------------|-----|
| Special Characters .....                                        | 148 |
| Basic Utilities .....                                           | 149 |
| less Is more: Display a Text File<br>One Screen at a Time ..... | 150 |
| Working with Files.....                                         | 151 |
| lpr: Prints a File.....                                         | 153 |
| (Pipe): Communicates Between<br>Processes.....                  | 158 |
| Compressing and Archiving<br>Files .....                        | 161 |
| Obtaining User and System<br>Information .....                  | 168 |
| Tutorial: Creating and Editing<br>a File Using vim .....        | 174 |

When Linus Torvalds introduced Linux and for a long time thereafter, Linux did not have a graphical user interface (GUI): It ran on character-based terminals only. All the tools ran from a command line. Today the Linux GUI is important but many people—especially system administrators—run many command-line programs. Command-line utilities are often faster, more powerful, or more complete than their GUI counterparts. Sometimes there is no GUI counterpart to a textual utility; some people just prefer the hands-on feeling of the command line.

When you work with a command-line interface, you are working with a shell (Chapters 7, 9, and 27). Before you start working with a shell, it is important that you understand something about the characters that are special to the shell, so this chapter starts with a discussion of special characters. The chapter then describes five basic utilities: `ls`, `cat`, `rm`, `less`, and `hostname`. It continues by describing several other file manipulation utilities as well as utilities that find out who is logged in; that communicate with other users; that print, compress, and decompress files; and that pack and unpack archive files.

## Run these utilities from a command line

**tip** This chapter describes command line, or textual, utilities. You can experiment with these utilities from a terminal, a terminal emulator within a GUI (page 118), or a virtual console (page 137).

## SPECIAL CHARACTERS

*Special characters*, which have a special meaning to the shell, are discussed in “File-name Generation/Pathname Expansion” on page 243. These characters are mentioned here so that you can avoid accidentally using them as regular characters until you understand how the shell interprets them. For example, it is best to avoid using any of the following characters in a filename (even though *emacs* and some other programs do) because they make the file harder to reference on the command line:

& ; | \* ? ' " ` [ ] ( ) \$ < > { } # / \ ! ~

**Whitespace** Although not considered special characters, RETURN, SPACE, and TAB also have special meanings to the shell. RETURN usually ends a command line and initiates execution of a command. The SPACE and TAB characters separate elements on the command line and are collectively known as *whitespace* or *blanks*.

**Quoting special characters** If you need to use a character that has a special meaning to the shell as a regular character, you can *quote* (or *escape*) it. When you quote a special character, you keep the shell from giving it special meaning. The shell treats a quoted special character as a regular character. However, a slash (/) is always a separator in a path-name, even when you quote it.

**Backslash** To quote a character, precede it with a backslash (\). When two or more special characters appear together, you must precede each with a backslash (for example, you would enter *\*\** as \\*\\*). You can quote a backslash just as you would quote any other special character—by preceding it with a backslash (\\).

**Single quotation marks** Another way of quoting special characters is to enclose them between single quotation marks: *'\*\*'*. You can quote many special and regular characters between a pair of single quotation marks: *'This is a special character: >'*. The regular characters are interpreted as usual, and the shell also interprets the special characters as regular characters.

The only way to quote the erase character (CONTROL-H), the line kill character (CONTROL-U), and other control characters (try CONTROL-M) is by preceding each with a CONTROL-V. Single quotation marks and backslashes do not work. Try the following:

```
$ echo 'xxxxxxCONTROL-U'
$ echo xxxxxxCONTROL-V CONTROL-U
```

**optional** Although you cannot see the CONTROL-U displayed by the second of the preceding pair of commands, it is there. The following command sends the output of echo



(page 159) through a pipe (page 158) to `od` (see the `od` man page) to display `CONTROL-U` as octal 25 (025):

```
$ echo xxxxxxCONTROL-V CONTROL-U | od -c
00000000  x  x  x  x  x  x  x 025  \n
0000010
```

The `\n` is the `NEWLINE` character that `echo` sends at the end of its output.

## BASIC UTILITIES

One of the important advantages of Linux is that it comes with thousands of utilities that perform myriad functions. You will use utilities whenever you work with Linux, whether you use them directly by name from the command line or indirectly from a menu or icon. The following sections discuss some of the most basic and important utilities; these utilities are available from a character-based interface. Some of the more important utilities are also available from a GUI; others are available only from a GUI.

**Folder** The term *directory* is used extensively in the next sections. A directory is a resource that can hold files. On other operating systems, including Windows and Macintosh, and frequently when speaking about a Linux GUI, a directory is referred to as a folder. That is a good analogy: A traditional manila folder holds files just as a directory does.

### In this chapter you work in your home directory

**tip** When you log in on the system, you are working in your *home directory*. In this chapter that is the only directory you use: All the files you create in this chapter are in your home directory. Chapter 6 goes into more detail about directories.

## ls: LISTS THE NAMES OF FILES

Using the editor of your choice, create a small file named **practice**. (A tutorial on the `vim` editor appears on page 174.) After exiting from the editor, you can use the `ls` (list) utility to display a list of the names of the files in your home directory. In the first command in Figure 5-1 (next page), `ls` lists the name of the **practice** file. (You may also see files the system or a program created automatically.) Subsequent commands in Figure 5-1 display the contents of the file and remove the file. These commands are described next.

## cat: DISPLAYS A TEXT FILE

The `cat` utility displays the contents of a text file. The name of the command is derived from *catenate*, which means to join together, one after the other. (Figure 7-8 on page 234 shows how to use `cat` to string together the contents of three files.)

```
$ ls
practice
$ cat practice
This is a small file that I created
with a text editor.
$ rm practice
$ ls
$ cat practice
cat: practice: No such file or directory
$
```

**Figure 5-1** Using `ls`, `cat`, and `rm` on the file named `practice`

A convenient way to display the contents of a file to the screen is by giving the command `cat`, followed by a SPACE and the filename. Figure 5-1 shows `cat` displaying the contents of `practice`. This figure shows the difference between the `ls` and `cat` utilities: The `ls` utility displays the *name* of a file, whereas `cat` displays the *contents* of a file.

## rm: DELETES A FILE

The `rm` (remove) utility deletes a file. Figure 5-1 shows `rm` deleting the file named `practice`. After `rm` deletes the file, `ls` and `cat` show that `practice` is no longer in the directory. The `ls` utility does not list its filename, and `cat` says that no such file exists. Use `rm` carefully.

### A safer way of removing files

**tip** You can use the interactive form of `rm` to make sure that you delete only the file(s) you intend to delete. When you follow `rm` with the `-i` option (see page 126 for a tip on options) and the name of the file you want to delete, `rm` displays the name of the file and then waits for you to respond with **y** (yes) before it deletes the file. It does not delete the file if you respond with a string that does not begin with **y**. The `-i` option is set up by default for the **root** user under Fedora/RHEL:

```
$ rm -i toollist
rm: remove regular file 'toollist'? y
```

**Optional:** You can create an alias (page 332) for `rm -i` and put it in your startup file (page 192) so that `rm` always runs in interactive mode.

## less Is more: DISPLAY A TEXT FILE ONE SCREEN AT A TIME

**Pagers** When you want to view a file that is longer than one screen, you can use either the `less` utility or the `more` utility. Each of these utilities pauses after displaying a screen of text. Because these utilities show one page at a time, they are called *paggers*. Although `less` and `more` are very similar, they have subtle differences. At the end of the file, for example, `less` displays an EOF (end of file) message and waits for you to press **q** before returning you to the shell. In contrast, `more` returns you directly to the shell. In both utilities you can press **h** to display a Help screen that lists commands you can use while paging through a file. Give the commands `less practice` and `more practice` in place of the `cat` command in Figure 5-1 to see how these commands work. Use the command `less /usr/share/dict/words` instead if you want to experiment with a longer file. Refer to the `less` man page for more information.

## hostname: DISPLAYS THE SYSTEM NAME

The `hostname` utility displays the name of the system you are working on. Use this utility if you are not sure that you are logged in on the right machine.

```
$ hostname
bravo.example.com
```

---

## WORKING WITH FILES

This section describes utilities that copy, move, print, search through, display, sort, and compare files.

### Filename completion

**tip** After you enter one or more letters of a filename (following a command) on a command line, press TAB and the Bourne Again Shell will complete as much of the filename as it can. When only one filename starts with the characters you entered, the shell completes the filename and places a SPACE after it. You can keep typing or you can press RETURN to execute the command at this point. When the characters you entered do not uniquely identify a filename, the shell completes what it can and waits for more input. When pressing TAB does not change the display, press TAB again to display a list of possible completions. For more information refer to “Pathname Completion” on page 328.

## cp: COPIES A FILE

The `cp` (copy) utility (Figure 5-2) makes a copy of a file. This utility can copy any file, including text and executable program (binary) files. You can use `cp` to make a backup copy of a file or a copy to experiment with.

The `cp` command line uses the following syntax to specify source and destination files:

*cp source-file destination-file*

The *source-file* is the name of the file that `cp` will copy. The *destination-file* is the name that `cp` assigns to the resulting (new) copy of the file.

The `cp` command line in Figure 5-2 copies the file named `memo` to `memo.copy`. The period is part of the filename—just another character. The initial `ls` command shows that `memo` is the only file in the directory. After the `cp` command, a second `ls` shows two files in the directory, `memo` and `memo.copy`.

```
$ ls
memo
$ cp memo memo.copy
$ ls
memo memo.copy
```

**Figure 5-2** `cp` copies a file

Sometimes it is useful to incorporate the date in the name of a copy of a file. The following example includes the date January 30 (**0130**) in the copied file:

```
$ cp memo memo.0130
```

Although it has no significance to Linux, the date can help you find a version of a file that you created on a certain date. Including the date can also help you avoid overwriting existing files by providing a unique filename each day. For more information refer to “Filenames” on page 189.

Use `scp` (page 625) or `ftp` (page 643) when you need to copy a file from one system to another on a common network.

---

### **cp can destroy a file**

**caution** If the *destination-file* exists *before* you give a `cp` command, `cp` overwrites it. Because `cp` overwrites (and destroys the contents of) an existing *destination-file* without warning, you must take care not to cause `cp` to overwrite a file that you still need. The `cp -i` (interactive) option prompts you before it overwrites a file. See page 126 for a tip on options.

The following example assumes that the file named **orange.2** exists before you give the `cp` command. The user answers **y** to overwrite the file:

```
$ cp -i orange orange.2
cp: overwrite 'orange.2'? y
```

---

## **mv: CHANGES THE NAME OF A FILE**

The `mv` (move) utility can rename a file without making a copy of it. The `mv` command line specifies an existing file and a new filename using the same syntax as `cp`:

*mv existing-filename new-filename*

The command line in Figure 5-3 changes the name of the file **memo** to **memo.0130**. The initial `ls` command shows that **memo** is the only file in the directory. After you give the `mv` command, **memo.0130** is the only file in the directory. Compare this result to that of the earlier `cp` example.

The `mv` utility can be used for more than changing the name of a file. Refer to “`mv`, `cp`: Move or Copy Files” on page 201. See the `mv` info page for more information.

---

### **mv can destroy a file**

**caution** Just as `cp` can destroy a file, so can `mv`. Also like `cp`, `mv` has a `-i` (interactive) option. See the caution box labeled “`cp` can destroy a file.”

---

```
$ ls
memo
$ mv memo memo.0130
$ ls
memo.0130
```

**Figure 5-3** `mv` renames a file

## lpr: PRINTS A FILE

The `lpr` (line printer) utility places one or more files in a print queue for printing. Linux provides print queues so that only one job is printed on a given printer at a time. A queue allows several people or jobs to send output simultaneously to a single printer with the expected results. On systems that have access to more than one printer, you can use `lpstat -p` to display a list of available printers. Use the `-P` option to instruct `lpr` to place the file in the queue for a specific printer—even one that is connected to another system on the network. The following command prints the file named `report`:

```
$ lpr report
```

Because this command does not specify a printer, the output goes to the default printer, which is *the* printer when you have only one printer.

The next command line prints the same file on the printer named `mailroom`:

```
$ lpr -P mailroom report
```

You can see which jobs are in the print queue by giving an `lpstat -o` command or by using the `lpq` utility:

```
$ lpq
lp is ready and printing
Rank  Owner   Job Files                      Total Size
active alex    86 (standard input)          954061 bytes
```

In this example, Alex has one job that is being printed; no other jobs are in the queue. You can use the job number (86 in this case) with the `lprm` utility to remove the job from the print queue and stop it from printing:

```
$ lprm 86
```

You can send more than one file to the printer with a single command. The following command line prints three files on the printer named `laser1`:

```
$ lpr -P laser1 05.txt 108.txt 12.txt
```

Refer to Chapter 14 for information on setting up a printer and defining the default printer.

## grep: SEARCHES FOR A STRING

The `grep`<sup>1</sup> utility searches through one or more files to see whether any contain a specified string of characters. This utility does not change the file it searches but simply displays each line that contains the string.

---

1. Originally the name `grep` was a play on an `ed`—an original UNIX editor, available on Fedora/RHEL—command: `g/re/p`. In this command `g` stands for global, `re` is a regular expression delimited by slashes, and `p` means print.

```
$ cat memo

Helen:

In our meeting on June 6 we
discussed the issue of credit.
Have you had any further thoughts
about it?

                                Alex
$ grep 'credit' memo
discussed the issue of credit.
```

**Figure 5-4** `grep` searches for a string

The `grep` command in Figure 5-4 searches through the file `memo` for lines that contain the string `credit` and displays a single line that meets this criterion. If `memo` contained such words as `discredit`, `creditor`, or `accreditation`, `grep` would have displayed those lines as well because they contain the string it was searching for. The `-w` option causes `grep` to match only whole words. Although you do not need to enclose the string you are searching for in single quotation marks, doing so allows you to put SPACES and special characters in the search string.

The `grep` utility can do much more than search for a simple string in a single file. Refer to the `grep` info page and Appendix A, “Regular Expressions,” for more information.

## head: DISPLAYS THE BEGINNING OF A FILE

By default the `head` utility displays the first ten lines of a file. You can use `head` to help you remember what a particular file contains. For example, if you have a file named `months` that lists the 12 months of the year in calendar order, one to a line, then `head` displays `Jan` through `Oct` (Figure 5-5).

This utility can display any number of lines, so you can use it to look at only the first line of a file, at a full screen, or even more. To specify the number of lines displayed, include a hyphen followed by the number of lines in the `head` command. For example, the following command displays only the first line of `months`:

```
$ head -1 months
Jan
```

The `head` utility can also display parts of a file based on a count of blocks or characters rather than lines. Refer to the `head` info page for more information.

## tail: DISPLAYS THE END OF A FILE

The `tail` utility is similar to `head` but by default displays the *last* ten lines of a file. Depending on how you invoke it, this utility can display fewer or more than ten lines, use a count of blocks or characters rather than lines to display parts of a file,

```
$ cat months
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

$ head months
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
```

**Figure 5-5** head displays the first ten lines of a file

and display lines being added to a file that is changing. The following command causes tail to display the last five lines, **Aug** through **Dec**, of the **months** file shown in Figure 5-5:

```
$ tail -5 months
Aug
Sep
Oct
Nov
Dec
```

You can monitor lines as they are added to the end of the growing file named **logfile** with the following command:

```
$ tail -f logfile
```

Press the interrupt key (usually **CONTROL-C**) to stop tail and display the shell prompt. Refer to the tail info page for more information.

## sort: DISPLAYS A FILE IN ORDER

The sort utility displays the contents of a file in order by lines but does not change the original file. For example, if a file named **days** contains the name of each day of

```
$ cat days
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
$ sort days
Friday
Monday
Saturday
Sunday
Thursday
Tuesday
Wednesday
```

**Figure 5-6** sort displays the lines of a file in order

the week in calendar order, each on a separate line, then `sort` displays the file in alphabetical order (Figure 5-6).

The `sort` utility is useful for putting lists in order. The `-u` option generates a sorted list in which each line is unique (no duplicates). The `-n` option puts a list of numbers in order. Refer to the `sort` info page for more information.

## uniq: REMOVES DUPLICATE LINES FROM A FILE

The `uniq` (unique) utility displays a file, skipping adjacent duplicate lines, but does not change the original file. If a file contains a list of names and has two successive entries for the same person, `uniq` skips the extra line (Figure 5-7).

If a file is sorted before it is processed by `uniq`, this utility ensures that no two lines in the file are the same. (Of course, `sort` can do that all by itself with the `-u` option.) Refer to the `uniq` info page for more information.

```
$ cat dups
Cathy
Fred
Joe
John
Mary
Mary
Paula
$ uniq dups
Cathy
Fred
Joe
John
Mary
Paula
```

**Figure 5-7** `uniq` removes duplicate lines



```
$ diff -u colors.1 colors.2
--- colors.1      Tue Nov 25 15:45:32 2008
+++ colors.2      Tue Nov 25 15:24:46 2008
@@ -1,6 +1,5 @@
    red
+blue
    green
    yellow
-pink
-purple
    orange
```

**Figure 5-8** diff displaying the unified output format

## diff: COMPARES TWO FILES

The **diff** (difference) utility compares two files and displays a list of the differences between them. This utility does not change either file, so it is useful when you want to compare two versions of a letter or a report or two versions of the source code for a program.

The **diff** utility with the **-u** (unified output format) option first displays two lines indicating which of the files you are comparing will be denoted by a plus sign (+) and which by a minus sign (-). In Figure 5-8, a minus sign indicates the **colors.1** file; a plus sign indicates the **colors.2** file.

The **diff -u** command breaks long, multiline text into *hunks*. Each hunk is preceded by a line starting and ending with two at signs (@@). This hunk identifier indicates the starting line number and the number of lines from each file for this hunk. In Figure 5-8, the hunk covers the section of the **colors.1** file (indicated by a minus sign) from the first line through the sixth line. The **+1,5** then indicates that the hunk covers **colors.2** from the first line through the fifth line.

Following these header lines, **diff -u** displays each line of text with a leading minus sign, a leading plus sign, or nothing. A leading minus sign indicates that the line occurs only in the file denoted by the minus sign. A leading plus sign indicates that the line comes from the file denoted by the plus sign. A line that begins with neither a plus sign nor a minus sign occurs in both files in the same location. Refer to the **diff** info page for more information.

## file: TESTS THE CONTENTS OF A FILE

You can use the **file** utility to learn about the contents of any file on a Linux system without having to open and examine the file yourself. In the following example, **file** reports that **letter\_e.bz2** contains data that was compressed by the **bzip2** utility (page 162):

```
$ file letter_e.bz2
letter_e.bz2: bzip2 compressed data, block size = 900k
```

Next file reports on two more files:

```
$ file memo zach.jpg
memo:      ASCII text
zach.jpg:  JPEG image data, ... resolution (DPI), 72 x 72
```

Refer to the file man page for more information.

---

## | (PIPE): COMMUNICATES BETWEEN PROCESSES

Because pipes are integral to the functioning of a Linux system, they are introduced here for use in examples. Pipes are covered in detail beginning on page 238.

A *process* is the execution of a command by Linux (page 314). Communication between processes is one of the hallmarks of both UNIX and Linux. A *pipe* (written as a vertical bar, |, on the command line and appearing as a solid or broken vertical line on keyboards) provides the simplest form of this kind of communication. Simply put, a pipe takes the output of one utility and sends that output as input to another utility. Using UNIX/Linux terminology, a pipe takes standard output of one process and redirects it to become standard input of another process. (For more information refer to “Standard Input and Standard Output” on page 230.) Most of what a process displays on the screen is sent to standard output. If you do not redirect it, this output appears on the screen. Using a pipe, you can redirect the output so that it becomes instead standard input of another utility. For example, a utility such as `head` can take its input from a file whose name you specify on the command line following the word `head`, or it can take its input from standard input. Thus, you can give the command shown in Figure 5-5 on page 155 as follows:

```
$ cat months | head
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
```

The next command displays the number of files in a directory. The `wc` (word count) utility with the `-w` option displays the number of words in its standard input or in a file you specify on the command line:

```
$ ls | wc -w
14
```

You can use a pipe to send output of a program to the printer:

```
$ tail months | lpr
```

```
$ ls
memo memo.0714 practice
$ echo Hi
Hi
$ echo This is a sentence.
This is a sentence.
$ echo star: *
star: memo memo.0714 practice
$
```

**Figure 5-9** echo copies the command line (but not the word **echo**) to the screen

## FOUR MORE UTILITIES

The **echo** and **date** utilities are two of the most frequently used members of the large collection of Linux utilities. The **script** utility records part of a session in a file, and **unix2dos** makes a copy of a text file that can be read on either a Windows or a Macintosh machine.

### echo: DISPLAYS TEXT

The **echo** utility copies anything you put on the command line after **echo** to the screen. Some examples appear in Figure 5-9. The last example shows what the shell does with an unquoted asterisk (\*) on the command line: It expands the asterisk into a list of filenames in the directory.

The **echo** utility is a good tool for learning about the shell and other Linux programs. Some examples on page 244 use **echo** to illustrate how special characters, such as the asterisk, work. Throughout Chapters 7, 9, and 27, **echo** helps explain how shell variables work and how you can send messages from shell scripts to the screen. Refer to the **echo** info page for more information.

### date: DISPLAYS THE TIME AND DATE

The **date** utility displays the current date and time:

```
$ date
Tue Feb  5 14:41:11 PST 2008
```

The following example shows how you can choose the format and select the contents of the output of **date**:

```
$ date +"%A %B %d"
Tuesday February 05
```

Refer to the **date** info page for more information.

## script: RECORDS A SHELL SESSION

The `script` utility records all or part of a login session, including your input and the system's responses. This utility is useful only from character-based devices, such as a terminal or a terminal emulator. It does capture a session with `vim`; however, because `vim` uses control characters to position the cursor and display different typefaces, such as bold, the output will be difficult to read and may not be useful. When you `cat` a file that has captured a `vim` session, the session quickly passes before your eyes.

By default `script` captures the session in a file named **typescript**. To use a different filename, follow the `script` command with a `SPACE` and the new filename. To append to a file, use the `-a` option after **script** but before the filename; otherwise `script` overwrites an existing file. Following is a session being recorded by `script`:

```
$ script
Script started, file is typescript
$ date
Sun Jan 20 10:28:56 PST 2008
$ who am i
alex      pts/4    Jan  8 22:15
$ apropos vim
vim (1)           - Vi IMproved, a programmers text editor
vimdiff (1)       - edit two or three versions of a file with ...
vimtutor (1)      - the vim tutor
$ exit
Script done, file is typescript
$
```

Use the `exit` command to terminate a `script` session. You can then view the file you created with `cat`, `less`, `more`, or an editor. Following is the file that was created by the preceding `script` command:

```
$ cat typescript
Script started on Sun Jan 20 10:28:44 2008
$ date
Sun Jan 20 10:28:56 PST 2008
$ who am i
alex      pts/4    Jan  8 22:15
$ apropos vim
vim (1)           - Vi IMproved, a programmers text editor
vimdiff (1)       - edit two or three versions of a file with ...
vimtutor (1)      - the vim tutor
$ exit
Script done on Sun Jan 20 10:29:58 2008
$
```

If you will be editing the file with `vim`, `emacs`, or another editor, you can use `dos2unix` to eliminate from the **typescript** file the `^M` characters that appear at the ends of the lines. Refer to the `script` man page for more information.

## unix2dos: CONVERTS LINUX AND MACINTOSH FILES TO WINDOWS FORMAT

If you want to share a text file that you created on a Linux system with someone on a Windows or Macintosh system, you need to convert the file before the person on the other system can read it easily. The `unix2dos` utility converts a Linux text file so that it can be read on a Windows or Macintosh system. Give the following command to convert a file named `memo.txt` (created with a text editor) to a DOS-format file:

```
$ unix2dos memo.txt
```

Without any options `unix2dos` overwrites the original file. You can now email the file as an attachment to someone on a Windows or Macintosh system.

`dos2unix` You can use the `dos2unix` utility to convert Windows or Macintosh files so they can be read on a Linux system:

```
$ dos2unix memo.txt
```

See the `unix2dos` and `dos2unix` man pages for more information.

You can also use `tr` to change a Windows or Macintosh text file into a Linux text file. In the following example, the `-d` option causes `tr` to remove RETURNS (represented by `\r`) as it makes a copy of the file:

```
$ cat memo | tr -d '\r' > memo.txt
```

The greater than (`>`) symbol redirects the standard output of `tr` to the file named `memo.txt`. For more information refer to “Redirecting Standard Output” on page 232. Converting a file the other way without using `unix2dos` is not as easy.

---

## COMPRESSING AND ARCHIVING FILES

Large files use a lot of disk space and take longer than smaller files to transfer from one system to another over a network. If you do not need to look at the contents of a large file very often, you may want to save it on a CD, DVD, or another medium and remove it from the hard disk. If you have a continuing need for the file, retrieving a copy from a CD may be inconvenient. To reduce the amount of disk space you use without removing the file entirely, you can compress the file without losing any of the information it holds. Similarly a single archive of several files packed into a larger file is easier to manipulate, upload, download, and email than multiple files. You may frequently download compressed, archived files from the Internet. The utilities described in this section compress and decompress files and pack and unpack archives.

## bzip2: COMPRESSES A FILE

The **bzip2** utility compresses a file by analyzing it and recoding it more efficiently. The new version of the file looks completely different. In fact, because the new file contains many nonprinting characters, you cannot view it directly. The **bzip2** utility works particularly well on files that contain a lot of repeated information, such as text and image data, although most image data is already in a compressed format.

The following example shows a boring file. Each of the 8,000 lines of the **letter\_e** file contains 72 e's and a **NEWLINE** character that marks the end of the line. The file occupies more than half a megabyte of disk storage.

```
$ ls -l
-rw-rw-r-- 1 sam sam 584000 Mar  1 22:31 letter_e
```

The **-l** (long) option causes **ls** to display more information about a file. Here it shows that **letter\_e** is 584,000 bytes long. The **--verbose** (or **-v**) option causes **bzip2** to report how much it was able to reduce the size of the file. In this case, it shrank the file by 99.99 percent:

```
$ bzip2 -v letter_e
letter_e: 11680.00:1, 0.001 bits/byte, 99.99% saved, 584000 in, 50 out.
$ ls -l
-rw-rw-r-- 1 sam sam 50 Mar  1 22:31 letter_e.bz2
```

**.bz2 filename extension** Now the file is only 50 bytes long. The **bzip2** utility also renamed the file, appending **.bz2** to its name. This naming convention reminds you that the file is compressed; you would not want to display or print it, for example, without first decompressing it. The **bzip2** utility does not change the modification date associated with the file, even though it completely changes the file's contents.

In the following, more realistic example, the file **zach.jpg** contains a computer graphics image:

```
$ ls -l
-rw-r--r-- 1 sam sam 33287 Mar  1 22:40 zach.jpg
```

The **bzip2** utility can reduce the size of the file by only 28 percent because the image is already in a compressed format:

```
$ bzip2 -v zach.jpg
zach.jpg: 1.391:1, 5.749 bits/byte, 28.13% saved, 33287 in, 23922 out.
$ ls -l
-rw-r--r-- 1 sam sam 23922 Mar  1 22:40 zach.jpg.bz2
```

Refer to the **bzip2** man page, [www.bzip.org](http://www.bzip.org), and the *Bzip2 mini-HOWTO* (see page 130) for more information.

## bunzip2 AND bzipcat: DECOMPRESS A FILE

You can use the **bunzip2** utility to restore a file that has been compressed with **bzip2**:

```
$ bunzip2 letter_e.bz2
$ ls -l
-rw-rw-r-- 1 sam sam 584000 Mar 1 22:31 letter_e

$ bunzip2 zach.jpg.bz2
$ ls -l
-rw-r--r-- 1 sam sam 33287 Mar 1 22:40 zach.jpg
```

The `bzcat` utility displays a file that has been compressed with `bzip2`. The equivalent of `cat` for `.bz2` files, `bzcat` decompresses the compressed data and displays the contents of the decompressed file. Like `cat`, `bzcat` does not change the source file. The pipe in the following example redirects the output of `bzcat` so that instead of being displayed on the screen it becomes the input to `head`, which displays the first two lines of the file:

```
$ bzcat letter_e.bz2 | head -2
ee
ee
```

After `bzcat` is run, the contents of `letter_e.bz` is unchanged; the file is still stored on the disk in compressed form.

`bzip2recover` The `bzip2recover` utility supports limited data recovery from media errors. Give the command `bzip2recover` followed by the name of the compressed, corrupted file from which you want to try to recover data.

## gzip: COMPRESSES A FILE

`gunzip` and `zcat` The `gzip` (GNU zip) utility is older and less efficient than `bzip2`. Its flags and operation are very similar to those of `bzip2`. A file compressed by `gzip` is marked by a `.gz` filename extension. Linux stores manual pages in `gzip` format to save disk space; likewise, files you download from the Internet are frequently in `gzip` format. Use `gzip`, `gunzip`, and `zcat` just as you would use `bzip2`, `bunzip2`, and `bzcat`, respectively. Refer to the `gzip` info page for more information.

`compress` The `compress` utility can also compress files, albeit not as well as `gzip`. This utility marks a file it has compressed by adding `.Z` to its name.

### gzip versus zip

**tip** Do not confuse `gzip` and `gunzip` with the `zip` and `unzip` utilities. These last two are used to pack and unpack `zip` archives containing several files compressed into a single file that has been imported from or is being exported to a system running Windows. The `zip` utility constructs a `zip` archive, whereas `unzip` unpacks `zip` archives. The `zip` and `unzip` utilities are compatible with PKZIP, a Windows program that compresses and archives files.

## tar: PACKS AND UNPACKS ARCHIVES

The `tar` utility performs many functions. Its name is short for *tape archive*, as its original function was to create and read archive and backup tapes. Today it is used to create a single file (called a *tar file*, *archive*, or *tarball*) from multiple files or directory hierarchies and to extract files from a `tar` file. The `cpio` utility performs a similar function.

In the following example, the first `ls` shows the existence and sizes of the files `g`, `b`, and `d`. Next `tar` uses the `-c` (create), `-v` (verbose), and `-f` (write to or read from a file) options<sup>2</sup> to create an archive named `all.tar` from these files. Each line output displays the name of the file `tar` is appending to the archive it is creating.

The `tar` utility adds overhead when it creates an archive. The next command shows that the archive file `all.tar` occupies about 9,700 bytes, whereas the sum of the sizes of the three files is about 6,000 bytes. This overhead is more appreciable on smaller files, such as the ones in this example:

```
$ ls -l g b d
-rw-r--r-- 1 jenny jenny 1302 Aug 20 14:16 g
-rw-r--r-- 1 jenny other 1178 Aug 20 14:16 b
-rw-r--r-- 1 jenny jenny 3783 Aug 20 14:17 d

$ tar -cvf all.tar g b d
g
b
d
$ ls -l all.tar
-rw-r--r-- 1 jenny jenny 9728 Aug 20 14:17 all.tar
$ tar -tvf all.tar
-rw-r--r-- jenny/jenny 1302 2008-08-20 14:16 g
-rw-r--r-- jenny/other 1178 2008-08-20 14:16 b
-rw-r--r-- jenny/jenny 3783 2008-08-20 14:17 d
```

The final command in the preceding example uses the `-t` option to display a table of contents for the archive. Use `-x` instead of `-t` to extract files from a `tar` archive. Omit the `-v` option if you want `tar` to do its work silently.

You can use `bzip2`, `compress`, or `gzip` to compress `tar` files, making them easier to store and handle. Many files you download from the Internet will already be in one of these formats. Files that have been processed by `tar` and compressed by `bzip2` frequently have a filename extension of `.tar.bz2` or `.tbz`. Those processed by `tar` and `gzip` have an extension of `.tar.gz` or `.tz`, whereas files processed by `tar` and `compress` use `.tar.Z` as the extension.

You can unpack a tarred and gzipped file in two steps. (Follow the same procedure if the file was compressed by `bzip2`, but use `bunzip2` instead of `gunzip`.) The next example shows how to unpack the GNU `make` utility after it has been downloaded ([ftp.gnu.org/pub/gnu/make/make-3.80.tar.gz](http://ftp.gnu.org/pub/gnu/make/make-3.80.tar.gz)):

```
$ ls -l mak*
-rw-rw-r-- 1 sam sam 1211924 Jan 20 11:49 make-3.80.tar.gz

$ gunzip mak*
$ ls -l mak*
-rw-rw-r-- 1 sam sam 4823040 Jan 20 11:49 make-3.80.tar
```

---

2. Although the original UNIX `tar` did not use a leading hyphen to indicate an option on the command line, it now accepts hyphens. The GNU `tar` described here will accept `tar` commands with or without a leading hyphen. This book uses the hyphen for consistency with most other utilities.



```
$ tar -xvf mak*
make-3.80/
make-3.80/po/
make-3.80/po/Makefile.in.in
...
make-3.80/tests/run_make_tests.pl
make-3.80/tests/test_driver.pl
```

The first command lists the downloaded tarred and gzipped file: **make-3.80.tar.gz** (about 1.2 megabytes). The asterisk (\*) in the filename matches any characters in any filenames (page 244), so you end up with a list of files whose names begin with **mak**; in this case there is only one. Using an asterisk saves typing and can improve accuracy with long filenames. The **gunzip** command decompresses the file and yields **make-3.80.tar** (no **.gz** extension), which is about 4.8 megabytes. The **tar** command creates the **make-3.80** directory in the working directory and unpacks the files into it.

```
$ ls -ld mak*
drwxrwxr-x  8 sam sam   4096 Oct  3  2002 make-3.80
-rw-rw-r--  1 sam sam 4823040 Jan 20 11:49 make-3.80.tar
$ ls -l make-3.80
total 1816
-rw-r--r--  1 sam sam   24687 Oct  3  2002 ABOUT-NLS
-rw-r--r--  1 sam sam   1554 Jul  8  2002 AUTHORS
-rw-r--r--  1 sam sam   18043 Dec 10  1996 COPYING
-rw-r--r--  1 sam sam   32922 Oct  3  2002 ChangeLog
...
-rw-r--r--  1 sam sam   16520 Jan 21  2000 vmsify.c
-rw-r--r--  1 sam sam   16409 Aug  9  2002 vpath.c
drwxrwxr-x  5 sam sam   4096 Oct  3  2002 w32
```

After **tar** extracts the files from the archive, the working directory contains two files whose names start with **mak**: **make-3.80.tar** and **make-3.80**. The **-d** (directory) option causes **ls** to display only file and directory names, not the contents of directories as it normally does. The final **ls** command shows the files and directories in the **make-3.80** directory. Refer to the **tar** info page for more information.

### tar: the **-x** option may extract a lot of files

**caution** Some tar archives contain many files. To list the files in the archive without unpacking them, run **tar** with the **-t** option and the name of the tar file. In some cases you may want to create a new directory (**mkdir** [page 195]), move the tar file into that directory, and expand it there. That way the unpacked files will not mingle with your existing files, and no confusion will occur. This strategy also makes it easier to delete the extracted files. Some tar files automatically create a new directory and put the files into it. Refer to the preceding example.

### tar: the **-x** option can overwrite files

**caution** The **-x** option to **tar** overwrites a file that has the same filename as a file you are extracting. Follow the suggestion in the preceding caution box to avoid overwriting files.

**optional** You can combine the `gunzip` and `tar` commands on one command line with a pipe (`|`), which redirects the output of `gunzip` so that it becomes the input to `tar`:

```
$ gunzip -c make-3.80.tar.gz | tar -xvf -
```

The `-c` option causes `gunzip` to send its output through the pipe instead of creating a file. Refer to “Pipes” (page 238) and `gzip` (page 163) for more information about how this command line works.

A simpler solution is to use the `-z` option to `tar`. This option causes `tar` to call `gunzip` (or `gzip` when you are creating an archive) directly and simplifies the preceding command line to

```
$ tar -xvzf make-3.80.tar.gz
```

In a similar manner, the `-j` option calls `bzip2` or `bunzip2`.

## LOCATING COMMANDS

The `whereis` and `apropos` utilities can help you find a command whose name you have forgotten or whose location you do not know. When multiple copies of a utility or program are present, which tells you which copy you will run. The `locate` utility searches for files on the local system.

### which AND whereis: LOCATE A UTILITY

When you give Linux a command, the shell searches a list of directories for a program with that name and runs the first one it finds. This list of directories is called a *search path*. For information on how to change the search path, refer to “PATH: Where the Shell Looks for Programs” on page 306. If you do not change the search path, the shell searches only a standard set of directories and then stops searching. Other directories on the system may also contain useful utilities, however.

**which** The `which` utility locates utilities by displaying the full pathname of the file for the utility. (Chapter 6 contains more information on pathnames and the structure of the Linux filesystem.) The local system may include several commands that have the same name. When you type the name of a command, the shell searches for the command in your search path and runs the first one it finds. You can find out which copy of the program the shell will run by using `which`. In the following example, `which` reports the location of the `tar` command:

```
$ which tar
/bin/tar
```

The `which` utility can be helpful when a command seems to be working in unexpected ways. By running `which`, you may discover that you are running a non-standard version of a tool or a different one than you expected. (“Important

Standard Directories and Files” on page 198 provides a list of standard locations for executable files.) For example, if `tar` is not working properly and you find that you are running `/usr/local/bin/tar` instead of `/bin/tar`, you might suspect that the local version is broken.

### which, whereis, and builtin commands

**caution** Both the `which` and `whereis` utilities report only the names for commands as they are found on the disk; they do not report shell builtins (utilities that are built into a shell; see page 247). When you use `whereis` to try to find where the `echo` command (which exists as both a utility program and a shell builtin) is kept, you get the following result:

```
$ whereis echo
echo: /bin/echo /usr/share/man/man1/echo.1.gz
```

The `whereis` utility does not display the `echo` builtin. Even the `which` utility reports the wrong information:

```
$ which echo
/bin/echo
```

Under `bash` you can use the `type` builtin (page 937) to determine whether a command is a builtin:

```
$ type echo
echo is a shell builtin
```

**whereis** The `whereis` utility searches for files related to a utility by looking in standard locations instead of using your search path. For example, you can find the locations for files related to `tar`:

```
$ whereis tar
tar: /bin/tar /usr/share/man/man1/tar.1.gz
```

In this example `whereis` finds two references to `tar`: the `tar` utility file and the `tar` man page.

### which versus whereis

**tip** Given the name of a program, `which` looks through the directories in your *search path*, in order, and locates the program. If the search path includes more than one program with the specified name, `which` displays the name of only the first one (the one you would run).

The `whereis` utility looks through a list of *standard directories* and works independently of your search path. Use `whereis` to locate a binary (executable) file, any manual pages, and source code for a program you specify; `whereis` displays all the files it finds.

## apropos: SEARCHES FOR A KEYWORD

When you do not know the name of the command you need to carry out a particular task, you can use `apropos` with a keyword to search for it. This utility searches for the keyword in the short description line (the top line) of all man pages and displays those that contain a match. The `man` utility, when called with the `-k` (keyword) option, gives you the same output as `apropos` (it is the same command).

The database `apropos` uses, named **whatis**, is not on Fedora/RHEL systems when they are first installed, but is built automatically by `cron` (page 565) using `makewhatis`. (The `cron` utility runs the `/etc/cron.weekly/makewhatis.cron` script to build the **whatis** database.) If you turn the system off periodically (as with a laptop), the script may not be run. If `apropos` does not produce any output, run the command `makewhatis -w` as `root`.

The following example shows the output of `apropos` when you call it with the **who** keyword. The output includes the name of each command, the section of the manual that contains it, and the brief description from the top of the `man` page. This list includes the utility that you need (`who`) and identifies other, related tools that you might find useful:

```
$ apropos who
at.allow [at]      (5) - determine who can submit jobs via at or batch
at.deny [at]      (5) - determine who can submit jobs via at or batch
jwhois            (1) - client for the whois service
ldapwhoami        (1) - LDAP who am i? tool
w                 (1) - Show who is logged on and what they are doing
who               (1) - show who is logged on
whoami            (1) - print effective userid

whatis The whatis utility is similar to apropos but finds only complete word matches for the
name of the utility:

$ whatis who
who                (1) - show who is logged on
```

## locate: SEARCHES FOR A FILE

The `locate` utility searches for files on the local system:

```
$ locate motd
/etc/motd
/lib/security/pam_motd.so
/usr/share/doc/pam-1.1.0/html/sag-pam_motd.html
/usr/share/doc/pam-1.1.0/txts/README.pam_motd
/usr/share/man/man8/pam_motd.8.gz
```

Before you can use `locate` the `updatedb` utility must build or update the `locate` database. Typically the database is updated once a day by a `cron` script (page 565).

### If you are not on a network, skip the rest of this chapter

---

**tip** If you are the only user on a system that is not connected to a network, you may want to skip the rest of this chapter. If you are not on a network but are set up to send and receive email, read “Email” on page 174.

---

---

## OBTAINING USER AND SYSTEM INFORMATION

This section covers utilities that provide information about who is using the system, what those users are doing, and how the system is running. To find out who is using

```
$ who
root      console    Mar 27 05:00
alex      pts/4       Mar 27 12:23
alex      pts/5       Mar 27 12:33
jenny     pts/7       Mar 26 08:45
```

**Figure 5-10** who lists who is logged in

the local system, you can employ one of several utilities that vary in the details they provide and the options they support. The oldest utility, `who`, produces a list of users who are logged in on the local system, the device each person is using, and the time each person logged in.

The `w` and `finger` utilities show more detail, such as each user's full name and the command line each user is running. You can use the `finger` utility to retrieve information about users on remote systems if your computer is attached to a network. Table 5-1 on page 172 summarizes the output of these utilities.

## who: LISTS USERS ON THE SYSTEM

The `who` utility displays a list of users who are logged in. In Figure 5-10 the first column that `who` displays shows that Alex and Jenny are logged in. (Alex is logged in from two locations.) The second column shows the device that each user's terminal, workstation, or terminal emulator is connected to. The third column shows the date and time the user logged in. An optional fourth column shows (in parentheses) the name of the system that a remote user logged in from; this column does not appear in Figure 5-10.

The information that `who` displays is useful when you want to communicate with a user at your installation. When the user is logged in, you can use `write` (page 172) to establish communication immediately. If `who` does not list the user or if you do not need to communicate immediately, you can send email to that person (page 174).

If the output of `who` scrolls off the screen, you can redirect the output through a pipe (`|`, page 158) so that it becomes the input to `less`, which displays the output one page at a time. You can also use a pipe to redirect the output through `grep` to look for a specific name.

If you need to find out which terminal you are using or what time you logged in, you can use the command `who am i`:

```
$ who am i
alex      pts/5       Mar 27 12:33
```

## finger: LISTS USERS ON THE SYSTEM

You can use `finger` to display a list of the users who are logged in on the system. In addition to usernames, `finger` supplies each user's full name along with information about which device the user's terminal is connected to, how recently the user typed something on the keyboard, when the user logged in, and what contact information

```
$ finger
Login  Name           Tty  Idle  Login Time   Office   Office Phone
root   root             1    1:35  May 24 08:38
alex   Alex Watson      /0           Jun  7 12:46 (:0)
alex   Alex Watson      /1    19    Jun  7 12:47 (:0)
jenn   Jenny Chen       /2    2:24  Jun  2 05:33 (bravo.example.com)
hls    Helen Simpson    */2     2    Jun  2 05:33 (bravo.example.com)
```

**Figure 5-11** finger I: lists who is logged in

is available. If the user has logged in over the network, the name of the remote system is shown as the user’s location. For example, in Figure 5-11 **jenny** and **hls** are logged in from the remote system named **bravo**. The asterisk (\*) in front of the name of Helen’s device (TTY) indicates that she has blocked others from sending messages directly to her terminal (refer to “mesg: Denies or Accepts Messages” on page 173).

**finger can be a security risk**

**security** On systems where security is a concern, the system administrator may disable **finger**. This utility can reveal information that can help a malicious user break into a system.

You can also use **finger** to learn more about an individual by specifying the name of that user on the command line. In Figure 5-12, **finger** displays detailed information about the user named Alex. Alex is logged in and actively using one of his terminals (**pts/1**); he has not used his other terminal (**pts/0**) for 5 minutes and 52 seconds. You also learn from **finger** that if you want to set up a meeting with Alex, you should contact Jenny at extension 1693.

**.plan and .project** Most of the information in Figure 5-12 was collected by **finger** from system files. The information shown after the heading **Plan:**, however, was supplied by Alex. The **finger** utility searched for a file named **.plan** in Alex’s home directory and displayed its contents. (Filenames that begin with a period, such as **.plan**, are not normally

```
$ finger alex
Login: alex                               Name: Alex Watson
Directory: /home/alex                     Shell: /bin/bash
On since Wed Jun  7 12:46 (PDT) on pts/0 from :0
5 minutes 52 seconds idle
On since Wed Jun  7 12:47 (PDT) on pts/1 from bravo
Last login Wed Jun  7 12:47 (PDT) on 1 from bravo
New mail received Sat Jun  7 13:16 2008 (PDT)
Unread since Mon May 26 15:32 2008 (PDT)
Plan:
I will be at a conference in Hawaii all next week.  If you need
to see me, contact Jenny Chen, x1693.
```

**Figure 5-12** finger II: lists details about one user

listed by `ls` and are called hidden filenames [page 192].) You may find it helpful to create a `.plan` file for yourself; it can contain any information you choose, such as your schedule, interests, phone number, or address. In a similar manner, `finger` displays the contents of the `.project` and `.pgpkey` files in your home directory. If Alex had not been logged in, `finger` would have reported only his user information, the last time he logged in, the last time he read his email, and his plan.

You can also use `finger` to display a user's username. For example, on a system with a user named Helen Simpson, you might know that Helen's last name is Simpson but might not guess that her username is `hls`. The `finger` utility, which is not case sensitive, can search for information on Helen using her first or last name. The following commands find the information you seek as well as information on other users whose names are Helen or Simpson:

```
$ finger HELEN
Login: hls                               Name: Helen Simpson.
...

$ finger simpson
Login: hls                               Name: Helen Simpson.
...
```

See page 374 for information about using `finger` over a network.

## W: LISTS USERS ON THE SYSTEM

The `w` utility displays a list of the users who are logged in. As discussed in the section on `who`, the information that `w` displays is useful when you want to communicate with someone at your installation.

The first column in Figure 5-13 shows that Alex, Jenny, and Scott are logged in. The second column shows the designation of the device that each user's terminal is connected to. The third column shows the system that a remote user is logged in from. The fourth column shows the time when each user logged in. The fifth column indicates how long each user has been idle (how much time has elapsed since the user pressed a key on the keyboard). The next two columns identify how much computer processor time each user has used during this login session and on the task that is running. The last column shows the command each user is running.

```
$ w
 8:20am up 4 days, 2:28, 3 users, load average: 0.04, 0.04, 0.00
USER  TTY      FROM            LOGIN@   IDLE   JCPU   PCPU   WHAT
alex   pts/4    :0               5:55am   13:45  0.15s  0.07s  w
alex   pts/5    :0               5:55am   27     2:55   1:01   bash
jenny  pts/7    bravo           5:56am   13:44  0.51s  30s    vim 3.txt
scott  pts/12   bravo           7:17pm   1.00s  0:14s  run_bdgt
```

**Figure 5-13** The `w` utility

The first line that the `w` utility displays includes the time of day, the period of time the computer has been running (in days, hours, and minutes), the number of users logged in, and the load average (how busy the system is). The three load average numbers represent the number of jobs waiting to run, averaged over the past 1, 5, and 15 minutes. Use the `uptime` utility to display just this line. Table 5-1 compares the `w`, `who`, and `finger` utilities.

**Table 5-1** Comparison of `w`, `who`, and `finger`

| Information displayed                                           | <code>w</code> | <code>who</code> | <code>finger</code> |
|-----------------------------------------------------------------|----------------|------------------|---------------------|
| Username                                                        | x              | x                | x                   |
| Terminal-line identification (tty)                              | x              | x                | x                   |
| Login day and time                                              | x              |                  |                     |
| Login date and time                                             |                | x                | x                   |
| Idle time                                                       | x              |                  | x                   |
| Program the user is executing                                   | x              |                  |                     |
| Location the user logged in from                                |                |                  | x                   |
| CPU time used                                                   | x              |                  |                     |
| Full name (or other information from <code>/etc/passwd</code> ) |                |                  | x                   |
| User-supplied vanity information                                |                |                  | x                   |
| System uptime and load average                                  | x              |                  |                     |

## COMMUNICATING WITH OTHER USERS

The utilities discussed in this section exchange messages and files with other users either interactively or through email.

### write: SENDS A MESSAGE

The `write` utility sends a message to another user who is logged in. When you and another user use `write` to send messages to each other, you establish two-way communication. Initially a `write` command (Figure 5-14) displays a banner on the other user's terminal, saying that you are about to send a message.

The syntax of a `write` command line is

```
write username [terminal]
```

The *username* is the username of the user you want to communicate with. The *terminal* is an optional device name that is useful if the user is logged in more



```
$ write alex
Hi Alex, are you there? o
```

**Figure 5-14** The write utility I

than once. You can display the usernames and device names of all users who are logged in on the local system by using `who`, `w`, or `finger`.

To establish two-way communication with another user, you and the other user must each execute `write`, specifying the other's username as the *username*. The `write` utility then copies text, line by line, from one keyboard/display to the other (Figure 5-15). Sometimes it helps to establish a convention, such as typing `o` (for “over”) when you are ready for the other person to type and typing `oo` (for “over and out”) when you are ready to end the conversation. When you want to stop communicating with the other user, press `CONTROL-D` at the beginning of a line. Pressing `CONTROL-D` tells `write` to quit, displays EOF (end of file) on the other user's terminal, and returns you to the shell. The other user must do the same.

If the **Message from** banner appears on your screen and obscures something you are working on, press `CONTROL-L` or `CONTROL-R` to refresh the screen and remove the banner. Then you can clean up, exit from your work, and respond to the person who is writing to you. You have to remember who is writing to you, however, because the banner will no longer appear on the screen.

## mesg: DENIES OR ACCEPTS MESSAGES

Give the following command when you do not wish to receive messages from another user:

```
$ mesg n
```

If Alex had given this command before Jenny tried to send him a message, Jenny would have seen the following message:

```
$ write alex
Permission denied
```

You can allow messages again by entering `mesg y`. Give the command `mesg` by itself to display `is y` (for “yes, messages are allowed”) or `is n` (for “no, messages are *not* allowed”).

```
$ write alex
Hi Alex, are you there? o

Message from alex@bravo.example.com on pts/0 at 16:23 ...
Yes Jenny, I'm here. o
```

**Figure 5-15** The write utility II

## EMAIL

Email enables you to communicate with users on the local system and, if the installation is part of a network, with other users on the network. If you are connected to the Internet, you can communicate electronically with users around the world.

Email utilities differ from `write` in that email utilities can send a message when the recipient is not logged in. These utilities can also send the same message to more than one user at a time.

Many email programs are available for Linux, including the original character-based mail program, Mozilla/Thunderbird, pine, mail through `emacs`, KMail, and `evolution`. Another popular graphical email program is `sylpheed` (`sylpheed.sraoss.jp/en`).

Two programs are available that can make any email program easier to use and more secure. The `procmail` program ([www.procmail.org](http://www.procmail.org)) creates and maintains email servers and mailing lists; preprocesses email by sorting it into appropriate files and directories; starts various programs depending on the characteristics of incoming email; forwards email; and so on. The GNU Privacy Guard (GPG or GPG, page 1048) encrypts and decrypts email and makes it almost impossible for an unauthorized person to read.

Refer to Chapter 20 for more information on setting email clients and servers.

Network addresses If your system is part of a LAN, you can generally send email to and receive email from users on other systems on the LAN by using their usernames. Someone sending Alex email on the Internet would need to specify his *domain name* (page 1080) along with his username. Use this address to send email to the author of this book: `mgs@sobell.com`.

---

## TUTORIAL: CREATING AND EDITING A FILE USING `vim`

This section explains how to start `vim`, enter text, move the cursor, correct text, save the file to the disk, and exit from `vim`. The tutorial discusses three of the modes of operation of `vim` and explains how to switch from one mode to another.

### The full version of `vim` is not installed by default

**tip** By default, Fedora/RHEL systems install a minimal build of `vim` that is run by the command `vi` (see the tip on the next page). The commands `vim` and `vimtutor` do not work. Working as `root` (page 408), give the following `yum` (page 500) command to install the full version of `vim`:

```
# yum install vim-enhanced
```

You can use the minimal build of `vim` to work through the examples in this chapter: Substitute the command `vi` for `vim` in the examples.

---

`vimtutor` In addition to working with this tutorial, you may want to try `vim`'s tutor, named `vimtutor`: Give its name as a command to run it.

Specifying a terminal Because vim takes advantage of features that are specific to various kinds of terminals, you must tell it what type of terminal or terminal emulator you are using. On many systems, and usually when you work on a terminal emulator, your terminal type is set automatically. If you need to specify your terminal type explicitly, refer to “Specifying a Terminal” on page 1040.

## STARTING vim

Start vim with the following command line to create and edit a file named **practice**:

```
$ vim practice
```

When you press RETURN, the command line disappears, and the screen looks similar to the one shown in Figure 5-16.

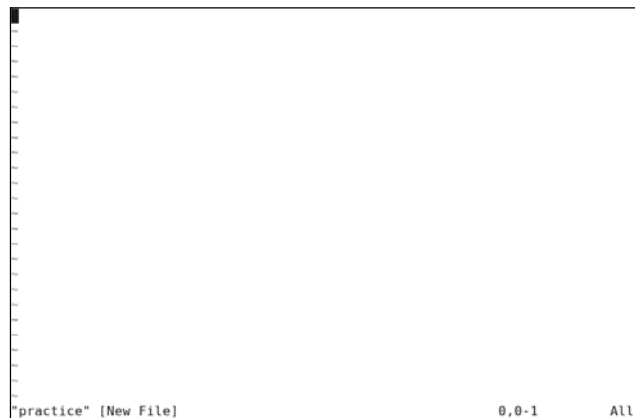
The tildes (~) at the left of the screen indicate that the file is empty. They disappear as you add lines of text to the file. If your screen looks like a distorted version of the one shown in Figure 5-16, your terminal type is probably not set correctly.

### The vi command runs vim

**tip** On Fedora/RHEL systems the command **vi** runs a minimal build of vim that is compact and faster to load than vim but includes fewer features. See “The compatible Parameter” on page 181 for information on running vim in vi-compatible mode.

If you start vim with a terminal type that is not in the **terminfo** database, vim displays an error message. In the following example, the user set the terminal type to one that is not in the database:

```
$ vim practice
E437: terminal capability "cm" required
Press ENTER or type command to continue :q!
```



**Figure 5-16** Starting vim

```

VIM - Vi IMproved
      version 7.2.245
    by Bram Moolenaar et al.
 Modified by <bugzilla@redhat.com>
 Vim is open source and freely distributable

  Sponsor Vim development!
type  :help sponsor<Enter>    for information

type  :q<Enter>                to exit
type  :help<Enter> or <F1>    for on-line help
type  :help version7<Enter>  for version info

                                0,0-1      All

```

**Figure 5-17** Starting vim without a filename

If you get this message, give the following command to exit from vim and get the shell prompt back:

**:q!**

Normally, when you enter the colon (:), vim moves the cursor to the bottom line of the screen (it does nothing in this case). The characters **q!** tell vim to quit without saving your work. (You will not ordinarily exit from vim this way because you typically want to save your work.) You must press RETURN after you give this command. Once you get the shell prompt back, refer to “Specifying a Terminal” on page 1040, and then start vim again.

If you start this editor without a filename, vim assumes that you are a novice and tells you how to get started (Figure 5-17).

The **practice** file is new so it does not contain any text. The vim editor displays a message similar to the one shown in Figure 5-16 on the status (bottom) line of the terminal to indicate that you are creating and editing a new file. When you edit an existing file, vim displays the first few lines of the file and gives status information about the file on the status line.

## COMMAND AND INPUT MODES

Two of vim’s modes of operation are *Command mode* (also called *Normal mode*) and *Input mode* (Figure 5-18). While vim is in Command mode, you can give vim commands. For example, you can delete text or exit from vim. You can also command vim to enter Input mode. In Input mode, vim accepts anything you enter as text and displays it on the screen. Press ESCAPE to return vim to Command mode. By default the vim editor keeps you informed about which mode it is in: It displays **INSERT** at the lower-left corner of the screen while it is in Insert mode.

The following command causes vim to display line numbers next to the text you are editing:

**:set number RETURN**

**Last Line mode** The colon (:) in the preceding command puts vim into another mode, *Last Line mode*. While in this mode, vim keeps the cursor on the bottom line of the screen. When you finish entering the command by pressing RETURN, vim restores the cursor to its place in the text. Give the command **:set nonumber RETURN** to turn off line numbers.

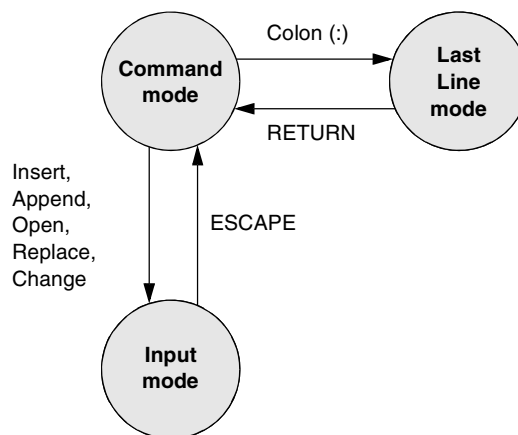
**vim is case sensitive** When you give vim a command, remember that the editor is case sensitive. In other words, vim interprets the same letter as two different commands, depending on whether you enter an uppercase or lowercase character. Beware of the CAPS LOCK (SHIFTLOCK) key. If you set this key to enter uppercase text while you are in Input mode and then exit to Command mode, vim interprets your commands as uppercase letters. It can be confusing when this happens because vim does not appear to be executing the commands you are entering.

## ENTERING TEXT

**i/a (Input mode)** When you start vim, you must put it in Input mode before you can enter text. To put vim in Input mode, press the **i** key (insert before the cursor) or the **a** key (append after the cursor).

If you are not sure whether vim is currently in Input mode, press the ESCAPE key; vim returns to Command mode if it was in Input mode or beeps, flashes, or does nothing if it is already in Command mode. You can put vim back in Input mode by pressing the **i** or **a** key again.

While vim is in Input mode, you can enter text by typing on the keyboard. If the text does not appear on the screen as you type, vim is not in Input mode.



**Figure 5-18** Modes in vim

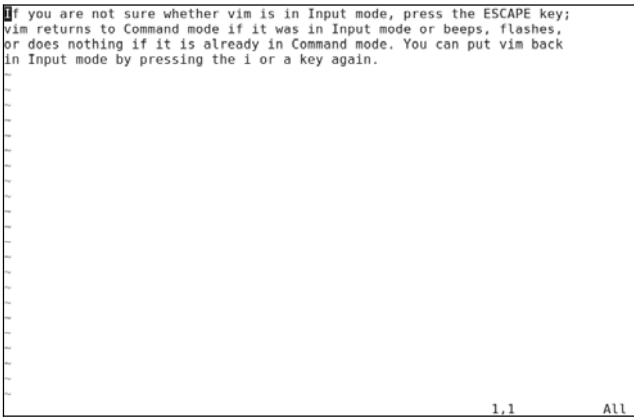


Figure 5-19    Entering text with vim

To continue with this tutorial, enter the sample paragraph shown in Figure 5-19, pressing the RETURN key at the end of each line. If you do not press RETURN before the cursor reaches the right side of the screen or window, vim will wrap the text so that it appears to start a new line. Physical lines will not correspond to programmatic (logical) lines in this situation, so editing will be more difficult. While you are using vim, you can always correct any typing mistakes you make. If you notice a mistake on the line you are entering, you can correct it before you continue (page 179). You can correct other mistakes later. When you finish entering the paragraph, press ESCAPE to return vim to Command mode.

GETTING HELP

To get help while you are using vim, give the command `:help [feature]` followed by RETURN (you must be in Command mode when you give this command). The colon

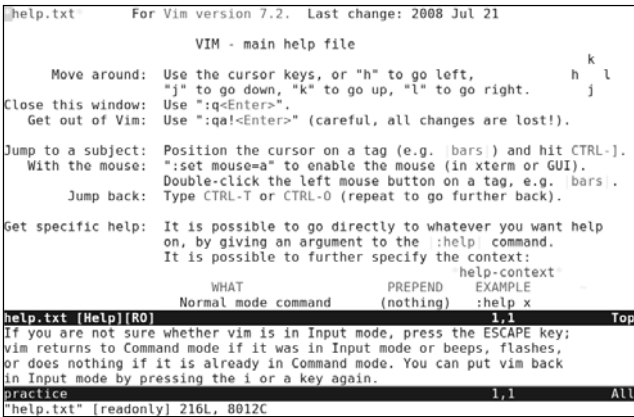


Figure 5-20    The main vim Help screen

moves the cursor to the last line of the screen. If you type **:help**, vim displays an introduction to vim Help (Figure 5-20). Each dark band near the bottom of the screen names the file that is displayed above it. (Each area of the screen that displays a file, such as the two areas shown in Figure 5-20, is a vim “window.”) The **help.txt** file occupies most of the screen (the upper window) in Figure 5-20. The file that is being edited (**practice**) occupies a few lines in the lower portion of the screen (the lower window).

Read through the introduction to Help by scrolling the text as you read. Press **j** or the DOWN ARROW key to move the cursor down one line at a time; press **CONTROL-D** or **CONTROL-U** to scroll the cursor down or up half a window at a time. Give the command **:q** to close the Help window.

You can get help with the insert commands by giving the command **:help insert** while vim is in Command mode (Figure 5-21).

## CORRECTING TEXT AS YOU INSERT IT

The keys that back up and correct a shell command line serve the same functions when vim is in Input mode. These keys include the erase, line kill, and word kill keys (usually **CONTROL-H**, **CONTROL-U**, and **CONTROL-W**, respectively). Although vim may not remove deleted text from the screen as you back up over it using one of these keys, the editor does remove it when you type over the text or press **RETURN**.

## MOVING THE CURSOR

You need to be able to move the cursor on the screen so that you can delete, insert, and correct text. While vim is in Command mode, you can use the **RETURN** key, the **SPACE** bar, and the **ARROW** keys to move the cursor. If you prefer to keep your hand closer to the center of the keyboard, if your terminal does not have **ARROW** keys, or if the emulator you are using does not support them, you can use the **h**, **j**, **k**, and **l** (lowercase “l”) keys to move the cursor left, down, up, and right, respectively.

```

<insert>      or      i  [insert]  <Insert>
i              Insert text before the cursor [count] times.
                When using CTRL-O in Insert mode i CTRL-O the count
                is not supported.

I              Insert text before the first non-blank in the line
                [count] times.
                When the 'H' flag is present in 'coptions' and the
                line only contains blanks, insert start just before
                the last blank.

gI            Insert text in column 1 [count] times. {not in Vi}

gi            Insert text in the same position as where Insert mode
                was stopped last time in the current buffer.
                This uses the '^' mark. It's different from '^i'
                when the mark is past the end of the line.
insert.txt.gz [Help][R0] 1656,20-53 88%
If you are not sure whether vim is in Input mode, press the ESCAPE key;
vim returns to Command mode if it was in Input mode or beeps, flashes,
or does nothing if it is already in Command mode. You can put vim back
in Input mode by pressing the i or a key again.
practice      1,1 All
insert.txt.gz" [readonly][noeol] 101L, 24257C

```

Figure 5-21 Help with insert commands

## DELETING TEXT

- x** (Delete character) You can delete a single character by moving the cursor until it is over the character you want to delete and then giving the command **x**. You can delete a word by positioning the cursor on the first letter of the word and then giving the command **dw** (Delete word) (Delete word). You can delete a line of text by moving the cursor until it is anywhere on the line and then giving the command **dd** (Delete line).

## UNDOING MISTAKES

- u** (Undo) If you delete a character, line, or word by mistake or give any command you want to reverse, give the command **u** (Undo) immediately after the command you want to undo. The vim editor will restore the text to the way it was before you gave the last command. If you give the **u** command again, vim will undo the command you gave before the one it just undid. You can use this technique to back up over many of your actions. With the **compatible** parameter (page 181) set, however, vim can undo only the most recent change.
- :redo** (Redo) If you undo a command you did not mean to undo, give a Redo command: **CONTROL-R** or **:redo** (followed by a **RETURN**). The vim editor will redo the undone command. As with the Undo command, you can give the Redo command many times in a row.

## ENTERING ADDITIONAL TEXT

- i** (Insert) When you want to insert new text within existing text, move the cursor so it is on the character that follows the new text you plan to enter. Then give the **i** (Insert) command to put vim in Input mode, enter the new text, and press **ESCAPE** to return vim to Command mode. Alternatively, you can position the cursor on the character that precedes the new text and use the **a** (Append) command.
- a** (Append)
- o/O** (Open) To enter one or more lines, position the cursor on the line above where you want the new text to go. Give the command **o** (Open). The vim editor opens a blank line, puts the cursor on it, and goes into Input mode. Enter the new text, ending each line with a **RETURN**. When you are finished entering text, press **ESCAPE** to return vim to Command mode. The **O** command works in the same way **o** works, except that it opens a blank line *above* the line the cursor is on.

## CORRECTING TEXT

To correct text, use **dd**, **dw**, or **x** to remove the incorrect text. Then use **i**, **a**, **o**, or **O** to insert the correct text.

For example, to change the word **pressing** to **hitting** in Figure 5-19 on page 178, you might use the **ARROW** keys to move the cursor until it is on top of the **p** in **pressing**. Then give the command **dw** to delete the word **pressing**. Put vim in Input mode by giving an **i** command, enter the word **hitting** followed by a **SPACE**, and press **ESCAPE**. The word is changed and vim is in Command mode, waiting for another command. A shorthand for the two commands **dw** followed by the **i** command is **cw** (Change word). The command **cw** puts vim into Input mode.



### Page breaks for the printer

**tip** `CONTROL-L` tells the printer to skip to the top of the next page. You can enter this character anywhere in a document by pressing `CONTROL-L` while you are in Input mode. If `^L` does not appear, press `CONTROL-V` before `CONTROL-L`.

---

## ENDING THE EDITING SESSION

While you are editing, vim keeps the edited text in an area named the *Work buffer*. When you finish editing, you must write out the contents of the Work buffer to a disk file so that the edited text is saved and available when you next want it.

Make sure that vim is in Command mode, and then use the `ZZ` command (you must use uppercase `Z`'s) to write your newly entered text to the disk and end the editing session. After you give the `ZZ` command, vim returns control to the shell. You can exit with `:q!` if you do not want to save your work.

### Do not confuse `ZZ` with `CONTROL-Z`

**caution** When you exit from vim with `ZZ`, make sure that you type `ZZ` and not `CONTROL-Z` (typically the suspend key). When you press `CONTROL-Z`, vim disappears from your screen, almost as though you had exited from it. In fact, vim will continue running in the background with your work unsaved. Refer to “Job Control” on page 294. If you try to start editing the same file with a new **vim** command, vim displays a message about a swap file.

---

## THE compatible PARAMETER

The **compatible** parameter makes vim more compatible with vi. By default this parameter is not set. From the command line use the `-C` option to set the **compatible** parameter and use the `-N` option to unset it. To get started with vim you can ignore this parameter.

Setting the **compatible** parameter changes many aspects of how vim works. For example, when the **compatible** parameter is set, the Undo command (page 180) can undo only your most recent change; in contrast, with the **compatible** parameter unset, you can call Undo repeatedly to undo many changes. To obtain more details on the **compatible** parameter, give the command `:help compatible` RETURN. To display a complete list of vim's differences from the original vi, use `:help vi-diff` RETURN. See page 178 for a discussion of the **help** command.

---

## CHAPTER SUMMARY

The utilities introduced in this chapter are a small but powerful subset of the many utilities available on a Fedora/RHEL system. Because you will use them frequently and because they are integral to the following chapters, it is important that you become comfortable using them.

The utilities listed in Table 5-2 manipulate, display, compare, and print files.

**Table 5-2** File utilities

| Utility | Function                                                                        |
|---------|---------------------------------------------------------------------------------|
| cp      | Copies one or more files (page 151)                                             |
| diff    | Displays the differences between two files (page 157)                           |
| file    | Displays information about the contents of a file (page 157)                    |
| grep    | Searches file(s) for a string (page 153)                                        |
| head    | Displays the lines at the beginning of a file (page 154)                        |
| lpq     | Displays a list of jobs in the print queue (page 153)                           |
| lpr     | Places file(s) in the print queue (page 153)                                    |
| lprm    | Removes a job from the print queue (page 153)                                   |
| mv      | Renames a file or moves file(s) to another directory (page 152)                 |
| sort    | Puts a file in order by lines (page 155)                                        |
| tail    | Displays the lines at the end of a file (page 154)                              |
| uniq    | Displays the contents of a file, skipping successive duplicate lines (page 156) |

To reduce the amount of disk space a file occupies, you can compress it with the `bzip2` utility. Compression works especially well on files that contain patterns, as do most text files, but reduces the size of almost all files. The inverse of `bzip2`—`bunzip2`—restores a file to its original, decompressed form. Table 5-3 lists utilities that compress and decompress files. The `bzip2` utility is the most efficient of these.

**Table 5-3** (De)compression utilities

| Utility  | Function                                                                                                             |
|----------|----------------------------------------------------------------------------------------------------------------------|
| bunzip2  | Returns a file compressed with <code>bzip2</code> to its original size and format (page 162)                         |
| bzcat    | Displays a file compressed with <code>bzip2</code> (page 162)                                                        |
| bzip2    | Compresses a file (page 162)                                                                                         |
| compress | Compresses a file (not as well as <code>gzip</code> ) (page 163)                                                     |
| gunzip   | Returns a file compressed with <code>gzip</code> or <code>compress</code> to its original size and format (page 163) |
| gzip     | Compresses a file (page 163)                                                                                         |
| zcat     | Displays a file compressed with <code>gzip</code> (page 163)                                                         |

An archive is a file, frequently compressed, that contains a group of files. The `tar` utility (Table 5-4) packs and unpacks archives. The filename extensions `.tar.bz2`, `.tar.gz`, and `.tgz` identify compressed tar archive files and are often seen on software packages obtained over the Internet.

**Table 5-4** Archive utility

| Utility          | Function                                                  |
|------------------|-----------------------------------------------------------|
| <code>tar</code> | Creates or extracts files from an archive file (page 163) |

The utilities listed in Table 5-5 determine the location of a utility on the local system. For example, they can display the pathname of a utility or a list of C++ compilers available on the local system.

**Table 5-5** Location utilities

| Utility              | Function                                                                      |
|----------------------|-------------------------------------------------------------------------------|
| <code>apropos</code> | Searches the man page one-line descriptions for a keyword (page 167)          |
| <code>locate</code>  | Searches for files on the local system (page 168)                             |
| <code>whereis</code> | Displays the full pathnames of a utility, source code, or man page (page 166) |
| <code>which</code>   | Displays the full pathname of a command you can run (page 166)                |

Table 5-6 lists utilities that display information about other users. You can easily learn a user's full name, the user's login status, the login shell of the user, and other items of information maintained by the system.

**Table 5-6** User and system information utilities

| Utility               | Function                                                                         |
|-----------------------|----------------------------------------------------------------------------------|
| <code>finger</code>   | Displays detailed information about users, including their full names (page 169) |
| <code>hostname</code> | Displays the name of the local system (page 151)                                 |
| <code>w</code>        | Displays detailed information about users who are logged in (page 171)           |
| <code>who</code>      | Displays information about users who are logged in (page 169)                    |

The utilities shown in Table 5-7 can help you stay in touch with other users on the local network.

**Table 5-7** User communication utilities

| Utility            | Function                                                    |
|--------------------|-------------------------------------------------------------|
| <code>mesg</code>  | Permits or denies messages sent by write (page 173)         |
| <code>write</code> | Sends a message to another user who is logged in (page 172) |

Table 5-8 lists miscellaneous utilities.

**Table 5-8** Miscellaneous utilities

| Utility | Function                                                         |
|---------|------------------------------------------------------------------|
| date    | Displays the current date and time (page 159)                    |
| echo    | Copies its <i>arguments</i> (page 1069) to the screen (page 159) |

---

## EXERCISES

1. Which commands can you use to determine who is logged in on a specific terminal?
2. How can you keep other users from using `write` to communicate with you? Why would you want to?
3. What happens when you give the following commands if the file named `done` already exists?  

```
$ cp to_do done  
$ mv to_do done
```
4. How can you find out which utilities are available on your system for editing files? Which utilities are available for editing on your system?
5. How can you find the phone number for Ace Electronics in a file named `phone` that contains a list of names and phone numbers? Which command can you use to display the entire file in alphabetical order? How can you remove adjacent duplicate lines from the file? How can you remove all duplicates?
6. What happens when you use `diff` to compare two binary files that are not identical? (You can use `gzip` to create the binary files.) Explain why the `diff` output for binary files is different from the `diff` output for ASCII files.
7. Create a `.plan` file in your home directory. Does `finger` display the contents of your `.plan` file?
8. What is the result of giving the `which` utility the name of a command that resides in a directory that is *not* in your search path?
9. Are any of the utilities discussed in this chapter located in more than one directory on your system? If so, which ones?
10. Experiment by calling the `file` utility with the names of files in `/usr/bin`. How many different types of files are there?
11. Which command can you use to look at the first few lines of a file named `status.report`? Which command can you use to look at the end of the file?

---

## ADVANCED EXERCISES

12. Re-create the `colors.1` and `colors.2` files used in Figure 5-8 on page 157. Test your files by running `diff -u` on them. Do you get the same results as in the figure?
13. Try giving these two commands:

```
$ echo cat
$ cat echo
```

Explain the differences between them.

14. Repeat exercise 5 using the file `phone.gz`, a compressed version of the list of names and phone numbers. Consider more than one approach to answer each question, and explain how you made your choices.
15. Find existing files or create files that
  - a. `gzip` compresses by more than 80 percent.
  - b. `gzip` compresses by less than 10 percent.
  - c. Get larger when compressed with `gzip`.
  - d. Use `ls -l` to determine the sizes of the files in question. Can you characterize the files in a, b, and c?
16. Older email programs were not able to handle binary files. Suppose that you are emailing a file that has been compressed with `gzip`, which produces a binary file, and the recipient is using an old email program. Refer to the man page on `uuencode`, which converts a binary file to ASCII. Learn about the utility and how to use it.
  - a. Convert a compressed file to ASCII using `uuencode`. Is the encoded file larger or smaller than the compressed file? Explain. (If `uuencode` is not on the local system, you can install it using `yum` [page 498]; it is part of the `sharutils` package.)
  - b. Would it ever make sense to use `uuencode` on a file before compressing it? Explain.

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# THE LINUX FILESYSTEM

## IN THIS CHAPTER

|                                                 |     |
|-------------------------------------------------|-----|
| The Hierarchical Filesystem . . . . .           | 188 |
| Directory Files and Ordinary<br>Files . . . . . | 188 |
| The Working Directory . . . . .                 | 192 |
| Your Home Directory . . . . .                   | 192 |
| Pathnames . . . . .                             | 193 |
| Relative Pathnames . . . . .                    | 194 |
| Working with Directories . . . . .              | 200 |
| Access Permissions . . . . .                    | 202 |
| ACLs: Access Control Lists . . . . .            | 207 |
| Hard Links . . . . .                            | 214 |
| Symbolic Links . . . . .                        | 216 |

A *filesystem* is a set of *data structures* (page 1078) that usually resides on part of a disk and that holds directories of files. Filesystems store user and system data that are the basis of users' work on the system and the system's existence. This chapter discusses the organization and terminology of the Linux filesystem, defines ordinary and directory files, and explains the rules for naming them. It also shows how to create and delete directories, move through the filesystem, and use absolute and relative pathnames to access files in various directories. It includes a discussion of important files and directories as well as file access permissions and Access Control Lists (ACLs), which allow you to share selected files with other users. It concludes with a discussion of hard and symbolic links, which can make a single file appear in more than one directory.

In addition to reading this chapter, you may want to refer to the `df` info page and to the `fsck`, `mkfs`, and `tune2fs` man pages for more information on filesystems.

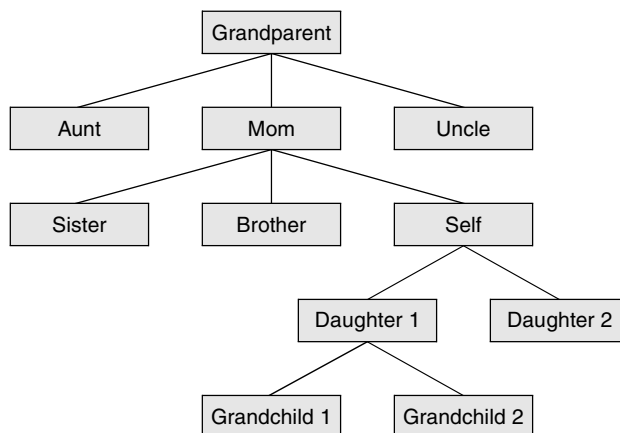
## THE HIERARCHICAL FILESYSTEM

- Family tree** A *hierarchical* structure (page 1085) frequently takes the shape of a pyramid. One example of this type of structure is found by tracing a family's lineage: A couple has a child, who may in turn have several children, each of whom may have more children. This hierarchical structure is called a *family tree* (Figure 6-1).
- Directory tree** Like the family tree it resembles, the Linux filesystem is called a *tree*. It consists of a set of connected files. This structure allows you to organize files so you can easily find any particular one. On a standard Linux system, each user starts with one directory, to which the user can add subdirectories to any desired level. By creating multiple levels of subdirectories, a user can expand the structure as needed.
- Subdirectories** Typically each subdirectory is dedicated to a single subject, such as a person, project, or event. The subject dictates whether a subdirectory should be subdivided further. For example, Figure 6-2 shows a secretary's subdirectory named **correspond**. This directory contains three subdirectories: **business**, **memos**, and **personal**. The **business** directory contains files that store each letter the secretary types. If you expect many letters to go to one client, as is the case with **milk\_co**, you can dedicate a subdirectory to that client.

One major strength of the Linux filesystem is its ability to adapt to users' needs. You can take advantage of this strength by strategically organizing your files so they are most convenient and useful for you.

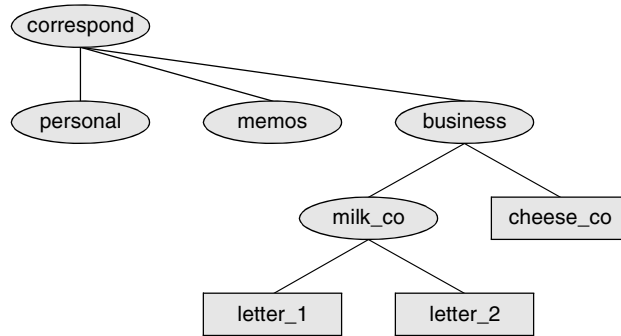
## DIRECTORY FILES AND ORDINARY FILES

Like a family tree, the tree representing the filesystem is usually pictured upside down, with its *root* at the top. Figures 6-2 and 6-3 show that the tree "grows"



**Figure 6-1** A family tree



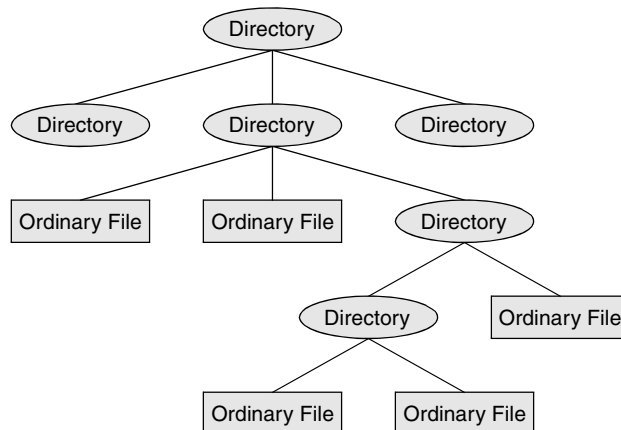


**Figure 6-2** A secretary's directories

downward from the root, with paths connecting the root to each of the other files. At the end of each path is either an ordinary file or a directory file. Special files, which can also be at the ends of paths, are described on page 482. *Ordinary files*, or simply *files*, appear at the ends of paths that cannot support other paths. *Directory files*, also referred to as *directories* or *folders*, are the points that other paths can branch off from. (Figures 6-2 and 6-3 show some empty directories.) When you refer to the tree, *up* is toward the root and *down* is away from the root. Directories directly connected by a path are called *parents* (closer to the root) and *children* (farther from the root). A *pathname* is a series of names that trace a path along branches from one file to another. More information about pathnames appears on page 193.

## FILENAMES

Every file has a *filename*. The maximum length of a filename varies with the type of filesystem; Linux supports several types of filesystems. Although most of today's filesystems allow you to create files with names up to 255 characters long, some filesystems



**Figure 6-3** Directories and ordinary files

restrict you to shorter names. While you can use almost any character in a filename, you will avoid confusion if you choose characters from the following list:

- Uppercase letters (A–Z)
- Lowercase letters (a–z)
- Numbers (0–9)
- Underscore (\_)
- Period (.)
- Comma (,)

/ or root The *root* directory is always named / (slash) and referred to by this single character. No other file can use this name or have a / in its name. However, in a pathname, which is a string of filenames including directory names, the slash *separates* filenames (page 193).

Like the children of one parent, no two files in the same directory can have the same name. (Parents give their children different names because it makes good sense, but Linux requires it.) Files in different directories, like the children of different parents, can have the same name.

The filenames you choose should mean something. Too often a directory is filled with important files with such unhelpful names as **hold1**, **wombat**, and **junk**, not to mention **foo** and **foobar**. Such names are poor choices because they do not help you recall what you stored in a file. The following filenames conform to the suggested syntax *and* convey information about the contents of the file:

- **correspond**
- **january**
- **davis**
- **reports**
- **2001**
- **acct\_payable**

Filename length When you share your files with users on other systems, you may need to make long filenames differ within the first few characters. Systems running DOS or older versions of Windows have an 8-character filename body length and a 3-character filename extension length limit. Some UNIX systems have a 14-character limit and older Macintosh systems have a 31-character limit. If you keep the filenames short, they are easy to type; later you can add extensions to them without exceeding the shorter limits imposed by some filesystems. The disadvantage of short filenames is that they are typically less descriptive than long filenames. See *stat* on page 440 for a way to determine the maximum length of a filename on the local system.

Long filenames enable you to assign descriptive names to files. To help you select among files without typing entire filenames, shells support filename completion. For more information about this feature, see the “Filename completion” tip on page 151.

Case sensitivity You can use uppercase and/or lowercase letters within filenames. Linux is case sensitive, so files named **JANUARY**, **January**, and **january** represent three distinct files.

**Do not use SPACES within filenames**

**caution** Although you can use SPACES within filenames, it is a poor idea. Because a SPACE is a special character, you must quote it on a command line. Quoting a character on a command line can be difficult for a novice user and cumbersome for an experienced user. Use periods or underscores instead of SPACES: **joe.05.04.26**, **new\_stuff**.

If you are working with a filename that includes a SPACE, such as a file from another operating system, you must quote the SPACE on the command line by preceding it with a backslash or by placing quotation marks on either side of the filename. The two following commands send the file named **my file** to the printer.

```
$ lpr my\ file
$ lpr "my file"
```

**FILENAME EXTENSIONS**

A *filename extension* is the part of the filename following an embedded period. In the filenames listed in Table 6-1, filename extensions help describe the contents of the file. Some programs, such as the C programming language compiler, default to specific filename extensions; in most cases, however, filename extensions are optional. Use extensions freely to make filenames easy to understand. If you like, you can use several periods within the same filename—for example, **notes.4.10.01** or **files.tar.gz**.

**Table 6-1** Filename extensions

| Filename with extension                                                                                                    | Meaning of extension                                                                                                        |
|----------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|
| <b>compute.c</b>                                                                                                           | A C programming language source file                                                                                        |
| <b>compute.o</b>                                                                                                           | The object code for the program                                                                                             |
| <b>compute</b>                                                                                                             | The same program as an executable file                                                                                      |
| <b>memo.0410.txt</b>                                                                                                       | A text file                                                                                                                 |
| <b>memo.pdf</b>                                                                                                            | A PDF file; view with <b>xpdf</b> under a GUI                                                                               |
| <b>memo.ps</b>                                                                                                             | A PostScript file; view with <b>gs</b> under a GUI                                                                          |
| <b>memo.Z</b>                                                                                                              | A file compressed with <b>compress</b> (page 163); use <b>uncompress</b> or <b>gunzip</b> (page 163) to decompress          |
| <b>memo.tgz</b> or <b>memo.tar.gz</b>                                                                                      | A tar (page 163) archive of files compressed with <b>gzip</b> (page 163)                                                    |
| <b>memo.gz</b>                                                                                                             | A file compressed with <b>gzip</b> (page 163); view with <b>zcat</b> or decompress with <b>gunzip</b> (both on page 163)    |
| <b>memo.bz2</b>                                                                                                            | A file compressed with <b>bzip2</b> (page 162); view with <b>bzcat</b> or decompress with <b>bunzip2</b> (both on page 162) |
| <b>memo.html</b>                                                                                                           | A file meant to be viewed using a Web browser, such as Firefox                                                              |
| <b>photo.gif</b> , <b>photo.jpg</b> ,<br><b>photo.jpeg</b> , <b>photo.bmp</b> ,<br><b>photo.tif</b> , or <b>photo.tiff</b> | A file containing graphical information, such as a picture                                                                  |

## HIDDEN FILENAMES

A filename that begins with a period is called a *hidden filename* (or a *hidden file* or sometimes an *invisible file*) because `ls` does not normally display it. The command `ls -a` displays *all* filenames, even hidden ones. Names of startup files (page 192) usually begin with a period so that they are hidden and do not clutter a directory listing. The `.plan` file (page 170) is also hidden. Two special hidden entries—a single and double period (`.` and `..`)—appear in every directory (page 197).

## THE WORKING DIRECTORY

`pwd` While you are logged in on a character-based interface to a Linux system, you are always associated with a directory. The directory you are associated with is called the *working directory* or *current directory*. Sometimes this association is referred to in a physical sense: “You are *in* (or *working in*) the **jenny** directory.” The `pwd` (print working directory) utility displays the pathname of the working directory.

## YOUR HOME DIRECTORY

When you first log in on a Linux system or start a terminal emulator window, your working directory is your *home directory*. To display the pathname of your home directory, use `pwd` just after you log in (Figure 6-4).

When used without any arguments, the `ls` utility displays a list of the files in the working directory. Because your home directory has been the only working directory you have used so far, `ls` has always displayed a list of files in your home directory. (All the files you have created up to this point were created in your home directory.)

## STARTUP FILES

*Startup files*, which appear in your home directory, give the shell and other programs information about you and your preferences. Frequently one of these files tells the shell what kind of terminal you are using (page 1040) and executes the `stty` (set terminal) utility to establish the erase (page 139) and line kill (page 139) keys.

Either you or the system administrator can put a shell startup file containing shell commands in your home directory. The shell executes the commands in this file each time you log in. Because the startup files have hidden filenames, you must use the `ls -a` command to see whether one is in your home directory. A GUI has many startup files. Usually you do not need to work with these files directly but can control startup sequences by using icons on the desktop. See page 281 for more information about startup files.

```
login: alex
Password:
Last login: Wed Oct 20 11:14:21 from bravo
$ pwd
/home/alex
```

**Figure 6-4** Logging in and displaying the pathname of your home directory

## PATHNAMES

This section discusses absolute and relative pathnames and explains how to use them to your advantage.

### ABSOLUTE PATHNAMES

Every file has a pathname. Figure 6-5 shows the pathnames of directories and ordinary files in part of a filesystem hierarchy. An absolute pathname always starts with a slash (/), the name of the root directory. You can then build the absolute pathname of a file by tracing a path from the root directory through all the intermediate directories to the file. String all the filenames in the path together, separating each from the next with a slash (/) and preceding the entire group of filenames with a slash (/). This path of filenames is called an *absolute pathname* because it locates a file absolutely by tracing a path from the root directory to the file. The part of a pathname following the final slash is called a *simple filename*, *filename*, or *basename*.

### ~ (TILDE) IN PATHNAMES

In another form of absolute pathname, the shell expands the characters ~/ (a tilde followed by a slash) at the start of a pathname into the pathname of your home directory. Using this shortcut, you can display your `.bashrc` startup file (page 281) with the following command, no matter which directory is your working directory:

```
$ less ~/.bashrc
```

A tilde quickly references paths that start with your or someone else's home directory. The shell expands a tilde followed by a username at the beginning of a pathname into the pathname of that user's home directory. For example, assuming he

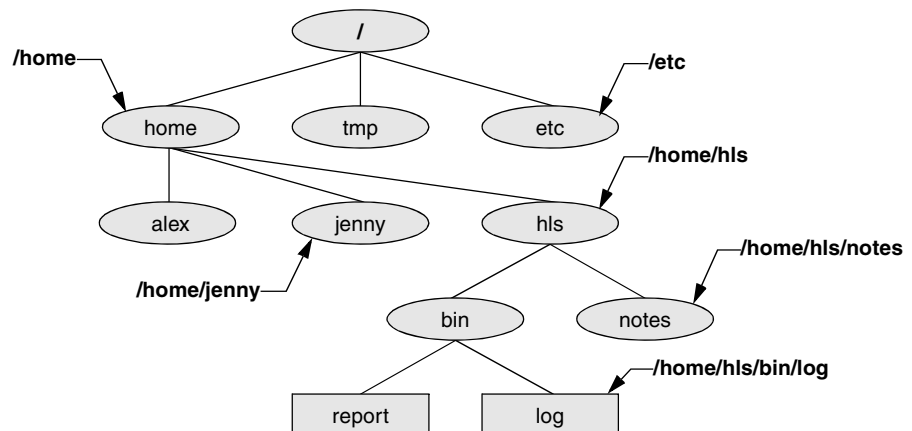


Figure 6-5 Absolute pathnames

has permission to do so, Alex can examine Scott's `.bashrc` file with the following command:

```
$ less ~scott/.bashrc
```

Refer to “Tilde Expansion” on page 345 for more information.

## RELATIVE PATHNAMES

A *relative pathname* traces a path from the working directory to a file. The pathname is *relative* to the working directory. Any pathname that does not begin with the root directory (`/`) or a tilde (`~`) is a relative pathname. Like absolute pathnames, relative pathnames can trace a path through many directories. The simplest relative pathname is a simple filename, which identifies a file in the working directory. The examples in the next sections use absolute and relative pathnames.

### When using a relative pathname, know which directory is the working directory

**caution** The location of the file that you are accessing with a relative pathname is dependent on (is relative to) the working directory. Always make sure you know which directory is the working directory before you use a relative pathname. Use `pwd` to verify the directory. If you are using `mkdir` and you are not where you think you are in the file hierarchy, the new directory will end up in an unexpected location.

It does not matter which directory is the working directory when you use an absolute pathname.

### SIGNIFICANCE OF THE WORKING DIRECTORY

To access any file in the working directory, you need only a simple filename. To access a file in another directory, you *must* use a pathname. Typing a long pathname is tedious and increases the chance of making a mistake. This possibility is less likely under a GUI, where you click filenames or icons. You can choose a working directory for any particular task to reduce the need for long pathnames. Your choice of a

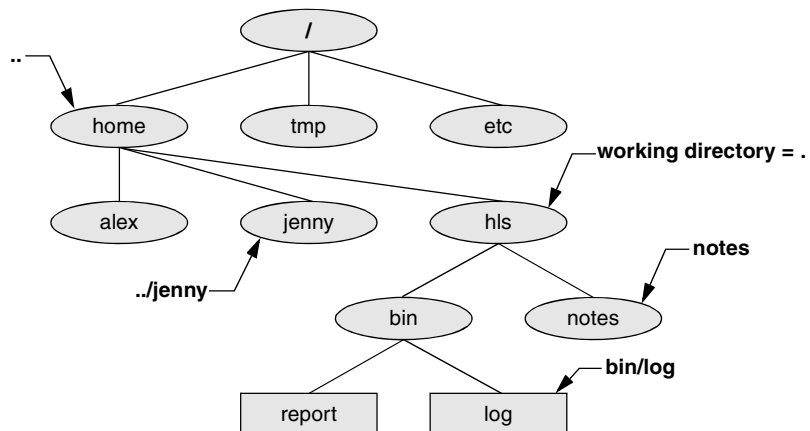


Figure 6-6 Relative pathnames

working directory does not allow you to do anything you could not do otherwise—it just makes some operations easier.

Refer to Figure 6-6 as you read this paragraph. Files that are children of the working directory can be referenced by simple filenames. Grandchildren of the working directory can be referenced by short relative pathnames: two filenames separated by a slash. When you manipulate files in a large directory structure, using short relative pathnames can save you time and aggravation. If you choose a working directory that contains the files used most often for a particular task, you need to use fewer long, cumbersome pathnames.

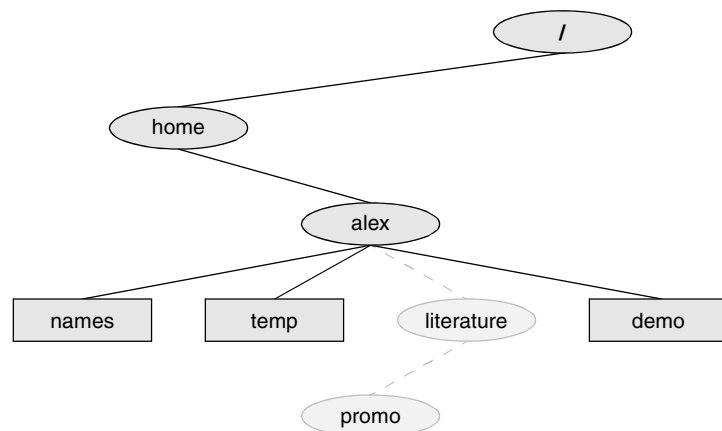
## DIRECTORY COMMANDS

This section discusses how to create directories (`mkdir`), switch between directories (`cd`), remove directories (`rmdir`), use pathnames to make your work easier, and move and copy files and directories between directories.

### `mkdir`: CREATES A DIRECTORY

The `mkdir` utility creates a directory. The *argument* (page 1069) to `mkdir` becomes the pathname of the new directory. The following examples develop the directory structure shown in Figure 6-7. In the figure, the directories that are added appear in a lighter shade than the others and are connected by dashes.

In Figure 6-8 (next page), `pwd` shows that Alex is working in his home directory (`/home/alex`) and `ls` shows the names of the files in his home directory: **demo**, **names**, and **temp**. Using `mkdir`, Alex creates a directory named **literature** as a child of his home directory. He uses a relative pathname (a simple filename) because he wants the **literature** directory to be a child of the working directory. Of course, Alex could have used an absolute pathname to create the same directory: `mkdir /home/alex/literature`.



**Figure 6-7** The file structure developed in the examples

```

$ pwd
/home/alex
$ ls
demo names temp
$ mkdir literature
$ ls
demo literature names temp
$ ls -F
demo literature/ names temp
$ ls literature
$

```

**Figure 6-8** The `mkdir` utility

The second `ls` in Figure 6-8 verifies the presence of the new directory. The `-F` option to `ls` displays a slash after the name of each directory and an asterisk after each executable file (shell script, utility, or application). When you call it with an argument that is the name of a directory, `ls` lists the contents of that directory. The final `ls` does not display anything because there are no files in the **literature** directory.

The following commands show two ways to create the **promo** directory as a child of the newly created **literature** directory. The first way checks that `/home/alex` is the working directory and uses a relative pathname:

```

$ pwd
/home/alex
$ mkdir literature/promo

```

The second way uses an absolute pathname:

```

$ mkdir /home/alex/literature/promo

```

Use the `-p` (parents) option to `mkdir` to create both the **literature** and **promo** directories with one command:

```

$ pwd
/home/alex
$ ls
demo names temp
$ mkdir -p literature/promo

```

or

```

$ mkdir -p /home/alex/literature/promo

```

## cd: CHANGES TO ANOTHER WORKING DIRECTORY

The `cd` (change directory) utility makes another directory the working directory but does *not* change the contents of the working directory. Figure 6-9 shows two ways to make the `/home/alex/literature` directory the working directory, as verified by `pwd`. First Alex uses `cd` with an absolute pathname to make **literature** his working directory—it does not matter which is your working directory when you give a command with an absolute pathname. A `pwd` command confirms the change made



```
$ cd /home/alex/literature
$ pwd
/home/alex/literature
$ cd
$ pwd
/home/alex
$ cd literature
$ pwd
/home/alex/literature
```

**Figure 6-9** `cd` changes your working directory

by Alex. When used without an argument, `cd` makes your home directory the working directory, as it was when you logged in. The second `cd` command in Figure 6-9 does not have an argument so it makes Alex's home directory the working directory. Finally, knowing that he is working in his home directory, Alex uses a simple filename to make the `literature` directory his working directory (`cd literature`) and confirms the change with `pwd`.

### The working directory versus your home directory

**tip** The working directory is not the same as your home directory. Your home directory remains the same for the duration of your session and usually from session to session. Immediately after you log in, you are always working in the same directory: your home directory.

Unlike your home directory, the working directory can change as often as you like. You have no set working directory, which explains why some people refer to it as the *current directory*. When you log in and until you change directories by using `cd`, your home directory is your working directory. If you were to change directories to Scott's home directory, then Scott's home directory would be your working directory.

---

## THE . AND .. DIRECTORY ENTRIES

The `mkdir` utility automatically puts two entries in each directory you create: a single period (.) and a double period (..). The . is synonymous with the pathname of the working directory and can be used in its place; the .. is synonymous with the pathname of the parent of the working directory. These entries are hidden because their filenames begin with a period.

With the `literature` directory as the working directory, the following example uses .. three times: first to list the contents of the parent directory (`/home/alex`), second to copy the `memoA` file to the parent directory, and third to list the contents of the parent directory again.

```
$ pwd
/home/alex/literature
$ ls ..
demo literature names temp
$ cp memoA ..
$ ls ..
demo literature memoA names temp
```

After using `cd` to make **promo** (a subdirectory of **literature**) his working directory, Alex can use a relative pathname to call `vim` to edit a file in his home directory.

```
$ cd promo
$ vim ../../names
```

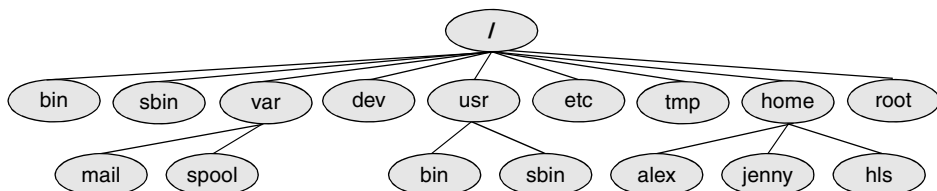
You can use an absolute or relative pathname or a simple filename virtually anywhere that a utility or program requires a filename or pathname. This usage holds true for `ls`, `vim`, `mkdir`, `rm`, and most other Linux utilities.

## IMPORTANT STANDARD DIRECTORIES AND FILES

Originally files on a Linux system were not located in standard places. The scattered files made it difficult to document and maintain a Linux system and just about impossible for someone to release a software package that would compile and run on all Linux systems. The first standard for the Linux filesystem, the FSSTND (Linux Filesystem Standard), was released on February 14, 1994. In early 1995 work was started on a broader standard covering many UNIX-like systems: FHS (Linux Filesystem Hierarchy Standard, [www.pathname.com/fhs](http://www.pathname.com/fhs)). More recently FHS has been incorporated in LSB (Linux Standard Base, [www.linuxbase.org](http://www.linuxbase.org)), a workgroup of FSG (Free Standards Group, [www.freestandards.org](http://www.freestandards.org)). Figure 6-10 shows the locations of some important directories and files as specified by FHS. The significance of many of these directories will become clear as you continue reading.

The following list describes the directories shown in Figure 6-10, some of the directories specified by FHS, and some other directories. Fedora/RHEL, however, does not use all the directories specified by FHS. Be aware that you cannot always determine the function of a directory by its name. For example, although `/opt` stores add-on software, `/etc/opt` stores configuration files for the software in `/opt`. See also “Important Files and Directories” on page 468.

- /** **Root** The root directory, present in all Linux filesystem structures, is the ancestor of all files in the filesystem.
- /bin** **Essential command binaries** Holds the files needed to bring the system up and run it when it first comes up in single-user mode (page 430).
- /boot** **Static files of the boot loader** Contains all of the files needed to boot the system.



**Figure 6-10** A typical FHS-based Linux filesystem structure

- /dev** **Device files** Contains all files that represent peripheral devices, such as disk drives, terminals, and printers. Previously this directory was filled with all possible devices. As of Fedora 3 and RHEL v.4, **udev** (page 482) provides a dynamic device directory that enables **/dev** to contain only devices that are present on the system.
- /etc** **Machine-local system configuration files** Holds administrative, configuration, and other system files. One of the most important is **/etc/passwd**, which contains a list of all users who have permission to use the system.
- /etc/opt** **Configuration files for add-on software packages kept in /opt**
- /etc/X11** **Machine-local configuration files for the X Window System**
- /home** **User home directories** Each user's home directory is typically one of many sub-directories of the **/home** directory. As an example, assuming that users' directories are under **/home**, the absolute pathname of Jenny's home directory is **/home/jenny**. On some systems the users' directories may not be found under **/home** but instead might be spread among other directories such as **/inhouse** and **/clients**.
- /lib** **Shared libraries**
- /lib/modules** **Loadable kernel modules**
- /mnt** **Mount point for temporarily mounting filesystems**
- /opt** **Add-on software packages (optional packages)**
- /proc** **Kernel and process information virtual filesystem**
- /root** **Home directory for root**
- /sbin** **Essential system binaries** Utilities used for system administration are stored in **/sbin** and **/usr/sbin**. The **/sbin** directory includes utilities needed during the booting process, and **/usr/sbin** holds utilities used after the system is up and running. In older versions of Linux, many system administration utilities were scattered through several directories that often included other system files (**/etc**, **/usr/bin**, **/usr/adm**, **/usr/include**).
- /sys** **Device pseudofilesystem** See **udev** on page 482 for more information.
- /tmp** **Temporary files**
- /usr** **Second major hierarchy** Traditionally includes subdirectories that contain information used by the system. Files in **/usr** subdirectories do not change often and may be shared by several systems.
- /usr/bin** **Most user commands** Contains the standard Linux utility programs—that is, binaries that are not needed in single-user mode (page 430).
- /usr/games** **Games and educational programs**
- /usr/include** **Header files included by C programs**
- /usr/lib** **Libraries**
- /usr/local** **Local hierarchy** Holds locally important files and directories that are added to the system. Subdirectories can include **bin**, **games**, **include**, **lib**, **sbin**, **share**, and **src**.

|                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>/usr/sbin</code>       | Nonvital system administration binaries See <code>/sbin</code> .                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <code>/usr/share</code>      | Architecture-independent data Subdirectories can include <code>dict</code> , <code>doc</code> , <code>games</code> , <code>info</code> , <code>locale</code> , <code>man</code> , <code>misc</code> , <code>terminfo</code> , and <code>zoneinfo</code> .                                                                                                                                                                                                                                                                                                                                                                                       |
| <code>/usr/share/doc</code>  | Documentation                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <code>/usr/share/info</code> | GNU info system's primary directory                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <code>/usr/share/man</code>  | Online manuals                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <code>/usr/src</code>        | Source code                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <code>/var</code>            | Variable data Files with contents that vary as the system runs are kept in subdirectories under <code>/var</code> . The most common examples are temporary files, system log files, spooled files, and user mailbox files. Subdirectories can include <code>cache</code> , <code>lib</code> , <code>lock</code> , <code>log</code> , <code>opt</code> , <code>run</code> , <code>spool</code> , <code>tmp</code> , and <code>yp</code> . Older versions of Linux scattered such files through several subdirectories of <code>/usr</code> ( <code>/usr/adm</code> , <code>/usr/mail</code> , <code>/usr/spool</code> , <code>/usr/tmp</code> ). |
| <code>/var/log</code>        | Log files Contains <code>lastlog</code> (a record of the last login by each user), <code>messages</code> (system messages from <code>rsyslogd</code> ), and <code>wttmp</code> (a record of all logins/logouts).                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <code>/var/spool</code>      | Spooled application data Contains <code>anacron</code> , <code>at</code> , <code>cron</code> , <code>lpd</code> , <code>mail</code> , <code>mqueue</code> , <code>samba</code> , and other directories. The file <code>/var/spool/mail</code> typically has a symbolic link in <code>/var</code> .                                                                                                                                                                                                                                                                                                                                              |

---

## WORKING WITH DIRECTORIES

This section covers deleting directories, copying and moving files between directories, and moving directories. It also describes how to use pathnames to make your work with Linux easier.

### rmmdir: DELETES A DIRECTORY

The `rmmdir` (remove directory) utility deletes a directory. You cannot delete the working directory or a directory that contains files other than the `.` and `..` entries. If you need to delete a directory that has files in it, first use `rm` to delete the files and then delete the directory. You do not have to (nor can you) delete the `.` and `..` entries; `rmmdir` removes them automatically. The following command deletes the `promo` directory:

```
$ rmmdir /home/alex/literature/promo
```

The `rm` utility has a `-r` option (`rm -r filename`) that recursively deletes files, including directories, within a directory and also deletes the directory itself.

#### Use `rm -r` carefully, if at all

**caution** Although `rm -r` is a handy command, you must use it carefully. Do not use it with an ambiguous file reference such as `*`. It is frighteningly easy to wipe out your entire home directory with a single short command.

---

## USING PATHNAMES

`touch` Use a text editor to create a file named **letter** if you want to experiment with the examples that follow. Alternatively you can use `touch` to create an empty file:

```
$ cd
$ pwd
/home/alex
$ touch letter
```

With `/home/alex` as the working directory, the following example uses `cp` with a relative pathname to copy the file **letter** to the `/home/alex/literature/promo` directory (you will need to create **promo** again if you deleted it earlier). The copy of the file has the simple filename **letter.0610**:

```
$ cp letter literature/promo/letter.0610
```

If Alex does not change to another directory, he can use `vim` to edit the copy of the file he just made:

```
$ vim literature/promo/letter.0610
```

If Alex does not want to use a long pathname to specify the file, he can use `cd` to make **promo** the working directory before using `vim`:

```
$ cd literature/promo
$ pwd
/home/alex/literature/promo
$ vim letter.0610
```

To make the parent of the working directory (named `/home/alex/literature`) the new working directory, Alex can give the following command, which takes advantage of the `..` directory entry:

```
$ cd ..
$ pwd
/home/alex/literature
```

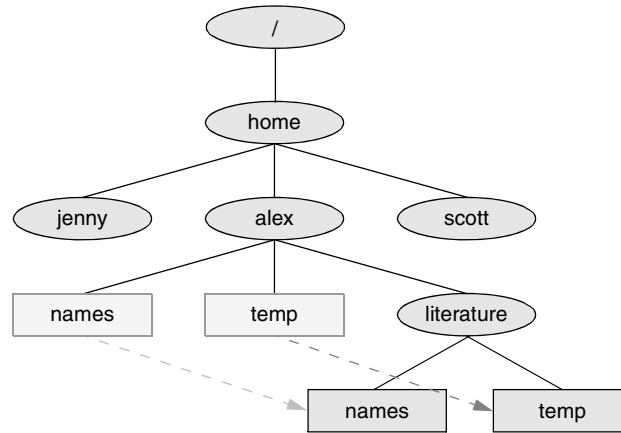
## mv, cp: MOVE OR COPY FILES

Chapter 5 discussed the use of `mv` to rename files. However, `mv` works even more generally: You can use this utility to move files from one directory to another (change the pathname of a file) as well as to change a simple filename. When used to move one or more files to a new directory, the `mv` command has this syntax:

```
mv existing-file-list directory
```

If the working directory is `/home/alex`, Alex can use the following command to move the files **names** and **temp** from the working directory to the **literature** directory:

```
$ mv names temp literature
```



**Figure 6-11** Using `mv` to move `names` and `temp`

This command changes the absolute pathnames of the `names` and `temp` files from `/home/alex/names` and `/home/alex/temp` to `/home/alex/literature/names` and `/home/alex/literature/temp`, respectively (Figure 6-11). Like most Linux commands, `mv` accepts either absolute or relative pathnames.

As you work with Linux and create more files, you will need to create new directories using `mkdir` to keep the files organized. The `mv` utility is a useful tool for moving files from one directory to another as you extend your directory hierarchy.

The `cp` utility works in the same way as `mv` does, except that it makes copies of the *existing-file-list* in the specified *directory*.

## mv: MOVES A DIRECTORY

Just as it moves ordinary files from one directory to another, so `mv` can move directories. The syntax is similar except that you specify one or more directories, not ordinary files, to move:

*mv existing-directory-list new-directory*

If *new-directory* does not exist, the *existing-directory-list* must contain just one directory name, which `mv` changes to *new-directory* (`mv` renames the directory). Although you can rename directories using `mv`, you cannot copy their contents with `cp` unless you use the `-r` option. Refer to the `tar` and `cpio` man pages for other ways to copy and move directories.

---

## ACCESS PERMISSIONS

In addition to the controls imposed by SELinux (page 414), Fedora/RHEL supports two methods of controlling who can access a file and how they can access



Figure 6-12 The columns displayed by the `ls -l` command

it: traditional Linux access permissions and Access Control Lists (ACLs, page 207). ACLs provide finer-grained control of access privileges. This section describes traditional Linux access permissions.

Three types of users can access a file: the owner of the file (*owner*), a member of a group that the file is associated with (*group*; see page 472 for more information on groups), and everyone else (*other*). A user can attempt to access an ordinary file in three ways: by trying to *read from*, *write to*, or *execute* it.

## ls -l: DISPLAYS PERMISSIONS

When you call `ls` with the `-l` option and the name of one or more ordinary files, `ls` displays a line of information about the file. The following example displays information for two files. The file `letter.0610` contains the text of a letter, and `check_spell` contains a shell script, a program written in a high-level shell programming language:

```
$ ls -l letter.0610 check_spell
-rw-r--r-- 1 alex  pubs  3355  May  2 10:52 letter.0610
-rwxr-xr-x 2 alex  pubs   852  May  5 14:03 check_spell
```

From left to right, the lines that an `ls -l` command displays contain the following information (refer to Figure 6-12):

- The type of file (first character)
- The file’s access permissions (the next nine characters)
- The ACL flag (present if the file has an ACL, page 207)
- The number of links to the file (page 212)
- The name of the owner of the file (usually the person who created the file)
- The name of the group that the file is associated with
- The size of the file in characters (bytes)
- The date and time the file was created or last modified
- The name of the file

The type of file (first column) for `letter.0610` is a hyphen (`-`) because it is an ordinary file (directory files have a `d` in this column).

The next three characters specify the access permissions for the *owner* of the file: **r** indicates read permission, **w** indicates write permission, and **x** indicates execute permission. A **-** in a column indicates that the owner does *not* have the permission that would have appeared in that position.

In a similar manner the next three characters represent permissions for the *group*, and the final three characters represent permissions for *other* (everyone else). In the preceding example, the owner of **letter.0610** can read from and write to the file, whereas the group and others can only read from the file and no one is allowed to execute it. Although execute permission can be allowed for any file, it does not make sense to assign execute permission to a file that contains a document, such as a letter. The **check\_spell** file is an executable shell script, so execute permission is appropriate for it. (The owner, group, and others have execute access permission.)

## chmod: CHANGES ACCESS PERMISSIONS

The owner of a file controls which users have permission to access the file and how they can access it. When you own a file, you can use the **chmod** (change mode) utility to change access permissions for that file. In the following example, **chmod** adds (+) read and write permissions (**rw**) for all (**a**) users:

```
$ chmod a+rw letter.0610
$ ls -l letter.0610
-rw-rw-rw- 1 alex pubs 3355 May 2 10:52 letter.0610
```

### You must have read permission to execute a shell script

**tip** Because a shell needs to read a shell script (a text file containing shell commands) before it can execute the commands within that script, you must have read permission for the file containing the script to execute it. You also need execute permission to execute a shell script directly on the command line. In contrast, binary (program) files do not need to be read; they are executed directly. You need only execute permission to run a binary (nonshell) program.

In the next example, **chmod** removes (-) read (**r**) and execute (**x**) permissions for users other (**o**) than the owner of the file (**alex**) and members of the group the file is associated with (**pubs**):

```
$ chmod o-rx check_spell
$ ls -l check_spell
-rwxr-x--- 2 alex pubs 852 May 5 14:03 check_spell
```

In addition to **a** (*all*) and **o** (*other*), you can use **g** (*group*) and **u** (*user*, although **user** refers to the owner of the file who may or may not be the user of the file at any given time) in the argument to **chmod**. You can also use absolute, or numeric, arguments with **chmod**. Refer to page 287 for more information on using **chmod** to make a file executable and to the **chmod** man page for information on absolute arguments and **chmod** in general. Refer to page 472 for more information on groups.

The Linux file access permission scheme lets you give other users access to the files you want to share yet keep your private files confidential. You can allow other users to read from *and* write to a file (handy if you are one of several people working on a joint project). You can allow others only to read from a file (perhaps a project



---

**chmod: o for other, u for owner**

---

**tip** When using `chmod`, many people assume that the **o** stands for *owner*; it does not. The **o** stands for *other*, whereas **u** stands for *owner (user)*. The acronym UGO (user-group-other) can help you remember how permissions are named.

---

specification you are proposing). Or you can allow others only to write to a file (similar to an inbox or mailbox, where you want others to be able to send you mail but do not want them to read your mail). Similarly you can protect entire directories from being scanned (covered shortly).

There is an exception to the access permissions just described. Anyone who knows the **root** password can log in as Superuser (page 405) and gain full access to *all* files, regardless of the file's owner or access permissions.

## SETUID AND SETGID PERMISSIONS

When you execute a file that has `setuid` (set user ID) permission, the process executing the file takes on the privileges of the file's owner. For example, if you run a `setuid` program that removes all files in a directory, you can remove files in any of the file owner's directories, even if you do not normally have permission to do so.

---

**Minimize use of `setuid` and `setgid` programs owned by `root`**

---

**security** Executable files that are `setuid` and owned by **root** have Superuser privileges when they are run, even if they are not run by **root**. This type of program is very powerful because it can do anything that Superuser can do (and that the program is designed to do). Similarly executable files that are `setgid` and belong to the group **root** have extensive privileges.

Because of the power they hold and their potential for destruction, it is wise to avoid indiscriminately creating and using `setuid` and `setgid` programs owned by or belonging to the group **root**. Because of their inherent dangers, many sites minimize the use of these programs on their systems. One necessary `setuid` program is `passwd`. See page 407 for a tip on `setuid` files owned by **root** and page 413 for a command that lists `setuid` files on the local system.

---

In a similar manner, `setgid` (set group ID) permission means that the process executing the file takes on the privileges of the group the file is associated with. The `ls` utility shows `setuid` permission by placing an `s` in the owner's executable position and `setgid` permission by placing an `s` in the group's executable position:

```
$ ls -l program1
-rwxr-xr-x  1 alex pubs 15828 Nov  5 06:28 program1
$ chmod u+s program1
$ ls -l program1
-rwsr-xr-x  1 alex pubs 15828 Nov  5 06:28 program1
$ chmod g+s program1
$ ls -l program1
-rwsr-sr-x  1 alex pubs 15828 Nov  5 06:28 program1
```

---

**Do not write `setuid` shell scripts**

---

**security** Never give shell scripts `setuid` permission. Several techniques for subverting them are well known.

---

## DIRECTORY ACCESS PERMISSIONS

Access permissions have slightly different meanings when they are used with directories. Although the three types of users can read from or write to a directory, the directory cannot be executed. Execute access permission is redefined for a directory: It means that you can `cd` into the directory and/or examine files that you have permission to read from in the directory. It has nothing to do with executing a file.

When you have only execute permission for a directory, you can use `ls` to list a file in the directory if you know its name. You cannot use `ls` without an argument to list the entire contents of the directory. In the following exchange, Jenny first verifies that she is logged in as herself. Then she checks the permissions on Alex's **info** directory. You can view the access permissions associated with a directory by running `ls` with the `-d` (directory) and `-l` (long) options:

```
$ who am i
jenny      pts/7    Aug 21 10:02
$ ls -ld /home/alex/info
drwx-----x  2 alex pubs 512 Aug 21 09:31 /home/alex/info
$ ls -l /home/alex/info
ls: /home/alex/info: Permission denied
```

The **d** at the left end of the line that `ls` displays indicates that **/home/alex/info** is a directory. Alex has read, write, and execute permissions; members of the **pubs** group have no access permissions; and other users have execute permission only, as indicated by the **x** at the right end of the permissions. Because Jenny does not have read permission for the directory, the `ls -l` command returns an error.

When Jenny specifies the names of the files she wants information about, she is not reading new directory information but rather searching for specific information, which she is allowed to do with execute access to the directory. She has read permission for **notes** so she has no problem using `cat` to display the file. She cannot display **financial** because she does not have read permission for it:

```
$ ls -l /home/alex/info/financial /home/alex/info/notes
-rw-----  1 alex pubs 34 Aug 21 09:31 /home/alex/info/financial
-rw-r--r--  1 alex pubs 30 Aug 21 09:32 /home/alex/info/notes

$ cat /home/alex/info/notes
This is the file named notes.
$ cat /home/alex/info/financial
cat: /home/alex/info/financial: Permission denied
```

Next Alex gives others read access to his **info** directory:

```
$ chmod o+r /home/alex/info
```

When Jenny checks her access permissions on **info**, she finds that she has both read and execute access to the directory. Now `ls -l` works just fine without arguments, but she still cannot read **financial**. (This restriction is an issue of file permissions, not directory permissions.) Finally, Jenny tries to create a file named **newfile** by

using touch. If Alex were to give her write permission to the **info** directory, Jenny would be able to create new files in it:

```
$ ls -ld /home/alex/info
drwx---r-x  2 alex pubs 512 Aug 21 09:31 /home/alex/info
$ ls -l /home/alex/info
total 8
-rw-----  1 alex pubs 34 Aug 21 09:31 financial
-rw-r--r--  1 alex pubs 30 Aug 21 09:32 notes
$ cat /home/alex/info/financial
cat: financial: Permission denied
$ touch /home/alex/info/newfile
touch: cannot touch '/home/alex/info/newfile': Permission denied
```

## ACLs: ACCESS CONTROL LISTS

Access Control Lists (ACLs) provide finer-grained control over which users can access specific directories and files than do traditional Linux permissions (page 202). Using ACLs you can specify the ways in which each of several users can access a directory or file. Because ACLs can reduce performance, do not enable them on filesystems that hold system files, where the traditional Linux permissions are sufficient. Also be careful when moving, copying, or archiving files: Not all utilities preserve ACLs. In addition, you cannot copy ACLs to filesystems that do not support ACLs.

### Most utilities do not preserve ACLs

**caution** When used with the **-p** (preserve) or **-a** (archive) option, **cp** preserves ACLs when it copies files. Another utility that is supplied with Fedora/RHEL that preserves ACLs is **mv**. When you use **cp** with the **-p** or **-a** option and it is not able to copy ACLs, and in the case where **mv** is unable to preserve ACLs, the utility performs the operation and issues an error message:

```
$ mv report /tmp
mv: preserving permissions for '/tmp/report': Operation not supported
```

Other utilities, such as **tar**, **cpio**, and **dump**, do not support ACLs. You can use **cp** with the **-a** option to copy directory hierarchies, including ACLs.

You can never copy ACLs to a filesystem that does not support ACLs or to a filesystem that does not have ACL support turned on.

An ACL comprises a set of rules. A rule specifies how a specific user or group can access the file that the ACL is associated with. There are two kinds of rules: *access rules* and *default rules*. (The documentation refers to *access ACLs* and *default ACLs*, even though there is only one type of ACL: There is one type of list [ACL] and there are two types of rules that an ACL can contain.)

An access rule specifies access information for a single file or directory. A default ACL pertains to a directory only; it specifies default access information (an ACL) for any file in the directory that is not given an explicit ACL.

## ENABLING ACLS

Fedora/RHEL officially supports ACLs on **ext2** and **ext3** filesystems only, although informal support for ACLs is available on other filesystems. By default, ACLs are turned on on **ext2** and **ext3** filesystems. To turn ACLs off, you must mount the device with the **no\_acl** option (**acl** is the default). For example, if you want to mount the device represented by **/home** so that you cannot use ACLs on files in **/home**, you can add **no\_acl** to its options list in **/etc/fstab**:

```
$ grep home /etc/fstab
LABEL=/home          /home          ext3    defaults,no_acl    1 2
```

After changing **fstab**, you need to remount **/home** to turn off ACLs. If no one else is using the system, you can unmount it and mount it again (working as **root**) as long as your working directory is not in the **/home** hierarchy. Alternatively you can use the **remount** option to mount to remount **/home** while the device is in use:

```
# mount -v -o remount /home
/dev/sda3 on /home type ext3 (rw,no_acl)
```

See page 490 for information on **fstab** and page 487 for information on **mount**.

## WORKING WITH ACCESS RULES

The **setfacl** utility modifies a file's ACL and the **getfacl** utility displays a file's ACL. When you use **getfacl** to obtain information about a file that does not have an ACL, it displays the same information as an **ls -l** command, albeit in a different format:

```
$ ls -l report
-rw-r--r-- 1 max max 9537 Jan 12 23:17 report

$ getfacl report
# file: report
# owner: max
# group: max
user::rw-
group::r--
other::r--
```

The first three lines of the **getfacl** output are called the header; they specify the name of the file, the owner of the file, and the group the file is associated with. For more information refer to “**ls -l: Displays Permissions**” on page 203. The **--omit-header** (or just **--omit**) option causes **getfacl** not to display the header:

```
$ getfacl --omit-header report
user::rw-
group::r--
other::r--
```

In the line that starts with **user**, the two colons (::) with no name between them indicate that the line specifies the permissions for the owner of the file. Similarly, the

two colons in the **group** line indicate that the line specifies permissions for the group the file is associated with. The two colons following **other** are there for consistency: No name can be associated with **other**.

The **setfacl --modify** (or **-m**) option adds or modifies one or more rules in a file's ACL using the following format:

```
setfacl --modify ugo:name:permissions file-list
```

where **ugo** can be either **u**, **g**, or **o** to indicate that the command sets file permissions for a user, a group, or all other users, respectively; **name** is the name of the user or group that permissions are being set for; **permissions** is the permissions in either symbolic or absolute format; and **file-list** is the list of files that the permissions are to be applied to. You must omit **name** when you specify permissions for other users (**o**). Symbolic permissions use letters to represent file permissions (**rw****x**, **r****-****x**, and so on), whereas absolute permissions use an octal number. While **chmod** uses three sets of permissions or three octal numbers (one each for the owner, group, and other users), **setfacl** uses a single set of permissions or a single octal number to represent the permissions being granted to the user or group represented by **ugo** and **name**.

For example, both of the following commands add a rule to the ACL for the **report** file that gives Sam read and write permission to that file:

```
$ setfacl --modify u:sam:rw- report
```

or

```
$ setfacl --modify u:sam:6 report
```

```
$ getfacl report
# file: report
# owner: max
# group: max
user::rw-
user:sam:rw-
group::r--
mask::rw-
other::r--
```

The line containing **user:sam:rw-** shows that the user named **sam** has read and write access (**rw-**) to the file. See page 203 for an explanation of how to read symbolic access permissions. See the following optional section for a description of the line that starts with **mask**.

When a file has an ACL, **ls -l** displays a plus sign (+) following the permissions, even if the ACL is empty:

```
$ ls -l report
-rw-rw-r--+ 1 max max 9537 Jan 12 23:17 report
```

**optional EFFECTIVE RIGHTS MASK**

The line that starts with **mask** specifies the *effective rights mask*. This mask limits the effective permissions granted to ACL groups and users. It does not affect the owner of the file or the group the file is associated with. In other words, it does not affect traditional Linux permissions. However, because **getfacl** always sets the effective rights mask to the least restrictive ACL permissions for the file, the mask has no effect unless you set it explicitly after you set up an ACL for the file. You can set the mask by specifying **mask** in place of **ugo** and by not specifying a **name** in a **setfacl** command.

The following example sets the effective rights mask to **read** for the **report** file:

```
$ setfacl -m mask::r-- report
```

The **mask** line in the following **getfacl** output shows the effective rights mask set to read (r--). The line that displays Sam's file access permissions shows them still set to read and write. However, the comment at the right end of the line shows that his effective permission is read.

```
$ getfacl report
# file: report
# owner: max
# group: max
user::rw-
user:sam:r--                    #effective:r--
group::r--
mask::r--
other::r--
```

As the next example shows, **setfacl** can modify ACL rules and can set more than one ACL rule at a time:

```
$ setfacl -m u:sam:r--,u:zach:rw- report
```

```
$ getfacl --omit-header report
user::rw-
user:sam:r--
user:zach:rw-
group::r--
mask::rw-
other::r--
```

The **-x** option removes ACL rules for a user or a group. It has no effect on permissions for the owner of the file or the group that the file is associated with. The next example shows **setfacl** removing the rule that gives Sam permission to access the file:

```
$ setfacl -x u:sam report
```

```
$ getfacl --omit-header report
user::rw-
user:zach:rw-
group::r--
mask::rw-
other::r--
```

You must not specify *permissions* when you use the `-x` option. Instead, specify only the *ugo* and *name*. The `-b` option, followed by a filename only, removes all ACL rules and the ACL itself from the file or directory you specify.

Both `setfacl` and `getfacl` have many options. Use the `--help` option to display brief lists of options or refer to the man pages for details.

## SETTING DEFAULT RULES FOR A DIRECTORY

The following example shows that the `dir` directory initially has no ACL. The `setfacl` command uses the `-d` option to add two default rules to the ACL for `dir`. These rules apply to all files in the `dir` directory that do not have explicit ACLs. The rules give members of the `pubs` group read and execute permissions and give members of the `admin` group read, write, and execute permissions.

```
$ ls -ld dir
drwx----- 2 max max 4096 Feb 12 23:15 dir
$ getfacl dir
# file: dir
# owner: max
# group: max
user::rwx
group:---
other:---

$ setfacl -d -m g:pubs:r-x,g:admin:rwx dir
```

The following `ls` command shows that the `dir` directory now has an ACL, as indicated by the `+` to the right of the permissions. Each of the default rules that `getfacl` displays starts with `default:`. The first two default rules and the last default rule specify the permissions for the owner of the file, the group that the file is associated with, and all other users. These three rules specify the traditional Linux permissions and take precedence over other ACL rules. The third and fourth rules specify the permissions for the `pubs` and `admin` groups. Next is the default effective rights mask.

```
$ ls -ld dir
drwx-----+ 2 max max 4096 Feb 12 23:15 dir
$ getfacl dir
# file: dir
# owner: max
# group: max
user::rwx
group:---
other:---
default:user::rwx
default:group:---
default:group:pubs:r-x
default:group:admin:rwx
default:mask::rwx
default:other:---
```

Remember that the default rules pertain to files held in the directory that are not assigned ACLs explicitly. You can also specify access rules for the directory itself.

When you create a file within a directory that has default rules in its ACL, the effective rights mask for that file is created based on the file's permissions. In some cases the mask may override default ACL rules.

In the next example, `touch` creates a file named **new** in the **dir** directory. The `ls` command shows that this file has an ACL. Based on the value of `umask` (page 440), both the owner and the group that the file is associated with have read and write permissions for the file. The effective rights mask is set to read and write so that the effective permission for **pubs** is read and the effective permissions for **admin** are read and write. Neither group has execute permission.

```
$ cd dir
$ touch new
$ ls -l new
-rw-rw----+ 1 max max 0 Feb 13 00:39 new
$ getfacl --omit new
user::rw-
group:----
group:pubs:r-x          #effective:r--
group:admin:rw-         #effective:rw-
mask::rw-
other:----
```

If you change the file's traditional permissions to read, write, and execute for the owner and the group, the effective rights mask changes to read, write, and execute and the groups specified by the default rules gain execute access to the file.

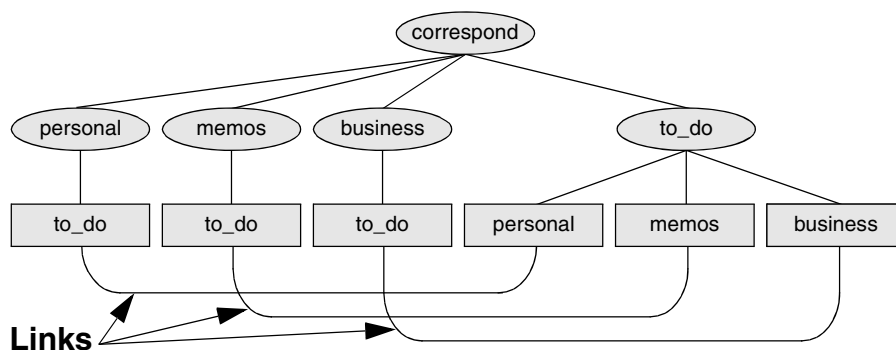
```
$ chmod 770 new
$ ls -l new
-rwxrwx---+ 1 max max 0 Feb 13 00:39 new
$ getfacl --omit new
user::rwx
group:----
group:pubs:r-x
group:admin:rwx
mask::rwx
other:----
```

---

## LINKS

A *link* is a pointer to a file. Every time you create a file by using `vim`, `touch`, `cp`, or any other means, you are putting a pointer in a directory. This pointer associates a filename with a place on the disk. When you specify a filename in a command, you are indirectly pointing to the place on the disk that holds the information you want.





**Figure 6-13** Using links to cross-classify files

Sharing files can be useful when two or more people are working on the same project and need to share some information. You can make it easy for other users to access one of your files by creating additional links to the file.

To share a file with another user, first give the user permission to read from and write to the file (page 204). You may also have to change the access permissions of the parent directory of the file to give the user read, write, or execute permission (page 206). Once the permissions are appropriately set, the user can create a link to the file so that each of you can access the file from your separate directory hierarchies.

A link can also be useful to a single user with a large directory hierarchy. You can create links to cross-classify files in your directory hierarchy, using different classifications for different tasks. For example, if you have the file layout depicted in Figure 6-2 on page 189, a file named **to\_do** might appear in each subdirectory of the **correspond** directory—that is, in **personal**, **memos**, and **business**. If you find it difficult to keep track of everything you need to do, you can create a separate directory named **to\_do** in the **correspond** directory. You can then link each subdirectory's to-do list into that directory. For example, you could link the file named **to\_do** in the **memos** directory to a file named **memos** in the **to\_do** directory. This set of links is shown in Figure 6-13.

Although it may sound complicated, this technique keeps all your to-do lists conveniently in one place. The appropriate list is easily accessible in the task-related directory when you are busy composing letters, writing memos, or handling personal business.

### About the discussion of hard links

**tip** Two kinds of links exist: hard links and symbolic (soft) links. Hard links are older and becoming outdated. The section on hard links is marked as optional; you can skip it, although it discusses inodes and gives you insight into the structure of the filesystem.

optional

## HARD LINKS

A hard link to a file appears as another file. If the file appears in the same directory as the linked-to file, the links must have different filenames because two files in the same directory cannot have the same name. You can create a hard link to a file only from within the filesystem that holds the file.

### ln: CREATES A HARD LINK

The `ln` (link) utility (without the `-s` or `--symbolic` option) creates a hard link to an existing file using the following syntax:

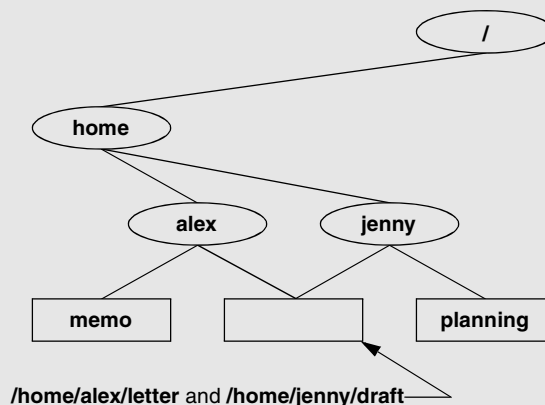
*ln existing-file new-link*

The next command makes the link shown in Figure 6-14 by creating a new link named `/home/alex/letter` to an existing file named `draft` in Jenny's home directory:

```
$ pwd
/home/jenny
$ ln draft /home/alex/letter
```

The new link appears in the `/home/alex` directory with the filename `letter`. In practice, Alex may need to change the directory and file permissions so that Jenny will be able to access the file. Even though `/home/alex/letter` appears in Alex's directory, Jenny is the owner of the file because she created it.

The `ln` utility creates an additional pointer to an existing file but it does *not* make another copy of the file. Because there is only one file, the file status information—such as access permissions, owner, and the time the file was last modified—is the same for all links; only the filenames differ. When Jenny modifies `/home/jenny/draft`, for example, Alex sees the changes in `/home/alex/letter`.



**Figure 6-14** Two links to the same file: `/home/alex/letter` and `/home/jenny/draft`

## cp VERSUS ln

The following commands verify that `ln` does not make an additional copy of a file. Create a file, use `ln` to make an additional link to the file, change the contents of the file through one link, and verify the change through the other link:

```
$ cat file_a
This is file A.
$ ln file_a file_b
$ cat file_b
This is file A.
$ vim file_b
...
$ cat file_b
This is file B after the change.
$ cat file_a
This is file B after the change.
```

If you try the same experiment using `cp` instead of `ln` and change a *copy* of the file, the difference between the two utilities will become clearer. Once you change a *copy* of a file, the two files are different:

```
$ cat file_c
This is file C.
$ cp file_c file_d
$ cat file_d
This is file C.
$ vim file_d
...
$ cat file_d
This is file D after the change.
$ cat file_c
This is file C.
```

**ls and link counts** You can use `ls` with the `-l` option, followed by the names of the files you want to compare, to confirm that the status information is the same for two links to the same file and is different for files that are not linked. In the following example, the 2 in the links field (just to the left of `alex`) shows there are two links to `file_a` and `file_b`:

```
$ ls -l file_a file_b file_c file_d
-rw-r--r-- 2 alex pubs 33 May 24 10:52 file_a
-rw-r--r-- 2 alex pubs 33 May 24 10:52 file_b
-rw-r--r-- 1 alex pubs 16 May 24 10:55 file_c
-rw-r--r-- 1 alex pubs 33 May 24 10:57 file_d
```

Although it is easy to guess which files are linked to one another in this example, `ls` does not explicitly tell you.

**ls and inodes** Use `ls` with the `-i` option to determine without a doubt which files are linked. The `-i` option lists the *inode* (page 1087) number for each file. An inode is the control structure for a file. If the two filenames have the same inode number, they share the same control structure and are links to the same file. Conversely, when two filenames have different inode numbers, they are different files. The following example

shows that **file\_a** and **file\_b** have the same inode number and that **file\_c** and **file\_d** have different inode numbers:

```
$ ls -li file_a file_b file_c file_d
3534 file_a    3534 file_b    5800 file_c    7328 file_d
```

All links to a file are of equal value: The operating system cannot distinguish the order in which multiple links were created. When a file has two links, you can remove either one and still access the file through the remaining link. You can remove the link used to create the file, for example, and, as long as one link remains, still access the file through that link.

## SYMBOLIC LINKS

In addition to hard links, Linux supports *symbolic links*, also called *soft links* or *symlinks*. A hard link is a pointer to a file (the directory entry points to the inode), whereas a symbolic link is an *indirect* pointer to a file (the directory entry contains the pathname of the pointed-to file—a pointer to the hard link to the file).

Advantages of  
symbolic links

Symbolic links were developed because of the limitations inherent in hard links. You cannot create a hard link to a directory, but you can create a symbolic link to a directory.

In many cases the Linux file hierarchy encompasses several filesystems. Because each filesystem keeps separate control information (that is, separate inode tables or filesystem structures) for the files it holds, it is not possible to create hard links between files in different filesystems. A symbolic link can point to any file, regardless of where it is located in the file structure, but a hard link to a file must be in the same filesystem as the other hard link(s) to the file. When you create links only among files in your home directory, you will not notice this limitation.

A major advantage of a symbolic link is that it can point to a nonexistent file. This ability is useful if you need a link to a file that is periodically removed and re-created. A hard link keeps pointing to a “removed” file, which the link keeps alive even after a new file is created. In contrast, a symbolic link always points to the newly created file and does not interfere when you delete the old file. For example, a symbolic link could point to a file that gets checked in and out under a source code control system, a **.o** file that is re-created by the C compiler each time you run **make**, or a log file that is repeatedly archived.

Although they are more general than hard links, symbolic links have some disadvantages. Whereas all hard links to a file have equal status, symbolic links do not have the same status as hard links. When a file has multiple hard links, it is analogous to a person having multiple full legal names, as many married women do. In contrast, symbolic links are analogous to nicknames. Anyone can have one or more nicknames, but these nicknames have a lesser status than legal names. The following sections describe some of the peculiarities of symbolic links.

### ln: CREATES A SYMBOLIC LINK

You use **ln** with the **--symbolic** (or **-s**) option to create a symbolic link. The following example creates a symbolic link **/tmp/s3** to the file **sum** in Alex’s home

directory. When you use an `ls -l` command to look at the symbolic link, `ls` displays the name of the link and the name of the file it points to. The first character of the listing is `l` (for link).

```
$ ln --symbolic /home/alex/sum /tmp/s3
$ ls -l /home/alex/sum /tmp/s3
-rw-rw-r-- 1 alex alex 38 Jun 12 09:51 /home/alex/sum
lrwxrwxrwx 1 alex alex 14 Jun 12 09:52 /tmp/s3 -> /home/alex/sum
$ cat /tmp/s3
This is sum.
```

The sizes and times of the last modifications of the two files are different. Unlike a hard link, a symbolic link to a file does not have the same status information as the file itself.

You can also use `ln` to create a symbolic link to a directory. When you use the `--symbolic` option, `ln` does not care whether the file you are creating a link to is an ordinary file or a directory.

### Use absolute pathnames with symbolic links

**tip** Symbolic links are literal and are not aware of directories. A link that points to a relative pathname, which includes simple filenames, assumes that the relative pathname is relative to the directory that the link was created *in* (not the directory the link was created *from*). In the following example, the link points to the file named **sum** in the **/tmp** directory. Because no such file exists, `cat` gives an error message:

```
$ pwd
/home/alex
$ ln --symbolic sum /tmp/s4
$ ls -l sum /tmp/s4
lrwxrwxrwx 1 alex alex 3 Jun 12 10:13 /tmp/s4 -> sum
-rw-rw-r-- 1 alex alex 38 Jun 12 09:51 sum
$ cat /tmp/s4
cat: /tmp/s4: No such file or directory
```

### optional **cd AND SYMBOLIC LINKS**

When you use a symbolic link as an argument to `cd` to change directories, the results can be confusing, particularly if you did not realize that you were using a symbolic link.

If you use `cd` to change to a directory that is represented by a symbolic link, the `pwd` shell builtin lists the name of the symbolic link. The `pwd` utility (**/bin/pwd**) lists the name of the linked-to directory, not the link, regardless of how you got there.

```
$ ln -s /home/alex/grades /tmp/grades.old
$ pwd
/home/alex
$ cd /tmp/grades.old
$ pwd
/tmp/grades.old
$ /bin/pwd
/home/alex/grades
```

When you change directories back to the parent, you end up in the directory holding the symbolic link:

```
$ cd ..
$ pwd
/tmp
$ /bin/pwd
/tmp
```

## rm: REMOVES A LINK

When you create a file, there is one hard link to it. You can then delete the file or, using Linux terminology, remove the link with the `rm` utility. When you remove the last hard link to a file, you can no longer access the information stored there and the operating system releases the space the file occupied on the disk for subsequent use by other files. This space is released even if symbolic links to the file remain. When there is more than one hard link to a file, you can remove a hard link and still access the file from any remaining link. Unlike DOS and Windows, Linux does not provide an easy way to undelete a file once you have removed it. A skilled hacker, however, can sometimes piece the file together with time and effort.

When you remove all hard links to a file, you will not be able to access the file through a symbolic link. In the following example, `cat` reports that the file `total` does not exist because it is a symbolic link to a file that has been removed:

```
$ ls -l sum
-rw-r--r-- 1 alex pubs 981 May 24 11:05 sum
$ ln -s sum total
$ rm sum
$ cat total
cat: total: No such file or directory
$ ls -l total
lrwxrwxrwx 1 alex pubs 6 May 24 11:09 total -> sum
```

When you remove a file, be sure to remove all symbolic links to it. Remove a symbolic link in the same way you remove other files:

```
$ rm total
```

## CHAPTER SUMMARY

Linux has a hierarchical, or treelike, file structure that makes it possible to organize files so that you can find them quickly and easily. The file structure contains directory files and ordinary files. Directories contain other files, including other directories; ordinary files generally contain text, programs, or images. The ancestor of all files is the root directory named `/`.

Most Linux filesystems support 255-character filenames. Nonetheless, it is a good idea to keep filenames simple and intuitive. Filename extensions can help make filenames more meaningful.

When you are logged in, you are always associated with a working directory. Your home directory is your working directory from the time you log in until you use `cd` to change directories.

An absolute pathname starts with the root directory and contains all the filenames that trace a path to a given file. The pathname starts with a slash, representing the root directory, and contains additional slashes between the other filenames in the path.

A relative pathname is similar to an absolute pathname but traces the path starting from the working directory. A simple filename is the last element of a pathname and is a form of a relative pathname.

A Linux filesystem contains many important directories, including `/usr/bin`, which stores most of the Linux utility commands, and `/dev`, which stores device files, many of which represent physical pieces of hardware. An important standard file is `/etc/passwd`; it contains information about users, such as each user's ID and full name.

Among the attributes associated with each file are access permissions. They determine who can access the file and how the file may be accessed. Three groups of users can potentially access the file: the owner, the members of a group, and all other users. An ordinary file can be accessed in three ways: read, write, and execute. The `ls` utility with the `-l` option displays these permissions. For directories, execute access is redefined to mean that the directory can be searched.

The owner of a file or Superuser can use the `chmod` utility to change the access permissions of a file. This utility specifies read, write, and execute permissions for the file's owner, the group, and all other users on the system.

Access Control Lists (ACLs) provide finer-grained control over which users can access specific directories and files than do traditional Linux permissions. Using ACLs you can specify the ways in which each of several users can access a directory or file. Few utilities preserve ACLs when working with these files.

An ordinary file stores user data, such as textual information, programs, or images. A directory is a standard-format disk file that stores information, including names, about ordinary files and other directory files. An inode is a data structure, stored on disk, that defines a file's existence and is identified by an inode number. A directory relates each of the filenames it stores to a specific inode.

A link is a pointer to a file. You can have several links to a single file so that you can share the file with other users or have the file appear in more than one directory. Because only one copy of a file with multiple links exists, changing the file through any one link causes the changes to appear in all the links. Hard links cannot link directories or span filesystems, whereas symbolic links can.

Table 6-2 summarizes the utilities introduced in this chapter.

**Table 6-2** Utilities introduced in Chapter 6

| Utility | Function                                                  |
|---------|-----------------------------------------------------------|
| cd      | Associates you with another working directory (page 196)  |
| chmod   | Changes the access permissions on a file (page 204)       |
| getfacl | Displays a file's ACL (page 208)                          |
| ln      | Makes a link to an existing file (page 214)               |
| mkdir   | Creates a directory (page 195)                            |
| pwd     | Displays the pathname of the working directory (page 192) |
| rmdir   | Deletes a directory (page 200)                            |
| setfacl | Modifies a file's ACL (page 208)                          |

---

## EXERCISES

- Is each of the following an absolute pathname, a relative pathname, or a simple filename?
  - milk\_co
  - correspond/business/milk\_co
  - /home/alex
  - /home/alex/literature/promo
  - ..
  - letter.0610
- List the commands you can use to perform these operations:
  - Make your home directory the working directory
  - Identify the working directory
- If your working directory is **/home/alex** with a subdirectory named **literature**, give three sets of commands that you can use to create a subdirectory named **classics** under **literature**. Also give several sets of commands you can use to remove the **classics** directory and its contents.
- The **df** utility displays all mounted filesystems along with information about each. Use the **df** utility with the **-h** (human-readable) option to answer the following questions.
  - How many filesystems are mounted on your Linux system?
  - Which filesystem stores your home directory?



- c. Assuming that your answer to exercise 4a is two or more, attempt to create a hard link to a file on another filesystem. What error message do you get? What happens when you attempt to create a symbolic link to the file instead?
5. Suppose that you have a file that is linked to a file owned by another user. How can you ensure that changes to the file are no longer shared?
6. You should have read permission for the `/etc/passwd` file. To answer the following questions, use `cat` or `less` to display `/etc/passwd`. Look at the fields of information in `/etc/passwd` for the users on your system.
  - a. Which character is used to separate fields in `/etc/passwd`?
  - b. How many fields are used to describe each user?
  - c. How many users are on your system?
  - d. How many different login shells are in use on your system? (*Hint*: Look at the last field.)
  - e. The second field of `/etc/passwd` stores user passwords in encoded form. If the password field contains an `x`, your system uses shadow passwords and stores the encoded passwords elsewhere. Does your system use shadow passwords?
7. If `/home/jenny/draft` and `/home/alex/letter` are links to the same file and the following sequence of events occurs, what will be the date in the opening of the letter?
  - a. Alex gives the command `vim letter`.
  - b. Jenny gives the command `vim draft`.
  - c. Jenny changes the date in the opening of the letter to January 31, 2008, writes the file, and exits from `vim`.
  - d. Alex changes the date to February 1, 2008, writes the file, and exits from `vim`.
8. Suppose that a user belongs to a group that has all permissions on a file named `jobs_list`, but the user, as the owner of the file, has no permissions. Describe which operations, if any, the user/owner can perform on `jobs_list`. Which command can the user/owner give that will grant the user/owner all permissions on the file?
9. Does the root directory have any subdirectories that you cannot search as a regular user? Does the root directory have any subdirectories that you cannot read as a regular user? Explain.
10. Assume that you are given the directory structure shown in Figure 6-2 on page 189 and the following directory permissions:

```
d--x--x--- 3 jenny pubs 512 Mar 10 15:16 business
drwxr-xr-x 2 jenny pubs 512 Mar 10 15:16 business/milk_co
```

For each category of permissions—owner, group, and other—what happens when you run each of the following commands? Assume that the working directory is the parent of **correspond** and that the file **cheese\_co** is readable by everyone.

- a. `cd correspond/business/milk_co`
- b. `ls -l correspond/business`
- c. `cat correspond/business/cheese_co`

---

## ADVANCED EXERCISES

- 11. What is an inode? What happens to the inode when you move a file within a filesystem?
- 12. What does the `..` entry in a directory point to? What does this entry point to in the root (`/`) directory?
- 13. How can you create a file named `-i`? Which techniques do not work, and why do they not work? How can you remove the file named `-i`?
- 14. Suppose that the working directory contains a single file named **andor**. What error message do you get when you run the following command line?

```
$ mv andor and\or
```

Under what circumstances is it possible to run the command without producing an error?

- 15. The `ls -li` command displays a filename preceded by the inode number of the file (page 215). Write a command to output inode/filename pairs for the files in the working directory, sorted by inode number. (*Hint:* Use a pipe.)
- 16. Do you think that the system administrator has access to a program that can decode user passwords? Why or why not? (See exercise 6.)
- 17. Is it possible to distinguish a file from a hard link to a file? That is, given a filename, can you tell whether it was created using an `ln` command? Explain.
- 18. Explain the error messages displayed in the following sequence of commands:

```
$ ls -l
total 1
drwxrwxr-x  2 alex pubs 1024 Mar  2 17:57 dirtmp
$ ls dirtmp
$ rmdir dirtmp
rmdir: dirtmp: Directory not empty
$ rm dirtmp/*
rm: No match.
```

# THE SHELL

## IN THIS CHAPTER

|                                                 |     |
|-------------------------------------------------|-----|
| The Command Line .....                          | 224 |
| Standard Input and Standard<br>Output .....     | 230 |
| Redirection .....                               | 232 |
| Pipes .....                                     | 238 |
| Running a Program in the<br>Background .....    | 241 |
| kill: Aborting a Background Job ..              | 242 |
| Filename Generation/Pathname<br>Expansion ..... | 243 |
| Builtins .....                                  | 247 |

This chapter takes a close look at the shell and explains how to use some of its features. For example, it discusses command-line syntax and also describes how the shell processes a command line and initiates execution of a program. The chapter also explains how to redirect input to and output from a command, construct pipes and filters on the command line, and run a command in the background. The final section covers filename expansion and explains how you can use this feature in your everyday work.

The exact wording of the shell output differs from shell to shell: What your shell displays may differ slightly from what appears in this book. Refer to Chapter 9 for more information on `bash` and to Chapter 27 for information on writing and executing `bash` shell scripts.

## THE COMMAND LINE

The shell executes a program when you give it a command in response to its prompt. For example, when you give the `ls` command, the shell executes the utility program named `ls`. You can cause the shell to execute other types of programs—such as shell scripts, application programs, and programs you have written—in the same way. The line that contains the command, including any arguments, is called the *command line*. In this book the term *command* refers to the characters you type on the command line as well as to the program that action invokes.

## SYNTAX

Command-line syntax dictates the ordering and separation of the elements on a command line. When you press the RETURN key after entering a command, the shell scans the command line for proper syntax. The syntax for a basic command line is

*command* [*arg1*] [*arg2*] ... [*argn*] RETURN

One or more SPACES must separate elements on the command line. The *command* is the name of the command, *arg1* through *argn* are arguments, and RETURN is the key-stroke that terminates all command lines. The brackets in the command-line syntax indicate that the arguments they enclose are optional. Not all commands require arguments: Some commands do not allow arguments; other commands allow a variable number of arguments; and others require a specific number of arguments. Options, a special kind of argument, are usually preceded by one or two hyphens (also called a dash or minus sign: -).

## COMMAND NAME

Usage message Some useful Linux command lines consist of only the name of the command without any arguments. For example, `ls` by itself lists the contents of the working directory. Most commands accept one or more arguments. Commands that require arguments typically give a short error message, called a *usage message*, when you use them without arguments, with incorrect arguments, or with the wrong number of arguments.

## ARGUMENTS

On the command line each sequence of nonblank characters is called a *token* or *word*. An *argument* is a token, such as a filename, string of text, number, or other object that a command acts on. For example, the argument to a `vim` or `emacs` command is the name of the file you want to edit.

The following command line shows `cp` copying the file named `temp` to `tempcopy`:

```
$ cp temp tempcopy
```

Arguments are numbered starting with the command itself as argument zero. In this example **cp** is argument zero, **temp** is argument one, and **tempcopy** is argument two. The **cp** utility requires two arguments on the command line. (The utility can take more arguments but not fewer.) Argument one is the name of an existing file. Argument two is the name of the file that **cp** is creating or overwriting. Here the arguments are not optional; both arguments must be present for the command to work. When you do not supply the right number or kind of arguments, **cp** displays a usage message. Try typing **cp** and then pressing RETURN.

## OPTIONS

An *option* is an argument that modifies the effects of a command. You can frequently specify more than one option, modifying the command in several different ways. Options are specific to and interpreted by the program that the command line calls, not the shell.

By convention, options are separate arguments that follow the name of the command and usually precede other arguments, such as filenames. Most utilities require you to prefix options with a single hyphen. However, this requirement is specific to the utility and not the shell. GNU program options are frequently preceded by two hyphens in a row. For example, **--help** generates a (sometimes extensive) usage message.

Figure 7-1 first shows what happens when you give an **ls** command without any options. By default **ls** lists the contents of the working directory in alphabetical order, vertically sorted in columns. Next the **-r** (reverse order; because this is a GNU utility, you can also use **--reverse**) option causes the **ls** utility to display the list of files in reverse alphabetical order, still sorted in columns. The **-x** option causes **ls** to display the list of files in horizontally sorted rows.

Combining options When you need to use several options, you can usually group multiple single-letter options into one argument that starts with a single hyphen; do not put SPACES between the options. You cannot combine options that are preceded by two

```
$ ls
alex house mark office personal test
hold jenny names oldstuff temp
$ ls -r
test personal office mark house alex
temp oldstuff names jenny hold
$ ls -x
alex hold house jenny mark names
office oldstuff personal temp test
$ ls -rx
test temp personal oldstuff office names
mark jenny house hold alex
```

**Figure 7-1** Using options

hyphens in this way, however. Specific rules for combining options depend on the program you are running. Figure 7-1 shows both the `-r` and `-x` options with the `ls` utility. Together these options generate a list of filenames in horizontally sorted columns, in reverse alphabetical order. Most utilities allow you to list options in any order; thus `ls -xr` produces the same results as `ls -rx`. The command `ls -x -r` also generates the same list.

### Displaying readable file sizes: the `-h` option

---

**tip** Most utilities that report on file sizes specify the size of a file in bytes. Bytes work well when you are dealing with smaller files, but the numbers can be difficult to read when you are working with file sizes that are measured in megabytes or gigabytes. Use the `-h` (or **human-readable**) option to display file sizes in kilo-, mega-, and gigabytes. Experiment with `df -h` (disk free) and `ls -lh` commands.

---

**Option arguments** Some utilities have options that themselves require arguments. For example, the `gcc` utility has a `-o` option that must be followed by the name you want to give the executable file that `gcc` generates. Typically an argument to an option is separated from its option letter by a SPACE:

```
$ gcc -o prog prog.c
```

**Arguments that start with a hyphen** Another convention allows utilities to work with arguments, such as filenames, that start with a hyphen. If a file's name is `-l`, the following command is ambiguous:

```
$ ls -l
```

This command could mean a long listing of all files in the working directory or a listing of the file named `-l`. It is interpreted as the former. You should avoid creating files whose names begin with hyphens. If you do create them, many utilities follow the convention that a `--` argument (two consecutive hyphens) indicates the end of the options (and the beginning of the arguments). To disambiguate the command, you can type

```
$ ls -- -l
```

You can use an alternative format in which the period refers to the working directory and the slash indicates that the name refers to a file in the working directory:

```
$ ls ./-l
```

Assuming that you are working in the `/home/alex` directory, the preceding command is functionally equivalent to

```
$ ls /home/alex/-l
```

You can give the following command to get a long listing of this file:

```
$ ls -l -- -l
```

These are conventions, not hard-and-fast rules, and a number of utilities do not follow them (e.g., `find`). Following such conventions is a good idea; it makes it much easier for users to work with your program. When you write shell programs that require options, follow the Linux option conventions.

### The `--help` option

**tip** Many utilities display a (sometimes extensive) help message when you call them with an argument of `--help`. All utilities developed by the GNU Project (page 2) accept this option. An example follows.

```
$ bzip2 --help
bzip2, a block-sorting file compressor.  Version 1.0.4, 20-Dec-2006.

usage: bzip2 [flags and input files in any order]

-h --help            print this message
-d --decompress      force decompression
-z --compress        force compression
-k --keep            keep (don't delete) input files
-f --force           overwrite existing output files
-t --test            test compressed file integrity
-c --stdout          output to standard out
-q --quiet           suppress noncritical error messages
-v --verbose         be verbose (a 2nd -v gives more)
...
```

## PROCESSING THE COMMAND LINE

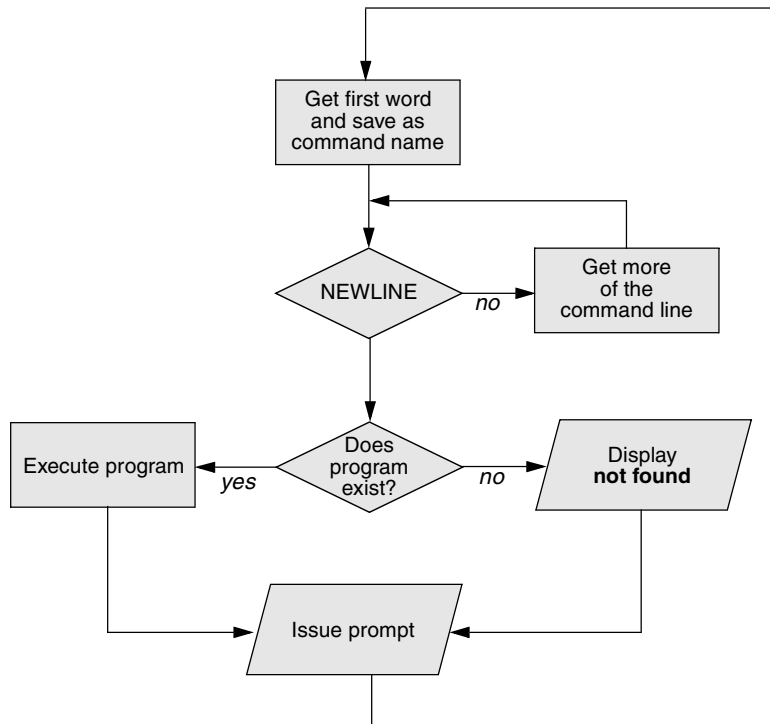
As you enter a command line, the Linux tty device driver (part of the Linux operating system kernel) examines each character to see whether it must take immediate action. When you press `CONTROL-H` (to erase a character) or `CONTROL-U` (to kill a line), the device driver immediately adjusts the command line as required; the shell never sees the character(s) you erased or the line you killed. Often a similar adjustment occurs when you press `CONTROL-W` (to erase a word). When the character you entered does not require immediate action, the device driver stores the character in a buffer and waits for additional characters. When you press `RETURN`, the device driver passes the command line to the shell for processing.

Parsing the  
command line

When the shell processes a command line, it looks at the line as a whole and *parses* (breaks) it into its component parts (Figure 7-2, next page). Next the shell looks for the name of the command. Usually the name of the command is the first item on the command line after the prompt (argument zero). The shell takes the first characters on the command line up to the first blank (`TAB` or `SPACE`) and then looks for a command with that name. The command name (the first token) can be specified on the command line either as a simple filename or as a pathname. For example, you can call the `ls` command in either of the following ways:

```
$ ls

$ /bin/ls
```



**Figure 7-2** Processing the command line

**optional** The shell does not require that the name of the program appear first on the command line. Thus you can structure a command line as follows:

```
$ >bb <aa cat
```

This command runs `cat` with standard input coming from the file named `aa` and standard output going to the file named `bb`. When the shell recognizes the redirect symbols (page 232), it recognizes and processes them and their arguments before finding the name of the program that the command line is calling. This is a properly structured—albeit rarely encountered and possibly confusing—command line.

Absolute versus  
relative pathnames

When you give an absolute pathname on the command line or a relative pathname that is not a simple filename (i.e., any pathname that includes at least one slash), the shell looks in the specified directory (`/bin` in the case of the `/bin/l`s command) for a file that has the name `ls` and that you have permission to execute. When you give a simple filename, the shell searches through a list of directories for a filename that matches the specified name and that you have execute permission for. The shell does not look through all directories but only the ones specified by the variable named `PATH`. Refer to page 306 for more information on `PATH`. Also refer to the discussion of the `which` and `whereis` utilities on page 166.



When it cannot find the executable file, the Bourne Again Shell (bash) displays a message such as the following:

```
$ abc
bash: abc: command not found
```

One reason the shell may not be able to find the executable file is that it is not in a directory in your **PATH**. Under bash the following command temporarily adds the working directory (.) to your **PATH**:

```
$ PATH=$PATH:.
```

For security reasons, you may not want to add the working directory to **PATH** permanently; see the adjacent tip and the one on page 307.

### Try giving a command as **./command**

**tip** You can always execute an executable file in the working directory by prepending **./** to the name of the file. For example, if **myprog** is an executable file in the working directory, you can execute it with the following command, regardless of how **PATH** is set:

```
$ ./myprog
```

When the shell finds the program but cannot execute it (you do not have execute permission for the file that contains the program), it displays a message similar to

```
$ def
bash: ./def: Permission denied
```

See “**ls -l**: Displays Permissions” on page 203 for information on displaying access permissions for a file and “**chmod**: Changes Access Permissions” on page 204 for instructions on how to change file access permissions.

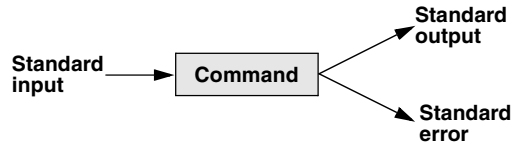
## EXECUTING THE COMMAND LINE

**Process** If it finds an executable file with the same name as the command, the shell starts a new process. A *process* is the execution of a command by Linux (page 314). The shell makes each command-line argument, including options and the name of the command, available to the called program. While the command is executing, the shell waits for the process to finish. At this point the shell is in an inactive state called *sleep*. When the program finishes execution, it passes its exit status (page 930) to the shell. The shell then returns to an active state (wakes up), issues a prompt, and waits for another command.

**The shell does not process arguments** Because the shell does not process command-line arguments but only hands them to the called program, the shell has no way of knowing whether a particular option or other argument is valid for a given program. Any error or usage messages about options or arguments come from the program itself. Some utilities ignore bad options.

## EDITING THE COMMAND LINE

You can repeat and edit previous commands and edit the current command line. See pages 140 and 318 for more information.



**Figure 7-3** The command does not know where standard input comes from or where standard output and standard error go

---

## STANDARD INPUT AND STANDARD OUTPUT

*Standard output* is a place that a program can send information, such as text. The program never “knows” where the information it sends to standard output is going (Figure 7-3). The information can go to a printer, an ordinary file, or the screen. The following sections show that by default the shell directs standard output from a command to the screen<sup>1</sup> and describe how you can cause the shell to redirect this output to another file.

*Standard input* is a place that a program gets information from. As with standard output the program never “knows” where the information came from. The following sections also explain how to redirect standard input to a command so that it comes from an ordinary file instead of from the keyboard (the default).

In addition to standard input and standard output, a running program normally has a place to send error messages: *standard error*. Refer to page 284 for more information on handling standard error.

## THE SCREEN AS A FILE

Chapter 6 introduced ordinary files, directory files, and hard and soft links. Linux has an additional type of file: a *device file*. A device file resides in the Linux file structure, usually in the `/dev` directory, and represents a peripheral device, such as a terminal emulator window, screen, printer, or disk drive.

The device name that the `who` utility displays after your username is the filename of your screen. For example, when `who` displays the device name `pts/4`, the pathname of your screen is `/dev/pts/4`. When you work with multiple windows, each window has its own device name. You can also use the `tty` utility to display the name of the device that you give the command from. Although you would not normally have occasion to do so, you can read from and write to this file as though it were a text file. Writing to it displays what you wrote on the screen; reading from it reads what you entered on the keyboard.

---

1. The term *screen* is used throughout this book to mean screen, terminal emulator window, or workstation. *Screen* refers to the device that you see the prompt and messages displayed on.

### chsh: changes your login shell

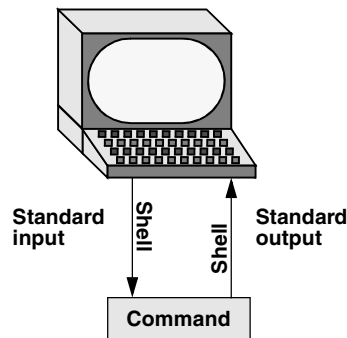
**tip** The person who sets up your account determines which shell you will use when you first log in on the system or when you open a terminal emulator window in a GUI environment. You can run any shell you like once you are logged in. Enter the name of the shell you want to use (`bash`, `tcsh`, or another shell) and press RETURN; the next prompt will be that of the new shell. Give an **exit** command to return to the previous shell. Because shells you call in this manner are nested (one runs on top of the other), you will be able to log out only from your original shell. When you have nested several shells, keep giving **exit** commands until you reach your original shell. You will then be able to log out.

Use the `chsh` utility when you want to change your login shell permanently. First give the command `chsh`. Then in response to the prompts enter your password and the absolute pathname of the shell you want to use (`/bin/bash`, `/bin/tcsh`, or the pathname of another shell). When you change your login shell in this manner using a terminal emulator (page 118) under a GUI, subsequent terminal emulator windows will not reflect the change until you log out of the system and log back in.

## THE KEYBOARD AND SCREEN AS STANDARD INPUT AND STANDARD OUTPUT

When you first log in, the shell directs standard output of your commands to the device file that represents your screen (Figure 7-4). Directing output in this manner causes it to appear on your screen. The shell also directs standard input to come from the same file, so that your commands receive as input anything you type on the keyboard.

**cat** The `cat` utility provides a good example of the way the keyboard and the screen function as standard input and standard output, respectively. When you use `cat`, it copies a file to standard output. Because the shell directs standard output to the screen, `cat` displays the file on the screen.



**Figure 7-4** By default, standard input comes from the keyboard and standard output goes to the screen

```

$ cat
This is a line of text.
This is a line of text.
Cat keeps copying lines of text
Cat keeps copying lines of text
until you press CONTROL-D at the beginning
until you press CONTROL-D at the beginning
of a line.
of a line.
CONTROL-D
$

```

**Figure 7-5** The cat utility copies standard input to standard output

Up to this point cat has taken its input from the filename (argument) you specified on the command line. When you do not give cat an argument (that is, when you give the command cat followed immediately by RETURN), cat takes its input from standard input. Thus, when called without an argument, cat copies standard input to standard output, one line at a time.

To see how cat works, type cat and press RETURN in response to the shell prompt. Nothing happens. Enter a line of text and press RETURN. The same line appears just under the one you entered. The cat utility is working. Because the shell associates cat's standard input with the keyboard and cat's standard output with the screen, when you type a line of text cat copies the text from standard input (the keyboard) to standard output (the screen). This exchange is shown in Figure 7-5.

CONTROL-D signals EOF The cat utility keeps copying text until you enter CONTROL-D on a line by itself. Pressing CONTROL-D sends an EOF (end of file) signal to cat to indicate that it has reached the end of standard input and there is no more text for it to copy. The cat utility then finishes execution and returns control to the shell, which displays a prompt.

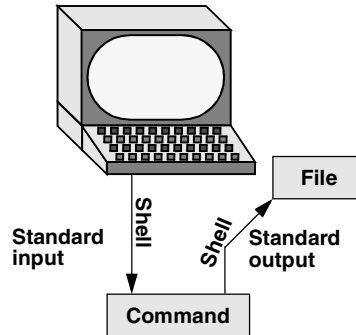
## REDIRECTION

The term *redirection* encompasses the various ways you can cause the shell to alter where standard input of a command comes from and where standard output goes to. By default the shell associates standard input and standard output of a command with the keyboard and the screen as mentioned earlier. You can cause the shell to redirect standard input or standard output of any command by associating the input or output with a command or file other than the device file representing the keyboard or the screen. This section demonstrates how to redirect input from and output to ordinary text files and utilities.

### REDIRECTING STANDARD OUTPUT

The *redirect output symbol* (>) instructs the shell to redirect the output of a command to the specified file instead of to the screen (Figure 7-6). The format of a command line that redirects output is

*command [arguments] > filename*



**Figure 7-6** Redirecting standard output

where *command* is any executable program (such as an application program or a utility), *arguments* are optional arguments, and *filename* is the name of the ordinary file the shell redirects the output to.

Figure 7-7 uses `cat` to demonstrate output redirection. This figure contrasts with Figure 7-5, where both standard input *and* standard output are associated with the keyboard and the screen. The input in Figure 7-7 comes from the keyboard. The redirect output symbol on the command line causes the shell to associate `cat`'s standard output with the `sample.txt` file specified on the command line.

After giving the command and typing the text shown in Figure 7-7, the `sample.txt` file contains the text you entered. You can use `cat` with an argument of `sample.txt` to display this file. The next section shows another way to use `cat` to display the file.

### Redirecting output can destroy a file I

**caution** Use caution when you redirect output to a file. If the file exists, the shell will overwrite it and destroy its contents. For more information see the tip “Redirecting output can destroy a file II” on page 236.

Figure 7-7 shows that redirecting the output from `cat` is a handy way to create a file without using an editor. The drawback is that once you enter a line and press RETURN, you cannot edit the text. While you are entering a line, the erase and kill keys work to delete text. This procedure is useful for making short, simple files.

```
$ cat > sample.txt
This text is being entered at the keyboard and
cat is copying it to a file.
Press CONTROL-D to indicate the
end of file.
CONTROL-D
$
```

**Figure 7-7** `cat` with its output redirected

```

$ cat stationery
2,000 sheets letterhead ordered: 10/7/09
$ cat tape
1 box masking tape ordered: 10/14/09
5 boxes filament tape ordered: 10/28/09
$ cat pens
12 doz. black pens ordered: 10/4/09

$ cat stationery tape pens > supply_orders

$ cat supply_orders
2,000 sheets letterhead ordered: 10/7/09
1 box masking tape ordered: 10/14/09
5 boxes filament tape ordered: 10/28/09
12 doz. black pens ordered: 10/4/09
$

```

**Figure 7-8** Using `cat` to concatenate files

Figure 7-8 shows how to use `cat` and the redirect output symbol to *catenate* (join one after the other—the derivation of the name of the `cat` utility) several files into one larger file. The first three commands display the contents of three files: `stationery`, `tape`, and `pens`. The next command shows `cat` with three filenames as arguments. When you call it with more than one filename, `cat` copies the files, one at a time, to standard output. In this case standard output is redirected to the file `supply_orders`. The final `cat` command shows that `supply_orders` contains the contents of all three files.

## REDIRECTING STANDARD INPUT

Just as you can redirect standard output, so you can redirect standard input. The *redirect input symbol* (`<`) instructs the shell to redirect a command's input to come from the specified file instead of from the keyboard (Figure 7-9). The format of a command line that redirects input is

*command [arguments] < filename*

where *command* is any executable program (such as an application program or a utility), *arguments* are optional arguments, and *filename* is the name of the ordinary file the shell redirects the input from.

Figure 7-10 shows `cat` with its input redirected from the `supply_orders` file that was created in Figure 7-8 and standard output going to the screen. This setup causes `cat` to display the sample file on the screen. The system automatically supplies an EOF (end of file) signal at the end of an ordinary file.

Utilities that take  
input from a file or  
standard input

Giving a `cat` command with input redirected from a file yields the same result as giving a `cat` command with the filename as an argument. The `cat` utility is a member of a class of Linux utilities that function in this manner. Other members of this class of utilities include `lpr`, `sort`, and `grep`. These utilities first examine the command line

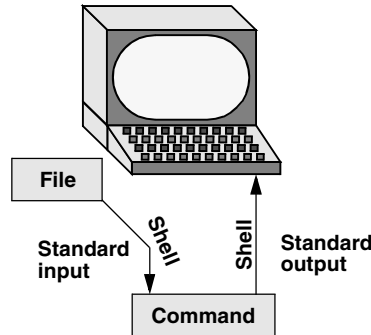


Figure 7-9 Redirecting standard input

that you use to call them. If you include a filename on the command line, the utility takes its input from the file you specify. If you do not specify a filename, the utility takes its input from standard input. It is the utility or program—not the shell or operating system—that functions in this manner.

## noclobber: AVOIDS OVERWRITING FILES

The shell provides a feature called **noclobber** that stops you from inadvertently overwriting an existing file using redirection. When you enable this feature by setting the **noclobber** variable and then attempt to redirect output to an existing file, the shell displays an error message and does not execute the command. If the preceding examples result in one of the following messages, the **noclobber** feature has been set. The following examples set **noclobber**, attempt to redirect the output from **echo** into an existing file, and then unset **noclobber**:

```

$ set -o noclobber
$ echo "hi there" > tmp
bash: tmp: Cannot overwrite existing file
$ set +o noclobber
$ echo "hi there" > tmp
$
  
```

You can override **noclobber** by putting a pipe symbol after the symbol you use for redirecting output (**>|**).

In the following example, the user first creates a file named **a** by redirecting the output of **date** to the file. Next the user sets the **noclobber** variable and tries redirecting

```

$ cat < supply_orders
2,000 sheets letterhead ordered: 10/7/09
1 box masking tape ordered:      10/14/09
5 boxes filament tape ordered:   10/28/09
12 doz. black pens ordered:      10/4/09
  
```

Figure 7-10 **cat** with its input redirected

output to **a** again. The shell returns an error message. Then the user tries the same thing but using a pipe symbol after the redirect symbol. This time the shell allows the user to overwrite the file. Finally, the user unsets **noclobber** (using a plus sign in place of the hyphen) and verifies that it is no longer set.

```
$ date > a
$ set -o noclobber
$ date > a
bash: a: Cannot overwrite existing file
$ date >| a
$ set +o noclobber
$ date > a
```

### Redirecting output can destroy a file II

---

**caution** Depending on which shell you are using and how your environment has been set up, a command such as the following may give you undesired results:

```
$ cat orange pear > orange
cat: orange: input file is output file
```

Although **cat** displays an error message, the shell goes ahead and destroys the contents of the existing **orange** file. The new **orange** file will have the same contents as **pear** because the first action the shell takes when it sees the redirection symbol (**>**) is to remove the contents of the original **orange** file. If you want to catenate two files into one, use **cat** to put the two files into a temporary file and then use **mv** to rename this third file:

```
$ cat orange pear > temp
$ mv temp orange
```

What happens in the next example can be even worse. The user giving the command wants to search through files **a**, **b**, and **c** for the word **apple** and redirect the output from **grep** (page 153) to the file **a.output**. Unfortunately the user enters the filename as **a output**, omitting the period and inserting a **SPACE** in its place:

```
$ grep apple a b c > a output
grep: output: No such file or directory
```

The shell obediently removes the contents of **a** and then calls **grep**. The error message may take a moment to appear, giving you a sense that the command is running correctly. Even after you see the error message, it may take a while to realize that you destroyed the contents of **a**.

---

## APPENDING STANDARD OUTPUT TO A FILE

The *append output symbol* (**>>**) causes the shell to add new information to the end of a file, leaving any existing information intact. This symbol provides a convenient way of catenating two files into one. The following commands demonstrate the action of the append output symbol. The second command accomplishes the catenation described in the preceding caution box:

```
$ cat orange
this is orange
$ cat pear >> orange
$ cat orange
this is orange
this is pear
```



You first see the contents of the **orange** file. Next the contents of the **pear** file is added to the end of (catenated with) the **orange** file. The final **cat** shows the result.

### Do not trust **noclobber**

**caution** Appending output is simpler than the two-step procedure described in the preceding caution box but you must be careful to include both greater than signs. If you accidentally use only one and the **noclobber** feature is not on, you will overwrite the **orange** file. Even if you have the **noclobber** feature turned on, it is a good idea to keep backup copies of files you are manipulating in these ways in case you make a mistake.

Although it protects you from making an erroneous redirection, **noclobber** does not stop you from overwriting an existing file using **cp** or **mv**. These utilities include the **-i** (interactive) option that helps protect you from this type of mistake by verifying your intentions when you try to overwrite a file. For more information see the tip “**cp** can destroy a file” on page 152.

The next example shows how to create a file that contains the date and time (the output from **date**), followed by a list of who is logged in (the output from **who**). The first line in Figure 7-11 redirects the output from **date** to the file named **whoson**. Then **cat** displays the file. Next the example appends the output from **who** to the **whoson** file. Finally **cat** displays the file containing the output of both utilities.

### /dev/null: MAKING DATA DISAPPEAR

The **/dev/null** device is a *data sink*, commonly referred to as a *bit bucket*. You can redirect output that you do not want to keep or see to **/dev/null**. The output disappears without a trace:

```
$ echo "hi there" > /dev/null
$
```

When you read from **/dev/null**, you get a null string. Give the following **cat** command to truncate a file named **messages** to zero length while preserving the ownership and permissions of the file:

```
$ ls -l messages
-rw-r--r-- 1 alex pubs 25315 Oct 24 10:55 messages
$ cat /dev/null > messages
$ ls -l messages
-rw-r--r-- 1 alex pubs 0 Oct 24 11:02 messages
```

```
$ date > whoson
$ cat whoson
Mon Mar 24 14:31:18 PST 2008
$ who >> whoson
$ cat whoson
Mon Mar 24 14:31:18 PST 2009
root      console      Mar 24 05:00(:0)
alex      pts/4        Mar 24 12:23(:0.0)
alex      pts/5        Mar 24 12:33(:0.0)
jenny     pts/7        Mar 23 08:45 (bravo.example.com)
```

**Figure 7-11** Redirecting and appending output

## PIPES

The shell uses a *pipe* to connect standard output of one command directly to standard input of another command. A pipe (sometimes referred to as a *pipeline*) has the same effect as redirecting standard output of one command to a file and then using that file as standard input to another command. A pipe does away with separate commands and the intermediate file. The symbol for a pipe is a vertical bar (`|`). The syntax of a command line using a pipe is

```
command_a [arguments] | command_b [arguments]
```

The preceding command line uses a pipe to generate the same result as the following group of command lines:

```
command_a [arguments] > temp
command_b [arguments] < temp
rm temp
```

In the preceding sequence of commands, the first line redirects standard output from *command\_a* to an intermediate file named *temp*. The second line redirects standard input for *command\_b* to come from *temp*. The final line deletes *temp*. The command using a pipe is not only easier to type but is generally more efficient because it does not create a temporary file.

- tr You can use a pipe with any of the Linux utilities that accept input either from a file specified on the command line or from standard input. You can also use pipes with commands that accept input only from standard input. For example, the `tr` (translate) utility takes its input from standard input only. In its simplest usage `tr` has the following format:

```
tr string1 string2
```

The `tr` utility accepts input from standard input and looks for characters that match one of the characters in *string1*. Upon finding a match, `tr` translates the matched character in *string1* to the corresponding character in *string2*. (The first character in *string1* translates into the first character in *string2*, and so forth.) The `tr` utility sends its output to standard output. In both of the following examples, `tr` displays the contents of the `abstract` file with the letters `a`, `b`, and `c` translated into `A`, `B`, and `C`, respectively:

```
$ cat abstract | tr abc ABC
$ tr abc ABC < abstract
```

```
$ ls > temp
$ lpr temp
$ rm temp
```

or

```
$ ls | lpr
```

Figure 7-12 A pipe

```

$ who > temp
$ sort < temp
alex      pts/4      Mar 24 12:23
alex      pts/5      Mar 24 12:33
jenny     pts/7      Mar 23 08:45
root      console    Mar 24 05:00
$ rm temp

```

**Figure 7-13** Using a temporary file to store intermediate results

The `tr` utility does not change the contents of the original file; it cannot change the original file because it does not “know” the source of its input.

- `lpr` The `lpr` (line printer) utility also accepts input from either a file or standard input. When you type the name of a file following `lpr` on the command line, it places that file in the print queue. When you do not specify a filename on the command line, `lpr` takes input from standard input. This feature enables you to use a pipe to redirect input to `lpr`. The first set of commands in Figure 7-12 shows how you can use `ls` and `lpr` with an intermediate file (**temp**) to send a list of the files in the working directory to the printer. If the **temp** file exists, the first command overwrites its contents. The second set of commands sends the same list (with the exception of **temp**) to the printer using a pipe.

The commands in Figure 7-13 redirect the output from the `who` utility to **temp** and then display this file in sorted order. The `sort` utility (page 155) takes its input from the file specified on the command line or, when a file is not specified, from standard input and sends its output to standard output. The `sort` command line in Figure 7-13 takes its input from standard input, which is redirected (`<`) to come from **temp**. The output that `sort` sends to the screen lists the users in sorted (alphabetical) order.

Because `sort` can take its input from standard input or from a filename on the command line, omitting the `<` symbol from Figure 7-13 yields the same result.

Figure 7-14 achieves the same result without creating the **temp** file. Using a pipe the shell redirects the output from `who` to the input of `sort`. The `sort` utility takes input from standard input because no filename follows it on the command line.

When many people are using the system and you want information about only one of them, you can send the output from `who` to `grep` (page 153) using a pipe. The `grep` utility displays the line containing the string you specify—**root** in the following example:

```

$ who | grep 'root'
root      console    Mar 24 05:00

```

```

$ who | sort
alex      pts/4      Mar 24 12:23
alex      pts/5      Mar 24 12:33
jenny     pts/7      Mar 23 08:45
root      console    Mar 24 05:00

```

**Figure 7-14** A pipe doing the work of a temporary file

Another way of handling output that is too long to fit on the screen, such as a list of files in a crowded directory, is to use a pipe to send the output through `less` or `more` (both on page 150).

```
$ ls | less
```

The `less` utility displays text one screen at a time. To view another screen, press the SPACE bar. To view one more line, press RETURN. Press `h` for help and `q` to quit.

Some utilities change the format of their output when you redirect it. Compare the output of `ls` by itself and when you send it through a pipe to `less`.

## FILTERS

A *filter* is a command that processes an input stream of data to produce an output stream of data. A command line that includes a filter uses a pipe to connect standard output of one command to the filter's standard input. Another pipe connects the filter's standard output to standard input of another command. Not all utilities can be used as filters.

In the following example, `sort` is a filter, taking standard input from standard output of `who` and using a pipe to redirect standard output to standard input of `lpr`. This command line sends the sorted output of `who` to the printer:

```
$ who | sort | lpr
```

The preceding example demonstrates the power of the shell combined with the versatility of Linux utilities. The three utilities `who`, `sort`, and `lpr` were not specifically designed to work with each other, but they all use standard input and standard output in the conventional way. By using the shell to handle input and output, you can piece standard utilities together on the command line to achieve the results you want.

## tee: SENDS OUTPUT IN TWO DIRECTIONS

The `tee` utility copies its standard input both to a file and to standard output. The utility is aptly named: It takes a single input and sends the output in two directions. In Figure 7-15 the output of `who` is sent via a pipe to standard input of `tee`. The `tee` utility saves a copy of standard input in a file named **who.out** and also sends a copy to standard output. Standard output of `tee` goes via a pipe to standard input of `grep`, which displays lines containing the string `root`.

```
$ who | tee who.out | grep root
root      console   Mar 24 05:00
$ cat who.out
root      console   Mar 24 05:00
alex      pts/4       Mar 24 12:23
alex      pts/5       Mar 24 12:33
jenny     pts/7       Mar 23 08:45
```

**Figure 7-15** Using `tee`

## RUNNING A PROGRAM IN THE BACKGROUND

**Foreground** In all the examples so far in this book, commands were run in the foreground. When you run a command in the *foreground*, the shell waits for it to finish before giving you another prompt and allowing you to continue. When you run a command in the *background*, you do not have to wait for the command to finish before you start running another command.

**Jobs** A *job* is a series of one or more commands that can be connected by pipes. You can have only one foreground job in a window or on a screen, but you can have many background jobs. By running more than one job at a time, you are using one of Linux's important features: multitasking. Running a command in the background can be useful when the command will run for a long time and does not need supervision. It leaves the screen free so that you can use it for other work. Of course, when you are using a GUI, you can open another window to run another job.

**Job number, PID number** To run a command in the background, type an ampersand (&) just before the RETURN that ends the command line. The shell assigns a small number to the job and displays this *job number* between brackets. Following the job number, the shell displays the *process identification (PID) number*—a larger number assigned by the operating system. Each of these numbers identifies the command running in the background. Then the shell displays another prompt and you can enter another command. When the background job finishes running, the shell displays a message giving both the job number and the command line used to run the command.

The next example runs in the background and sends its output through a pipe to `lpr`, which sends it to the printer.

```
$ ls -l | lpr &
[1] 22092
$
```

The [1] following the command line indicates that the shell has assigned job number 1 to this job. The 22092 is the PID number of the first command in the job. When this background job completes execution, you see the message

```
[1]+ Done          ls -l | lpr
```

(In place of `ls -l`, the shell may display something similar to `ls --color=tty -l`. This difference is due to the fact that `ls` is aliased [page 332] to `ls --color=tty`.)

## MOVING A JOB FROM THE FOREGROUND TO THE BACKGROUND

**CONTROL-Z** You can suspend a foreground job (stop it from running) by pressing the suspend key, usually CONTROL-Z. The shell then stops the process and disconnects standard input from the keyboard. You can put a suspended job in the background and restart it by using the `bg` command followed by the job number. You do not need to use the job number when there is only one stopped job.

Only the foreground job can take input from the keyboard. To connect the keyboard to a program running in the background, you must bring it into the foreground. Type **fg** without any arguments when only one job is in the background. When more than one job is in the background, type **fg**, or a percent sign (%), followed by the number of the job you want to bring into the foreground. The shell displays the command you used to start the job (**promptme** in the following example), and you can enter any input the program requires to continue:

```
bash $ fg 1
promptme
```

Redirect the output of a job you run in the background to keep it from interfering with whatever you are doing on the screen. Refer to “Separating and Grouping Commands” on page 290 for more detail about background tasks.

## Kill: ABORTING A BACKGROUND JOB

The interrupt key (usually CONTROL-C) cannot abort a process you are running in the background; you must use **kill** (page 409) for this purpose. Follow **kill** on the command line with either the PID number of the process you want to abort or a percent sign (%) followed by the job number.

Determining a PID number with **ps** If you forget the PID number, you can use the **ps** (process status) utility (page 314) to display it. The following example runs a **tail -f outfile** command (the **-f** option causes **tail** to watch **outfile** and display new lines as they are written to the file) as a background job, uses **ps** to display the PID number of the process, and aborts the job with **kill**:

```
$ tail -f outfile &
[1] 18228
$ ps | grep tail
18228 pts/4    00:00:00 tail
$ kill 18228
[1]+  Terminated                  tail -f outfile
$
```

If you forget the job number, you can use the **jobs** command to display a list of job numbers. The next example is similar to the previous one but uses the job number instead of the PID number to kill the job. Sometimes the message saying that the job is terminated does not appear until you press RETURN after the RETURN that ends the **kill** command:

```
$ tail -f outfile &
[1] 18236
$ bigjob &
[2] 18237
$ jobs
[1]-  Running                  tail -f outfile &
[2]+  Running                  bigjob &
$ kill %1
$ RETURN
[1]-  Terminated              tail -f outfile
$
```

## FILENAME GENERATION/PATHNAME EXPANSION

**Wildcards, globbing** When you give the shell abbreviated filenames that contain special characters, also called *metacharacters*, the shell can generate filenames that match the names of existing files. These special characters are also referred to as *wildcards* because they act as the jokers do in a deck of cards. When one of these characters appears in an argument on the command line, the shell expands that argument in sorted order into a list of filenames and passes the list to the program that the command line calls. Filenames that contain these special characters are called *ambiguous file references* because they do not refer to any one specific file. The process that the shell performs on these filenames is called *pathname expansion* or *globbing*.

Ambiguous file references refer to a group of files with similar names quickly, saving you the effort of typing the names individually. They can also help you find a file whose name you do not remember in its entirety. If no filename matches the ambiguous file reference, the shell generally passes the unexpanded reference—special characters and all—to the command.

### THE ? SPECIAL CHARACTER

The question mark (?) is a special character that causes the shell to generate filenames. It matches any single character in the name of an existing file. The following command uses this special character in an argument to the `lpr` utility:

```
$ lpr memo?
```

The shell expands the `memo?` argument and generates a list of files in the working directory that have names composed of `memo` followed by any single character. The shell then passes this list to `lpr`. The `lpr` utility never “knows” that the shell generated the filenames it was called with. If no filename matches the ambiguous file reference, the shell passes the string itself (`memo?`) to `lpr` or, if it is set up to do so, passes a null string (see `nullglob` on page 341).

The following example uses `ls` first to display the names of all files in the working directory and then to display the filenames that `memo?` matches:

```
$ ls
mem  memo12  memo9  memoalex  newmemo5
memo memo5  memoa  memos
$ ls memo?
memo5  memo9  memoa  memos
```

The `memo?` ambiguous file reference does not match `mem`, `memo`, `memo12`, `memoalex`, or `newmemo5`. You can also use a question mark in the middle of an ambiguous file reference:

```
$ ls
7may4report  may4report  mayqreport  may_report
may14report  may4report.79  mayreport  may_report
$ ls may?report
may.report  may4report  may_report  mayqreport
```

To practice generating filenames, you can use `echo` and `ls`. The `echo` utility displays the arguments that the shell passes to it:

```
$ echo may?report
may.report may4report may_report mayqreport
```

The shell first expands the ambiguous file reference into a list of all files in the working directory that match the string `may?report` and then passes this list to `echo`, as though you had entered the list of filenames as arguments to `echo`. Next `echo` displays the list of filenames.

A question mark does not match a leading period (one that indicates a hidden filename; see page 192). When you want to match filenames that begin with a period, you must explicitly include the period in the ambiguous file reference.

## THE \* SPECIAL CHARACTER

The asterisk (\*) performs a function similar to that of the question mark but matches any number of characters, *including zero characters*, in a filename. The following example shows all of the files in the working directory and then shows three commands that display all the filenames that begin with the string `memo`, end with the string `mo`, and contain the string `alx`:

```
$ ls
amemo  memo      memoalx.0620  memosally  user.memo
mem    memo.0612  memoalx.keep  sallymemo
memalx memoa      memorandum    typescript
$ echo memo*
memo memo.0612 memoa memoalx.0620 memoalx.keep memorandum memosally
$ echo *mo
amemo memo sallymemo user.memo
$ echo *alx*
memalx memoalx.0620 memoalx.keep
```

The ambiguous file reference `memo*` does not match `amemo`, `mem`, `sallymemo`, or `user.memo`. Like the question mark, an asterisk does *not* match a leading period in a filename.

The `-a` option causes `ls` to display hidden filenames. The command `echo *` does not display `.` (the working directory), `..` (the parent of the working directory), `.aaa`, or `.profile`. In contrast, the command `echo .*` displays only those four names:

```
$ ls
aaa      memo.sally  sally.0612  thurs
memo.0612 report      saturday
$ ls -a
.  .aaa      aaa      memo.sally  sally.0612  thurs
.. .profile  memo.0612  report      saturday
$ echo *
aaa memo.0612 memo.sally report sally.0612 saturday thurs
$ echo .*
.  .. .aaa .profile
```



In the following example `.p*` does not match `memo.0612`, `private`, `reminder`, or `report`. Next the `ls .*` command causes `ls` to list `.private` and `.profile` in addition to the contents of the `.` directory (the working directory) and the `..` directory (the parent of the working directory). When called with the same argument, `echo` displays the names of files (including directories) in the working directory that begin with a dot (`.`), but not the contents of directories.

```
$ ls -a
.      .private  memo.0612  reminder
..     .profile  private    report
$ echo .p*
.private .profile
$ ls .*
.private .profile

.:
memo.0612 private    reminder  report

..:
.
.
$ echo .*
. .. .private .profile
```

You can take advantage of ambiguous file references when you establish conventions for naming files. For example, when you end all text filenames with `.txt`, you can reference that group of files with `*.txt`. The next command uses this convention to send all the text files in the working directory to the printer. The ampersand causes `lpr` to run in the background.

```
$ lpr *.txt &
```

## THE [ ] SPECIAL CHARACTERS

A pair of brackets surrounding a list of characters causes the shell to match filenames containing the individual characters. Whereas `memo?` matches `memo` followed by any character, `memo[17a]` is more restrictive, and matches only `memo1`, `memo7`, and `memoa`. The brackets define a *character class* that includes all the characters within the brackets. (GNU calls this a *character list*; a GNU *character class* is something different.) The shell expands an argument that includes a character-class definition, by substituting each member of the character class, *one at a time*, in place of the brackets and their contents. The shell then passes the list of matching filenames to the program it is calling.

Each character-class definition can replace only a single character within a filename. The brackets and their contents are like a question mark that substitutes only the members of the character class.

The first of the following commands lists the names of all the files in the working directory that begin with `a`, `e`, `i`, `o`, or `u`. The second command displays the contents of the files named `page2.txt`, `page4.txt`, `page6.txt`, and `page8.txt`.

```
$ echo [aeiou]*
...
$ less page[2468].txt
...
```

A hyphen within brackets defines a range of characters within a character-class definition. For example, `[6–9]` represents `[6789]`, `[a–z]` represents all lowercase letters in English, and `[a–zA–Z]` represents all letters, both uppercase and lowercase, in English.

The following command lines show three ways to print the files named `part0`, `part1`, `part2`, `part3`, and `part5`. Each of these command lines causes the shell to call `lpr` with five filenames:

```
$ lpr part0 part1 part2 part3 part5

$ lpr part[01235]

$ lpr part[0-35]
```

The first command line explicitly specifies the five filenames. The second and third command lines use ambiguous file references, incorporating character-class definitions. The shell expands the argument on the second command line to include all files that have names beginning with `part` and ending with any of the characters in the character class. The character class is explicitly defined as `0`, `1`, `2`, `3`, and `5`. The third command line also uses a character-class definition but defines the character class to be all characters in the range `0–3` plus `5`.

The following command line prints 39 files, `part0` through `part38`:

```
$ lpr part[0-9] part[12][0-9] part3[0-8]
```

The next two examples list the names of some of the files in the working directory. The first lists the files whose names start with `a` through `m`. The second lists files whose names end with `x`, `y`, or `z`.

```
$ echo [a-m]*
...
$ echo *[x-z]
...
```

**optional** When an exclamation point (!) or a caret (^) immediately follows the opening bracket ([]) that defines a character class, the string enclosed by the brackets matches any character *not* between the brackets. Thus `[^ab]*` matches any filename that does not begin with `a` or `b`.

The following examples show that `*[^ab]` matches filenames that do not end with the letters `a` or `b` and that `[b-d]*` matches filenames that begin with `b`, `c`, or `d`.

```
$ ls
aa ab ac ad ba bb bc bd cc dd
```

```
$ ls *[^ab]
ac ad bc bd cc ddcc dd
$ ls [b-d]*
ba bb bc bd cc dd
```

You can match a hyphen (–) or a closing bracket (]) by placing it immediately before the final closing bracket.

The next example demonstrates that the `ls` utility cannot interpret ambiguous file references. First `ls` is called with an argument of `?old`. The shell expands `?old` into a matching filename, `hold`, and passes that name to `ls`. The second command is the same as the first, except the `?` is quoted (refer to “Special Characters” on page 148). The shell does not recognize this question mark as a special character and passes it on to `ls`. The `ls` utility generates an error message saying that it cannot find a file named `?old` (because there is no file named `?old`).

```
$ ls ?old
hold
$ ls \?old
ls: ?old: No such file or directory
```

Like most utilities and programs, `ls` cannot interpret ambiguous file references; that work is left to the shell.

### The shell expands ambiguous file references

**tip** *The shell does the expansion* when it processes an ambiguous file reference, not the program that the shell runs. In the examples in this section, *the utilities* (`ls`, `cat`, `echo`, `lpr`) *never see the ambiguous file references*. The shell expands the ambiguous file references and passes a list of ordinary filenames to the utility. In the previous examples, `echo` shows this to be true because it simply displays its arguments; it never displays the ambiguous file reference.

## BUILTINS

A *builtin* is a utility (also called a *command*) that is built into a shell. Each of the shells has its own set of builtins. When it runs a builtin, the shell does not fork a new process. Consequently builtins run more quickly and can affect the environment of the current shell. Because builtins are used in the same way as utilities, you will not typically be aware of whether a utility is built into the shell or is a stand-alone utility.

The `echo` utility is a shell builtin. The shell always executes a shell builtin before trying to find a command or utility with the same name. See page 936 for an in-depth discussion of builtin commands and page 949 for a list of `bash` builtins.

**Listing bash builtins** To get a complete list of `bash` builtins, give the command **info bash builtin**. To display a page with more information on each builtin, move the cursor to one of the lines listing a builtin command and press RETURN. Alternatively, after typing **info bash**, give the

command **/builtin** to search the **bash** documentation for the string **builtin**. The cursor will rest on the word **Builtin** in a menu; press RETURN to display the builtins menu.

Because **bash** was written by GNU, the **info** page has better information than does the **man** page. If you want to read about builtins in the **man** page, give the command **man bash** and then search for the section on builtins with the command **/^SHELL BUILTIN COMMANDS** (search for a line that begins with **SHELL . . .**).

---

## CHAPTER SUMMARY

The shell is the Linux command interpreter. It scans the command line for proper syntax, picking out the command name and any arguments. The first argument is argument one, the second is argument two, and so on. The name of the command itself is argument zero. Many programs use options to modify the effects of a command. Most Linux utilities identify an option by its leading one or two hyphens.

When you give it a command, the shell tries to find an executable program with the same name as the command. When it does, the shell executes the program. When it does not, the shell tells you that it cannot find or execute the program. If the command is a simple filename, the shell searches the directories given in the variable **PATH** in an attempt to locate the command.

When it executes a command, the shell assigns one file to the command's standard input and another file to its standard output. By default the shell causes a command's standard input to come from the keyboard and its standard output to go to the screen. You can instruct the shell to redirect a command's standard input from or standard output to any file or device. You can also connect standard output of one command to standard input of another command using a pipe. A filter is a command that reads its standard input from standard output of one command and writes its standard output to standard input of another command.

When a command runs in the foreground, the shell waits for it to finish before it displays a prompt and allows you to continue. When you put an ampersand (&) at the end of a command line, the shell executes the command in the background and displays another prompt immediately. Run slow commands in the background when you want to enter other commands at the shell prompt. The **jobs** builtin displays a list of jobs and includes the job number of each.

The shell interprets special characters on a command line to generate filenames. A question mark represents any single character, and an asterisk represents zero or more characters. A single character may also be represented by a character class: a list of characters within brackets. A reference that uses special characters (wildcards) to abbreviate a list of one or more filenames is called an ambiguous file reference.

A builtin is a utility that is built into a shell. Each shell has its own set of builtins. When it runs a builtin, the shell does not fork a new process. Consequently builtins run more quickly and can affect the environment of the current shell.

## UTILITIES AND BUILTINS INTRODUCED IN THIS CHAPTER

Table 7-1 lists the utilities introduced in this chapter.

**Table 7-1** New utilities

| Utility | Function                                                           |
|---------|--------------------------------------------------------------------|
| tr      | Maps one string of characters into another (page 238)              |
| tee     | Sends standard input to both a file and standard output (page 240) |
| bg      | Moves a process into the background (page 241)                     |
| fg      | Moves a process into the foreground (page 242)                     |
| jobs    | Displays a list of currently running jobs (page 242)               |

## EXERCISES

1. What does the shell ordinarily do while a command is executing? What should you do if you do not want to wait for a command to finish before running another command?
2. Using `sort` as a filter, rewrite the following sequence of commands:

```
$ sort list > temp
$ lpr temp
$ rm temp
```

3. What is a PID number? Why are these numbers useful when you run processes in the background? Which utility displays the PID numbers of the commands you are running?
4. Assume that the following files are in the working directory:

```
$ ls
intro      notesb    ref2      section1  section3  section4b
notesa     ref1      ref3      section2  section4a  sentrev
```

Give commands for each of the following, using wildcards to express file-names with as few characters as possible.

- a. List all files that begin with `section`.
- b. List the `section1`, `section2`, and `section3` files only.
- c. List the `intro` file only.
- d. List the `section1`, `section3`, `ref1`, and `ref3` files.

5. Refer to the documentation of utilities in the `man` pages to determine which commands will
  - a. Output the number of lines in the standard input that contain the *word* **a** or **A**.
  - b. Output only the names of the files in the working directory that contain the pattern `$(.`
  - c. List the files in the working directory in their reverse alphabetical order.
  - d. Send a list of files in the working directory to the printer, sorted by size.
6. Give a command to
  - a. Redirect the standard output from a `sort` command into a file named **phone\_list**. Assume that the input file is named **numbers**.
  - b. Translate all occurrences of the characters `[` and `{` to the character `(`, and all occurrences of the characters `]` and `}` to the character `)` in the file **permdemos.c**. (*Hint:* Refer to the `tr` `man` page.)
  - c. Create a file named **book** that contains the contents of two other files: **part1** and **part2**.
7. The `lpr` and `sort` utilities accept input either from a file named on the command line or from standard input.
  - a. Name two other utilities that function in a similar manner.
  - b. Name a utility that accepts its input only from standard input.
8. Give an example of a command that uses `grep`
  - a. With both input and output redirected.
  - b. With only input redirected.
  - c. With only output redirected.
  - d. Within a pipe.

In which of the preceding is `grep` used as a filter?

9. Explain the following error message. What filenames would a subsequent `ls` display?

```
$ ls
abc  abd  abe  abf  abg  abh
$ rm abc ab*
rm: cannot remove 'abc': No such file or directory
```

---

## ADVANCED EXERCISES

10. When you use the redirect output symbol (`>`) with a command, the shell creates the output file immediately, before the command is executed. Demonstrate that this is true.
11. In experimenting with shell variables, Alex accidentally deletes his `PATH` variable. He decides that he does not need the `PATH` variable. Discuss some of the problems he may soon encounter and explain the reasons for these problems. How could he *easily* return `PATH` to its original value?
12. Assume that your permissions allow you to write to a file but not to delete it.
  - a. Give a command to empty the file without invoking an editor.
  - b. Explain how you might have permission to modify a file that you cannot delete.
13. If you accidentally create a filename that contains a nonprinting character, such as a `CONTROL` character, how can you rename the file?
14. Why does the `noclobber` variable *not* protect you from overwriting an existing file with `cp` or `mv`?
15. Why do command names and filenames usually not have embedded `SPACES`? How would you create a filename containing a `SPACE`? How would you remove it? (This is a thought exercise, not recommended practice. If you want to experiment, create and work in a directory that contains only your experimental file.)
16. Create a file named `answer` and give the following command:  

```
$ > answers.0102 < answer cat
```

Explain what the command does and why. What is a more conventional way of expressing this command?

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# **PART III**

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## **DIGGING INTO FEDORA AND RED HAT ENTERPRISE LINUX**

### **CHAPTER 8**

**LINUX GUIs: X AND GNOME 255**

### **CHAPTER 9**

**THE BOURNE AGAIN SHELL 279**

### **CHAPTER 10**

**NETWORKING AND THE INTERNET 357**

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# LINUX GUIs: X AND GNOME

## IN THIS CHAPTER

|                                                 |     |
|-------------------------------------------------|-----|
| X Window System .....                           | 256 |
| Starting X from a Character-Based Display ..... | 258 |
| Remote Computing and Local Displays .....       | 258 |
| Desktop Environments/<br>Managers .....         | 263 |
| The Nautilus File Browser<br>Window .....       | 264 |
| The Nautilus Spatial View .....                 | 270 |
| GNOME Utilities .....                           | 272 |
| Run Application Window .....                    | 274 |
| GNOME Terminal<br>Emulator/Shell .....          | 275 |

This chapter covers the Linux graphical user interface (GUI). It continues where Chapter 4 left off, going into more detail about the X Window System, the basis for the Linux GUI. It presents a brief history of GNOME and KDE and discusses some of the problems and benefits of having two major Linux desktop environments. The section on the Nautilus File Browser covers the View and Side panes, the control bars, the menubar, and the Spatial view. The final section explores some GNOME utilities, including Terminal, the GNOME terminal emulator.

## X WINDOW SYSTEM

**History of X** The X Window System ([www.x.org](http://www.x.org)) was created in 1984 at the Massachusetts Institute of Technology (MIT) by researchers working on a distributed computing project and a campuswide distributed environment, called Project Athena. This system was not the first windowing software to run on a UNIX system, but it was the first to become widely available and accepted. In 1985, MIT released X (version 9) to the public, for use without a license. Three years later, a group of vendors formed the X Consortium to support the continued development of X, under the leadership of MIT. By 1998, the X Consortium had become part of the Open Group. In 2001, the Open Group released X version 11, release 6.6 (X11R6.6).

The X Window System was inspired by the ideas and features found in earlier proprietary window systems but is written to be portable and flexible. X is designed to run on a workstation, typically attached to a LAN. The designers built X with the network in mind. If you can communicate with a remote computer over a network, running an X application on that computer and sending the results to a local display is straightforward.

Although the X protocol has remained stable for a long time, additions to it in the form of extensions are quite common. One of the most interesting—albeit one that has not yet made its way into production—is the Media Application Server, which aims to provide the same level of network transparency for sound and video that X does for simple windowing applications.

**XFree86 and X.org** Many distributions of Linux used the XFree86 X server, which inherited its license from the original MIT X server, through release 4.3. In early 2004, just before the release of XFree86 4.4, the XFree86 license was changed to one that is more restrictive and not compatible with the GPL (page 4). In the wake of this change, a number of distributions abandoned XFree86 and replaced it with an X.org X server that is based on a pre-release version of XFree86 4.4, which predates the change in the XFree86 license. Fedora/RHEL use the X.org X server, named **Xorg**; it is functionally equivalent to the one distributed by XFree86 because most of the code is the same. Thus modules designed to work with one server work with the other.

**The X stack** The Linux GUI is built in layers (Figure 8-1). The bottom layer is the kernel, which provides the basic interfaces to the hardware. On top of the kernel is the X server, which is responsible for managing windows and drawing basic graphical primitives such as lines and bitmaps. Rather than directly generating X commands, most programs use Xlib, the next layer, which is a standard library for interfacing with an X server. Xlib is complicated and does not provide high-level abstractions, such as buttons and text boxes. Rather than using Xlib directly, most programs rely on a toolkit that provides high-level abstractions. Using a library not only makes programming easier, but also brings consistency to applications.

In recent years, the popularity of X has grown outside the UNIX community and extended beyond the workstation class of computers it was originally conceived for. Today X is available for Macintosh computers as well as for PCs running Windows.

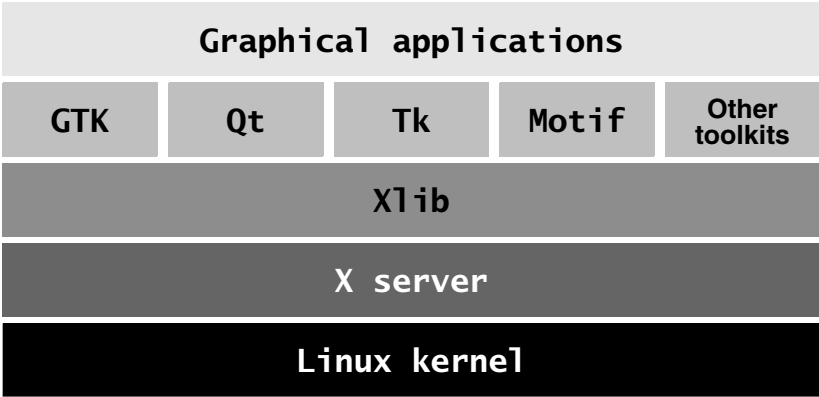


Figure 8-1 The X stack

Client/server  
environment

Computer networks are central to the design of X. It is possible to run an application on one computer and display the results on a screen attached to a different computer; the ease with which this can be done distinguishes X from other window systems available today. Thanks to this capability, a scientist can run and manipulate a program on a powerful supercomputer in another building or another country and view the results on a personal workstation or laptop computer. For more information refer to “Remote Computing and Local Displays” on page 258.

When you start an X Window System session, you set up a *client/server environment*. One process, called the *X server*, displays a desktop and windows under X. Each application program and utility that makes a request of the X server is a *client* of that server. Examples of X clients include *xterm*, *Compiz*, *gnome-calculator*, and such general applications as word processing and spreadsheet programs. A typical request from a client is to display an image or open a window.

**The roles of X client and server may be counterintuitive**

**tip** The terms *client* and *server*, when referring to X, have the opposite meanings of how you might think of them intuitively: The server runs the mouse, keyboard, and display; the application program is the client.

This disparity becomes even more apparent when you run an application program on a remote system. You might think of the system running the program as the server and the system providing the display as the client, but in fact it is the other way around. With X, the system providing the display is the server, and the system running the program is the client.

Events

The server also monitors keyboard and mouse actions (*events*) and passes them to the appropriate clients. For example, when you click the border of a window, the server sends this event to the window manager (client). Characters you type into a terminal emulation window are sent to that terminal emulator (client). The client takes appropriate action when it receives an event—for example, making a window active or displaying the typed character on the server.

Separating the physical control of the display (the server) from the processes needing access to the display (the client) makes it possible to run the server on one computer and the client on another computer. Most of the time, this book discusses running the X server and client applications on a single system. “Remote Computing and Local Displays” describes using X in a distributed environment.

**optional** You can run `xev` (X event) by giving the command `xev` from a terminal emulator window and then watch the information flow from the client to the server and back again. This utility opens the Event Tester window, which has a box in it, and asks the X server to send it events each time anything happens, such as moving the mouse pointer, clicking a mouse button, moving the mouse pointer into the box, typing, or resizing the window. The `xev` utility displays information about each event in the window you opened it from. You can use `xev` as an educational tool: Start it and see how much information is processed each time you move the mouse. Close the Event Tester window to exit from `xev`.

## USING X

This section provides basic information about starting and configuring X from the command line. For more information see the Xserver man page and the man pages listed at the bottom of the Xserver man page.

### STARTING X FROM A CHARACTER-BASED DISPLAY

Once you have logged in on a virtual console (page 137), you can start an X Window System server by using `startx`. See page 423 for information on changing the `initdefault` entry in the `/etc/inittab` file that causes Linux to boot into single-user mode, where it displays a textual interface. When you run `startx`, the X server displays an X screen, using the first available virtual console. The following command causes `startx` to run in the background so you can switch back to this virtual console and give other commands:

```
$ startx &
```

### REMOTE COMPUTING AND LOCAL DISPLAYS

Typically the X server and the X client run on the same machine. To identify a remote X server (display) an X application (client) is to use, you can either set a global shell variable or use a command-line option. Before you can connect to a remote X server, you must turn off two security features: You must turn off the Xorg `-nolisten tcp` option on the server and you must run `xhost` on the server to give the client permission to connect to the X server. You also need to disable the firewall or open TCP port 6000 (page 824). Unless you have a reason to leave these features off, turn them back on when you finish with the examples in this section—leaving them off weakens system security. These tasks must be performed on the X server because the features protect the server. You do not have to prepare the client. The examples in this section assume the server is named `tiny` and the client is named `dog`.

## Security and the Xorg `-nolisten tcp` option

**security** In a production environment, if you need to place an X server and the clients on different systems, it is best to forward (tunnel) X over ssh. This setup provides a secure, encrypted connection. The method described in this section is useful on local, secure networks and for understanding how X works. See “Forwarding X11” on page 638 for information on setting up ssh so it forwards X.

### THE X `-nolisten tcp` OPTION

As Fedora/RHEL is installed, the X server starts with the `-nolisten tcp` option, which protects the X server by preventing TCP connections to the X server. To connect to a remote X server, you must turn this option off on the server. To turn it off, add a `DisallowTCP=false` line to `/etc/gdm/custom.conf` following the `[security]` header as shown here:

```
max@tiny:~$ cat /etc/gdm/custom.conf
...
[security]
DisallowTCP=false
...
```

Reboot the system to restart the X server and gdm (gdm-binary) to make this change take effect.

### xhost GRANTS ACCESS TO A DISPLAY

As installed, xhost protects each user’s X server. A user who wants to grant access to his X server needs to run xhost. Assume Max is logged in on the system named **tiny** and wants to allow a user on **dog** to use his display (X server). Max runs the following command:

```
max@tiny:~$ xhost +dog
dog being added to access control list
max@tiny:~$ xhost
access control enabled, only authorized clients can connect
INET:dog
...
```

Without any arguments, xhost describes its state. In the preceding example, **INET** indicates an IPv4 connection. If Max wants to allow all systems to access his display, he can give the following command:

```
$ xhost +
access control disabled, clients can connect from any host
```

If you frequently work with other users via a network, you may find it convenient to add an xhost line to your `.bash_profile` file (page 281)—but see the adjacent tip regarding security and xhost. Be selective in granting access to your X display with xhost; if another system has access to your display, you may find your work frequently interrupted.

## Security and xhost

**security** Giving a remote system access to your display using `xhost` means any user on the remote system can watch everything you type in a terminal emulation window, including passwords. For this reason, some software packages, such as the Tcl/Tk development system ([www.tcl.tk](http://www.tcl.tk)), restrict their own capabilities when `xhost` permits remote access to the X server. If you are concerned about security or want to take full advantage of systems such as Tcl/Tk, you should use a safer means of granting remote access to your X session. See the `xaauth` man page for information about a more secure replacement for `xhost`.

---

### THE DISPLAY VARIABLE

The most common method of identifying a display is to use the **DISPLAY** shell environment variable to hold the X server ID string. This locally unique identification string is automatically set up when the X server starts. The **DISPLAY** variable holds the screen number of a display:

```
$ echo $DISPLAY
:0.0
```

The format of the complete (globally unique) ID string for a display is

```
[hostname]:display-number[.screen-number]
```

where *hostname* is the name of the system running the X server, *display-number* is the number of the logical (physical) display (0 unless multiple monitors or graphical terminals are attached to the system, or if you are running X over ssh), and *screen-number* is the logical number of the (virtual) terminal (0 unless you are running multiple instances of X). When you are working with a single physical screen, you can shorten the identification string. For example, you can use `tiny:0.0` or `tiny:0` to identify the only physical display on the system named `tiny`. When the X server and the X clients are running on the same system, you can shorten this identification string even further to `:0.0` or `:0`. An ssh connection shows **DISPLAY** as `localhost:10.0`. You may have to use `ssh -X` to see this value. See “X11 forwarding” on page 622 for information on setting up ssh so that it forwards X.

If **DISPLAY** is empty or not set, the screen you are working from is not running X. An application (the X client) uses the value of the **DISPLAY** variable to determine which display, keyboard, and mouse (collectively, the X server) to use. One way to run an X application, such as `gnome-calculator`, on the local system but have it use the X display on a remote system is to change the value of the **DISPLAY** variable on the client system so it identifies the remote X server.

```
sam@dog:~$ export DISPLAY=tiny:0.0
sam@dog:~$ gnome-calculator &
```

The preceding example shows Sam running `gnome-calculator` with the default X server running on the system named `tiny`. After setting the **DISPLAY** variable to the ID of the `tiny` server, all X programs (clients) Sam starts use `tiny` as their server (i.e., output appears on `tiny`'s display and input comes from `tiny`'s keyboard and mouse). Try running `xterm` in place of `gnome-calculator` and see which keyboard it accepts input from. If this example generates an error, refer back to the two preceding sections, which explain how to set up the server to allow a remote system to connect to it.



## When you change the value of DISPLAY

**tip** When you change the value of the **DISPLAY** variable, all X programs send their output to the new display named by **DISPLAY**.

### THE `-display` OPTION

For a single command, you can usually specify the X server on the command line:

```
sam@dog:~$ gnome-calculator -display tiny:0.0
```

Many X programs accept the `-display` option. Those that do not accept this option send their output to the display specified by the **DISPLAY** variable.

### RUNNING MULTIPLE X SERVERS

You can run multiple X servers on a single system. The most common reason for running a second X server is to use a second display that allocates a different number of bits to each screen pixel (uses a different *color depth* [page 1075]). The possible values are 8, 16, 24, and 32 bits per pixel. Most X servers available for Linux default to 24 or 32 bits per pixel, permitting the use of millions of colors simultaneously. Starting an X server with 8 bits per pixel permits the use of any combination of 256 colors at the same time. The maximum number of bits per pixel allowed depends on the computer graphics hardware and X server. With fewer bits per pixel, the system has to transfer less data, possibly making it more responsive. In addition, many games work with only 256 colors.

When you start multiple X servers, each must have a different ID string. The following command starts a second X server:

```
$ startx -- :1
```

The `--` option marks the end of the `startx` options and arguments. The `startx` script uses the arguments to the left of this option and passes arguments to the right of this option to the X server. When you give the preceding command in a graphical environment, such as from a terminal emulator, you must work with **root** privileges; you will initiate a privileged X session. The following command starts a second X server running at 16 bits per pixel:

```
$ startx -- :1 -depth 16 &
```

“Using Virtual Consoles” on page 137 describes how to switch to a virtual console to start a second server where you do not have to work with **root** privileges.

**Switch User**  
(*FEDORA*) To allow another user to log on while you remain logged in as yourself, select **Main menu: System->Log Out *username*...** and click **Switch User**. GNOME displays a login screen and another user can log on. When appropriate, that user can log off or switch users to allow you to log on and resume your session.

**X over ssh** See “Tunneling/Port Forwarding” on page 638 for information about running X over an ssh connection.

## STOPPING THE X SERVER

How you terminate a window manager depends on which window manager is running and how it is configured. If X stops responding, switch to a virtual terminal,

log in from another terminal or a remote system, or use `ssh` to access the system. Then kill (page 409) the process running Xorg.

## REMAPPING MOUSE BUTTONS

Throughout this book, each description of a mouse click refers to the button by its position (left, middle, or right, with left implied when no button is specified) because the position of a mouse button is more intuitive than an arbitrary name or number. X numbers buttons starting at the left and continuing with the mouse wheel. The buttons on a three-button mouse are numbered 1 (left), 2 (middle), and 3 (right). A mouse wheel, if present, is numbered 4 (rolling it up) and 5 (rolling it down). Clicking the wheel is equivalent to clicking the middle mouse button. The buttons on a two-button mouse are 1 (left) and 2 (right).

If you are right-handed, you can conveniently press the left mouse button with your index finger; X programs take advantage of this fact by relying on button 1 for the most common operations. If you are left-handed, your index finger rests most conveniently on button 2 or 3 (the right button on a two- or three-button mouse).

“Mouse Preferences” on page 97 describes how to use a GUI to change a mouse between right-handed and left-handed. You can also change how X interprets the mouse buttons using `xmodmap`. If you are left-handed and using a three-button mouse with a wheel, the following command causes X to interpret the right button as button 1 and the left button as button 3:

```
$ xmodmap -e 'pointer = 3 2 1 4 5'
```

Omit the 4 and 5 if the mouse does not have a wheel. The following command works for a two-button mouse without a wheel:

```
$ xmodmap -e 'pointer = 2 1'
```

If `xmodmap` displays a message complaining about the number of buttons, use the `xmodmap -pp` option to display the number of buttons X has defined for the mouse:

```
$ xmodmap -pp
There are 9 pointer buttons defined.
```

| Physical<br>Button | Button<br>Code |
|--------------------|----------------|
| 1                  | 1              |
| 2                  | 2              |
| 3                  | 3              |
| 4                  | 4              |
| 5                  | 5              |
| 6                  | 6              |
| 7                  | 7              |
| 8                  | 8              |
| 9                  | 9              |

Then expand the previous command, adding numbers to complete the list. If the `-pp` option shows nine buttons, give the following command:

```
$ xmodmap -e 'pointer = 3 2 1 4 5 6 7 8 9'
```

Changing the order of the first three buttons is critical to making the mouse suitable for a left-handed user. When you remap the mouse buttons, remember to reinterpret the descriptions in this book accordingly. When this book asks you to click the left button or does not specify which button to click, use the right button, and vice versa.

## DESKTOP ENVIRONMENTS/MANAGERS

Conceptually X is very simple. As a consequence, it does not provide some of the more common features found in GUIs, such as the ability to drag windows. The UNIX/Linux philosophy is one of modularity: X relies on a window manager, such as Metacity or Compiz, to draw window borders and handle moving and resizing operations.

Unlike a window manager, which has a clearly defined task, a desktop environment (manager) does many things. In general, a desktop environment, such as GNOME or KDE, provides a means of launching applications and utilities, such as a file manager, that work with a window manager.

### GNOME AND KDE

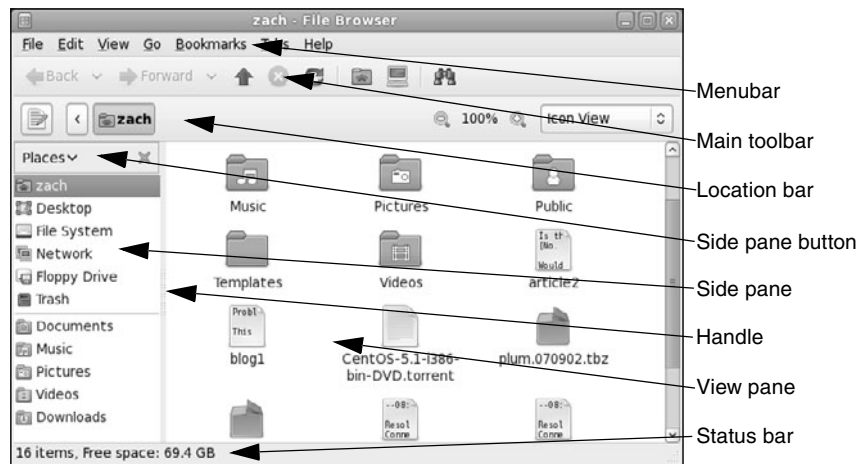
The KDE project began in 1996, with the aim of creating a consistent, user-friendly desktop environment for free UNIX-like operating systems. KDE is based on the Qt toolkit made by Trolltech. When KDE development began, the Qt license was not compatible with the GPL (page 4). For this reason the Free Software Foundation decided to support a different project, the GNU Network Object Model Environment (GNOME). More recently Qt has been released under the terms of the GPL, eliminating part of the rationale for GNOME's existence.

**GNOME** GNOME is the default desktop environment for Fedora/RHEL. It provides a simple, coherent user interface that is suitable for corporate use. GNOME uses GTK for drawing widgets. GTK, developed for the GNU Image Manipulation Program (gimp), is written in C, although bindings for C++ and other languages are available.

GNOME does not take much advantage of its component architecture. Instead, it continues to support the traditional UNIX philosophy of relying on many small programs, each of which is good at doing a specific task.

**KDE** KDE is written in C++ on top of the Qt framework. KDE tries to use existing technology, if it can be reused, but creates its own if nothing else is available or if a superior solution is needed. For example, KDE implemented an HTML rendering engine long before the Mozilla project was born. Similarly, work on KOffice began a long time before StarOffice became the open-source OpenOffice.org. In contrast, the GNOME office applications are stand-alone programs that originated outside the GNOME project. KDE's portability is demonstrated by the use of most of its core components, including Konqueror and KOffice, under Mac OS X.

**Interoperability** Since the release of version 2, the GNOME project has focused on simplifying the user interface, removing options where they are deemed unnecessary, and aiming



**Figure 8-2** A Nautilus File Browser window displaying icons

for a set of default settings that the end user will not wish to change. KDE has moved in the opposite direction, emphasizing configurability.

The freedesktop.org group ([freedesktop.org](http://freedesktop.org)), whose members are drawn from the GNOME and KDE projects, is improving interoperability and aims to produce standards that will allow the two environments to work together. One standard released by freedesktop.org allows applications to use the notification area of either the GNOME or KDE panel without being aware of which desktop environment they are running in.

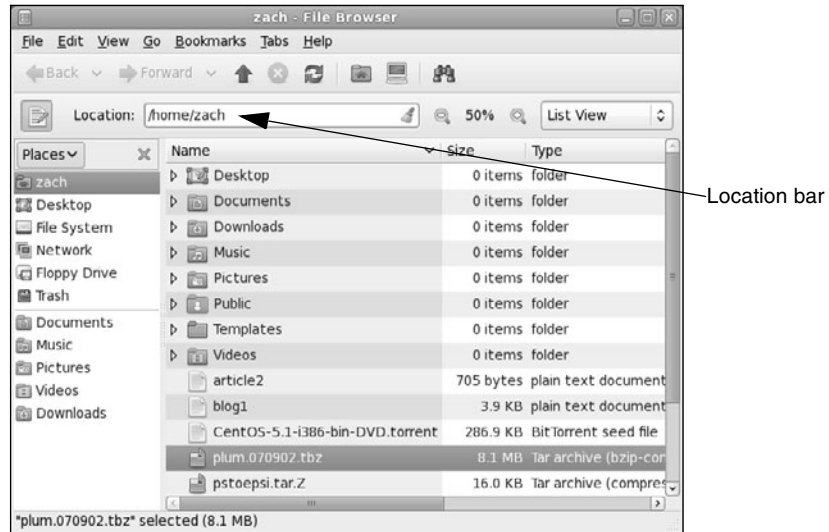
## GNUSTEP

The GNUStep project ([www.gnustep.org](http://www.gnustep.org)), which began before both the KDE and GNOME projects, is creating an open-source implementation of the OPENSTEP API and desktop environment. The result is a very clean and fast user interface.

The default look of WindowMaker, the GNUStep window manager, is somewhat dated, but it supports themes so you can customize its appearance. The user interface is widely regarded as one of the most intuitive found on a UNIX platform. Because GNUStep has less overhead than GNOME and KDE, it runs better on older hardware. If you are running Linux on hardware that struggles with GNOME and KDE or if you would prefer a user interface that does not attempt to mimic Windows, try GNUStep. WindowMaker is provided in the **WindowMaker** package.

## THE NAUTILUS FILE BROWSER WINDOW

“Using Nautilus to Work with Files” on page 98 presented an introduction to using Nautilus. This section discusses the Nautilus File Browser window in more depth.



**Figure 8-3** A Nautilus File Browser window displaying a List view and a textual location bar

### Turn off Spatial view; turn on File Browser windows

**tip** To make the Nautilus windows on the desktop you are working on correspond to the figures in this book, you must turn off Spatial view (page 270) and turn on File Browser windows. For more information refer to “The Two Faces of Nautilus” on page 99.

Figure 8-2 shows a File Browser window with a Side pane (sometimes called a *side-bar*), View pane, menubar, toolbar, location bar, and status bar. To display your home folder in a File Browser window, select **Main menu: Places**⇒**Home Folder**.

## THE VIEW PANE

The View pane displays icons or a list of filenames. Select the view you prefer from the drop-down list at the right end of the location bar. Figure 8-2 shows an Icon view and Figure 8-3 shows a List view. A Compact view is also available. Objects in the View pane behave exactly as objects on the desktop do. See the sections starting on page 92 for information on working with objects.

You can cut/copy and paste objects within a single View pane, between View panes, or between a View pane and the desktop. The Object context menu (right-click) has cut, copy, and paste selections. Alternatively, you can use the clipboard (page 116) to cut/copy and paste objects.

## THE SIDE PANE

The Side pane augments the information Nautilus displays in the View pane. Press **F9** or click the **X** at the top of the Side pane to close it. You can display the Side pane by pressing **F9** or by selecting **File Browser menubar: View**⇒**Side Pane**. To change the horizontal size of the Side pane, drag the handle (Figure 8-2) on its right side.

### Nautilus can open a terminal emulator

**tip** When you install the **nautilus-open-terminal** package (see page 501 for instructions) and log out and log back in, Nautilus presents an Open in Terminal selection in context menus where appropriate. For example, with this package installed, when you right-click a folder (directory) object and select **Open in Terminal**, Nautilus opens a terminal emulator with that directory as the working directory (page 192).

---

The Side pane can display six types of information. The button at its top controls which type it displays. This button is initially labeled **Places**; click it to display the Side pane drop-down list, which has the selections described next.

**Places** Places lists folders. Double-click one of these folders to display that folder in the View pane. You can open a directory in a new File Browser window by right-clicking the directory in Places and selecting **Open in New Window**. Under Fedora you can right-click and select **Open in New Tab** to open the directory in a new tab.

Places contains two parts: The list above the divider is static and holds your home directory, your desktop, the filesystem, the network, a CD-ROM drive (when it contains a disk), unmounted filesystems (if present), and the trash. The list below the divider holds bookmarks. Add a bookmark by displaying the directory you want to bookmark in the View pane and pressing **CONTROL-D** or by selecting **File Browser menubar: Bookmarks⇒Add Bookmark**. Remove a bookmark by selecting **File Browser menubar: Bookmarks⇒Edit Bookmarks** or by right-clicking the bookmark and selecting **Remove**. You can also use **Edit Bookmarks** to reorder bookmarks.

**Information** Information presents information about the folder displayed by the View pane.

**Tree** Tree presents an expandable tree view of your home folder, and each mounted filesystem. Each directory in the tree has a triangle to its left. Click a triangle that points right to expand a directory; click a triangle that points down to close a directory. Click a directory in the tree to display that directory in the View pane. Double-click a directory to expand it in the Side pane and display it in the View pane.

**History** History displays a chronological list of the folders that have been displayed in the View pane, with the most recently displayed folder at the top. Double-click a folder in this list to display it in the View pane.

**Notes** Notes provides a place to keep notes about the folder displayed in the View pane.

**Emblems** Similar to the Emblems tab in the Object Properties window (page 120), Emblems allows you to drag emblems from the Side pane and drop them on objects in the View pane. Drag and drop the **Erase** emblem to erase emblems associated with an object. You cannot erase emblems that Fedora/RHEL places on objects, such as locked and link emblems.

## CONTROL BARS

This section discusses the four control bars that initially appear in a File Browser window: the status bar, menubar, Main toolbar, and location bar (Figure 8-2). From

**File Browser menubar:** View, you can choose which of these bars to display—except for the menubar, which Nautilus always displays.

- Menubar The menubar appears at the top of the File Browser window and displays a menu when you click one of its selections. Which menu selections Nautilus displays depend on what the View pane is displaying and which objects are selected. The next section describes the menubar in detail.
- Main toolbar The Main toolbar appears below the menubar and holds navigation tool icons: Back, Forward, Up, Stop, Reload, Home, Computer, and Search. If the Main toolbar is too short to hold all icons, Nautilus displays a button with a triangle pointing down at the right end of the toolbar. Click this button to display a drop-down list of the remaining icons.
- Location bar Below the Main toolbar is the location bar, which displays the name of the directory that appears in the View pane. It can display this name in two formats: iconic (using buttons) and textual (using a text box). Press `CONTROL-L` to switch to textual format, and click the pencil-and-paper icon at the left of this bar to switch between iconic and textual formats.

In iconic format, each button represents a directory in a pathname (page 193). The View pane displays the directory of the depressed (darker) button. Click one of these buttons to display that directory. If the leftmost button holds a triangle that points to the left, Nautilus is not displaying buttons for all the directories in the absolute (full) pathname; click the button with a triangle in it to display more directory buttons.

In textual format, the text box displays the absolute pathname of the displayed directory. To have Nautilus display another directory, enter the pathname of the directory and press `RETURN`.

The location bar also holds the magnification selector and the View drop-down list. To change the magnification of the display in the View pane, click the plus or minus sign in a magnifying glass on either side of the magnification percentage. Right-click the magnification percentage itself to return to the default magnification. Left-click the magnification percentage to display a drop-down list of magnifications. Click the button found at the right side of the right-hand magnifying glass to choose whether to view files as icons, as a list, or in compact format.

- Status bar If no items are selected, the status bar, at the bottom of the window, indicates how many items are displayed in the View pane. If the directory you are viewing is on the local system, it also tells you how much free space is available on the device that holds the directory displayed by the View pane. If an item is selected, the status bar displays the name of the item and its size.

## MENUBAR

The Nautilus File Browser menubar controls which information the File Browser displays and how it displays that information. Many of the menu selections duplicate controls found elsewhere in the File Browser window. This section highlights



**Figure 8-4** The Connect to Server window

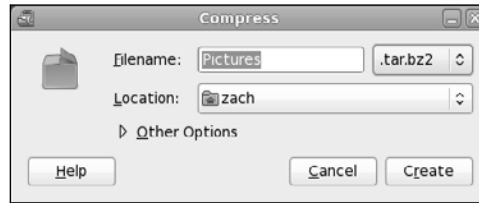
some of the selections on the menubar; click **Help** on the menubar and select **Contents** for more information. The menubar holds the menus described next.

**File** The several Open selections and the Property selection of File work with the highlighted object(s) in the View pane. If no objects are highlighted, these selections are grayed out or absent. Selecting **Connect to Server** (also available from **Main menu: Places**) displays the Connect to Server window (Figure 8-4). This window presents a **Service type** drop-down list that allows you to select FTP, SSH, Windows, or other types of servers. Enter the URL of the server in the text box labeled **Server**. For an FTP connection, do not enter the **ftp://** part of the URL. Fill in the optional information as appropriate. Click **Connect**. If the server requires authentication, Nautilus displays a window in which you can enter a username and password. Nautilus opens a window displaying a directory on the server and an object, named for the URL you specified, on the desktop. After you close the window, you can open the object to connect to and display a directory on the server.

**Edit** Many of the Edit selections work with highlighted object(s) in the View pane; if no objects are highlighted, these selections are grayed out or absent. This section discusses three selections from Edit: Compress, Backgrounds and Emblems, and Preferences.

The **Edit⇨Compress** selection creates a single archive file comprising the selected objects. This selection opens a Compress window (Figure 8-5) that allows you to specify the name and location of the archive. The drop-down list to the right of the text box labeled **Filename** allows you to specify a filename extension that determines the type of archive this tool creates. For example, **.tar.gz** creates a **tar** (page 163) file compressed by **gzip** (page 163) and **.tar.bz2** creates a **tar** file compressed by **bzip2** (page 162). Click the triangle to the left of Other Objects to specify a password for and/or to encrypt the archive (available only with certain types of archives). You can also split the archive into several files (volumes).

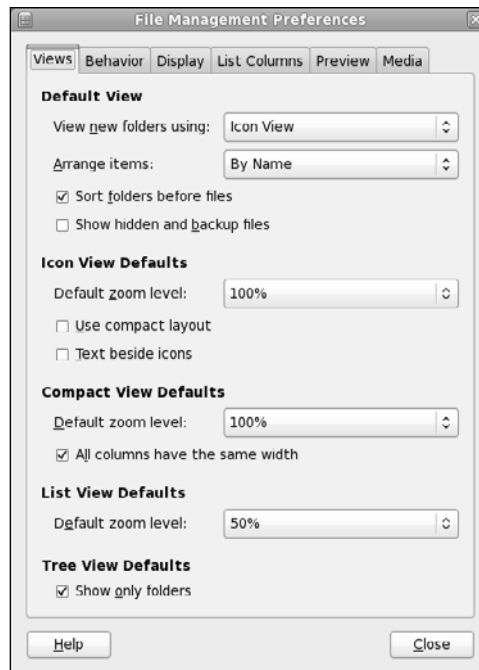




**Figure 8-5** The Compress window

The **Edit⇒Backgrounds and Emblems** selection has three buttons on the left: Patterns, Colors, and Emblems. Click **Patterns** to display many pattern objects on the right side of the window. Drag and drop one of these objects on the View pane of a File Browser window to change the background of all File Browser View panes. Drag and drop the Reset object to reset the background to its default color and pattern (usually white). The Colors button works the same way as the Patterns button. The Emblems button works the same way as the Emblems tab in the Side pane (page 266).

The **Edit⇒Preferences** selection displays the File Management Preferences window (Figure 8-6). This window has six tabs that control the appearance and behavior of File Browser windows.



**Figure 8-6** The File Management Preferences window, Views tab

The **Views** tab sets several defaults, including which view the File Browser displays (Icon, List, or Compact view), the arrangement of the objects, the default zoom level, and default settings for the Compact view.

Delete versus  
Move to Trash

The **Behavior** tab controls how many clicks it takes to open an object and what Nautilus does when it opens an executable text object (script). For more confident users, this tab has an option that includes a Delete selection in addition to the Move to Trash selection on several menus. The Delete selection immediately removes the selected object instead of moving it to the **Trash** folder. This tab also holds the check box labeled **Always open in browser window** that is described under “The Two Faces of Nautilus” on page 99.

The **Display** tab specifies which information Nautilus includes in object (icon) captions. The three drop-down lists specify the order in which Nautilus displays information as you increase the zoom level of the View pane. This tab also specifies the date format Nautilus uses.

The **List Columns** tab specifies which columns Nautilus displays, and in what order it displays them, in the View pane when you select **List View**.

The **Preview** tab controls when Nautilus displays or plays previews of files (Always, Local Files Only, Never).

The **Media** tab specifies which action Nautilus takes when you insert media such as a CD/DVD, or connect devices such as a flash drive, to the system.

**View** Click the **Main Toolbar**, **Side Pane**, **Location Bar**, and **Statusbar** selections in the View submenu to display or remove these elements from the window. The **Show Hidden Files** selection displays in the View pane those files with hidden filenames (page 192).

**Go** The Go selections display various folders in the View pane.

**Bookmarks** Bookmarks appear at the bottom of this menu and in the Side pane under Places. The Bookmarks selections are explained under “Places” on page 266.

**Tabs** The Tabs selections work with tabs in the Nautilus window (*FEDORA*).

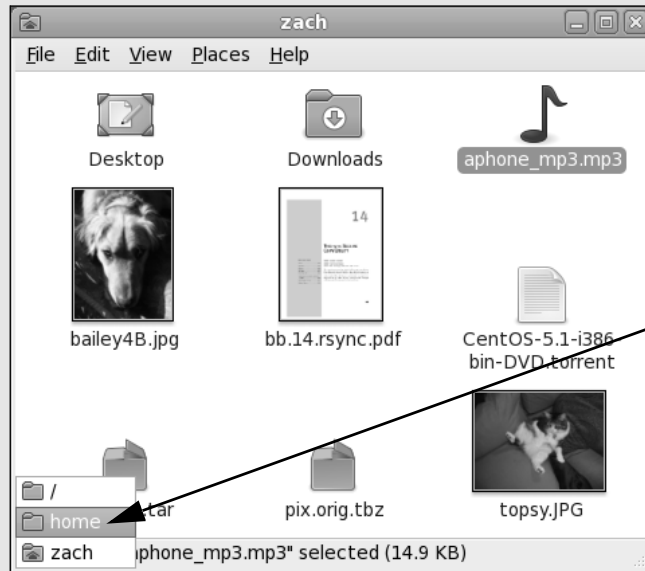
**Help** The Help selections display local information about Nautilus.

## optional

# THE NAUTILUS SPATIAL VIEW

Nautilus gives you two ways to work with files: the traditional File Browser view described in the previous section and the innovative Spatial view shown in Figure 8-7. By default, Fedora/RHEL display the Spatial view. Other than in this section, this book describes the more traditional File Browser window. See “The Two Faces of Nautilus” on page 99 for instructions on how to turn off the Spatial view and turn on the File Browser.

The Nautilus Spatial (as in “having the nature of space”) view has many powerful features but may take some getting used to. It always provides one window per folder. By default, when you open a folder, Nautilus displays a new window.



**Figure 8-7** The Nautilus Spatial view

To open a Spatial view of your home directory, double-click the Home icon on the desktop and experiment as you read this section. If you double-click the Desktop icon in the Spatial view, Nautilus opens a new window that displays the **Desktop** folder.

A Spatial view can display icons, a list of filenames, or a compact view. To select your preferred format, click **View** on the menubar and choose **Icons**, **List**, or **Compact**. To create files to experiment with, right-click in the window (not on an icon) to display the Nautilus context menu and select **Create Folder** or **Create Document**.

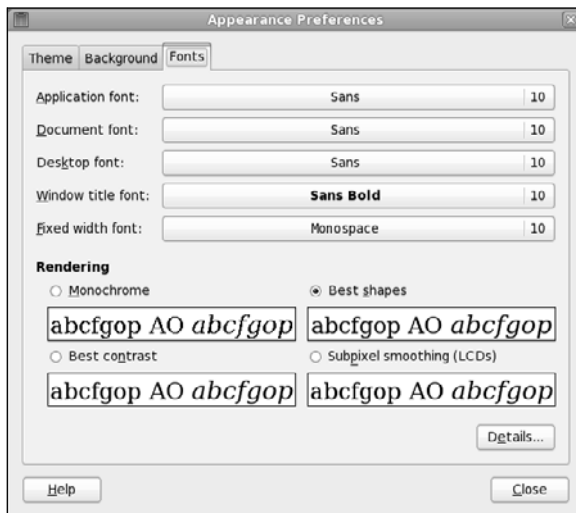
### Use SHIFT to close the current window as you open another window

**tip** If you hold the **SHIFT** key down when you double-click to open a new window, Nautilus closes the current window as it opens the new one. This behavior may be more familiar and can help keep the desktop from becoming overly cluttered. If you do not want to use the keyboard, you can achieve the same result by double-clicking the middle mouse button.

**Window memory** Move the window by dragging the titlebar. The Spatial view has *window memory*—that is, the next time you open that folder, Nautilus opens it at the same size and in the same location. Even the scrollbar will be in the same position.

**Parent-folders button** The key to closing the current window and returning to the window of the parent directory is the **Parent-folders** button (Figure 8-7). Click this button to display the Parent-folders pop-up menu. Select the directory you want to open from this menu. Nautilus then displays in a Spatial view the directory you specified.

From a Spatial view, you can open a folder in a traditional view by right-clicking the folder and selecting **Browse Folder**.



**Figure 8-8** The Appearance Preferences window, Fonts tab

## GNOME UTILITIES

GNOME comes with numerous utilities that can make your work with the desktop easier and more productive. This section covers several tools that are integral to the use of GNOME.

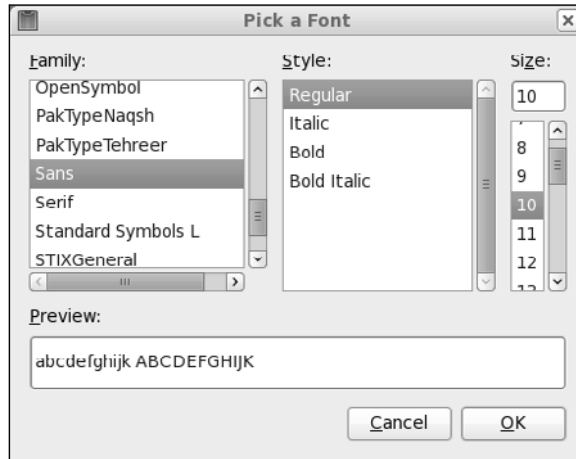
### FONT PREFERENCES (*FEDORA*)

The Fonts tab of the Appearance Preferences window (Figure 8-8) enables you to change the font GNOME uses for applications, documents, the desktop, window titles, and terminal emulators (fixed width). To display this window, select **Main menu: System**⇒**Preferences**⇒**Appearance** or enter **gnome-appearance-properties** on a command line. Click the **Fonts** tab. Click one of the five font bars in the upper part of the window to display the Pick a Font window (discussed next).

Examine the four sample boxes in the lower part of the window and select the one in which the letters look the best. Subpixel smoothing is usually best for LCD monitors. Click **Details** to refine the font rendering further, again picking the box in each section in which the letters look the best.

### PICK A FONT WINDOW (*FEDORA*)

The Pick a Font window (Figure 8-9) appears when you need to choose a font; see the previous section. From this window you can select a font family, a style, and a size. A preview of your choice appears in the Preview frame in the lower part of the window. Click **OK** when you are satisfied with your choice.

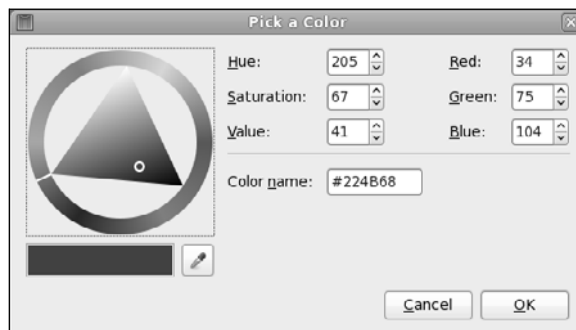


**Figure 8-9** The Pick a Font window

## PICK A COLOR WINDOW

The Pick a Color window (Figure 8-10) appears when you need to specify a color, such as when you specify a solid color for the desktop background (page 107) or a panel. To specify a color for a panel, right-click the panel to display its context menu, select **Properties**, click the **Background** tab, click the radio button labeled **Solid color**, and click within the box labeled **Color**. GNOME displays the Pick a Color window.

When the Pick a Color window opens, the bar below the color circle displays the current color. Click the desired color on the color ring, and click/drag the lightness of that color in the triangle. As you change the color, the right end of the bar below the color circle previews the color you are selecting, while the left end continues to display the current color. You can also use the eyedropper to pick up a color from the workspace: Click the eyedropper, and then click the resulting eyedropper mouse pointer on the color you want to select. The color you choose appears in the bar. Click **OK** when you are satisfied with the color you have specified.



**Figure 8-10** The Pick a Color window

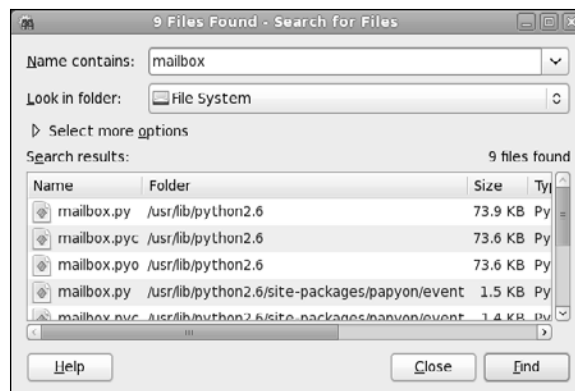
## RUN APPLICATION WINDOW

The Run Application window (Figure 4-4, page 95) enables you to run a program as though you had initiated it from a command line. To display the Run Application window, press ALT-F2. Enter a command in the text box. As soon as GNOME can uniquely identify the command you are entering, it completes the command and may display an object that identifies the application. Keep typing if the displayed command is not the one you want to run. Otherwise, press RETURN to run the command or TAB to accept the command in the text box. You can then continue entering information in the window. Click **Run with file** to specify a file to use as an argument to the command in the text box. Put a tick in the check box labeled **Run in terminal** to run a textual application, such as vim, in a terminal emulator window.

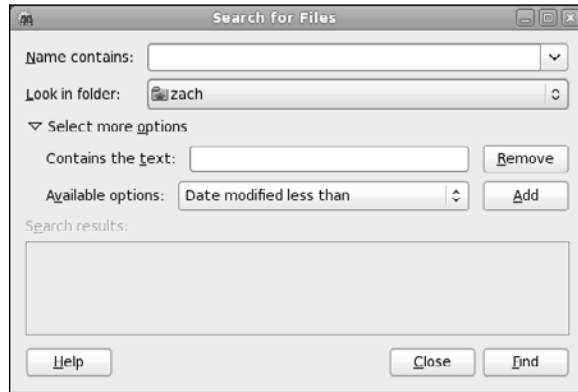
## SEARCHING FOR FILES

The Search for Files window (Figure 8-11) can help you find files whose locations or names you do not know or have forgotten. To open this window, select **Main menu: Places⇒Search for Files** or enter **gnome-search-tool** on a command line from a terminal emulator or Run Application window (ALT-F2). To search by filename or partial filename, enter the (partial) filename in the combo box labeled **Name contains** and then select the folder you want to search in from the drop-down list labeled **Look in folder**. When GNOME searches in a folder, it searches subfolders to any level (it searches the directory hierarchy). To search all directories in all mounted filesystems, select **File System** from the drop-down list labeled **Look in folder**. Select **Other** to search a folder not included in the drop-down list; GNOME opens the Browse/Save window (page 103). Once you have entered the search criteria, click **Find**. GNOME displays the list of files matching the criteria in the list box labeled **Search results**. Double-click a file in this list box to open it.

To refine the search, you can enter more search criteria. Click the triangle to the left of **Select more options** to expand the window and display more search criteria.



**Figure 8-11** The Search for Files window



**Figure 8-12** The Search for Files window with Select more options expanded

GNOME initially displays one search criterion and a line for adding criteria as shown in Figure 8-12. With this part of the window expanded, GNOME incorporates all visible search criteria when you click **Find**.

The first line below **Select more options** holds a text box labeled **Contains the text**. If nothing is entered in this text box, the search matches all files. You can leave this text box as is or remove the line by clicking **Remove** at the right end of the line. To search for a file that contains a specific string of characters (text), enter the string in this text box.

To add search criteria, make a selection from the list box labeled **Available options** and click **Add** to the right of the drop-down list. To remove criteria, click **Remove** at the right end of the line that holds the criterion you want to remove.

To select files that were modified fewer than a specified number of days ago, select **Date modified less than** from the drop-down list labeled **Available options** and click **Add**. The Search for Files window adds a line with a spin box labeled **Date modified less than**. With this spin box showing 0 (zero), as it does initially, no file matches the search criteria. Change this number as desired and click **Find** to begin the search.

## GNOME TERMINAL EMULATOR/SHELL

The GNOME terminal emulator displays a window that mimics a character-based terminal (page 118). To display a terminal emulator window, select **Main menu: Applications⇒System Tools⇒Terminal (FEDORA)**, **Main menu: Applications⇒Accessories⇒Terminal (RHEL)**, or enter **gnome-terminal** on a command line or from a Run Application window (ALT-F2). When the GNOME terminal emulator is already displayed, select **Terminal menubar: File⇒Open Terminal** or right-click within the Terminal window and select **Open Terminal** to display a new terminal emulator window.

To open an additional terminal session within the same Terminal window, right-click the window and select **Open Tab** from the context menu or select **Terminal**

**menubar: File⇒Open Tab.** A row of tabs appears below the menubar as `gnome-terminal` opens another terminal session on top of the existing one. Add as many terminal sessions as you like; click the tabs to switch between sessions.

### GNOME terminal emulator shortcuts

**tip** While using the GNOME terminal emulator, `CONTROL-SHIFT-N` opens a new window and `CONTROL-SHIFT-T` opens a new tab. New windows and tabs open to the working directory. In addition, you can use `CONTROL-PAGE UP` and `CONTROL-PAGE DOWN` to switch between tabs.

A session you add from the context menu uses the same profile as the session you open it from. When you use the menubar to open a session, GNOME gives you a choice of profiles, if more than one is available. You can add and modify profiles, including the Default profile, by selecting **Terminal menubar: Edit⇒Profiles**. Highlight the profile you want to modify or click **New** to design a new profile.

---

## CHAPTER SUMMARY

The X Window System GUI is portable and flexible and makes it easy to write applications that work on many different types of systems without having to know low-level details for the individual systems. This GUI can operate in a networked environment, allowing a user to run a program on a remote system and send the results to a local display. The client/server concept is integral to the operation of the X Window System, in which the X server is responsible for fulfilling requests made of X Window System applications or clients. Hundreds of clients are available that can run under X. Programmers can also write their own clients, using tools such as the GTK+ and GTK+2 GNOME libraries to write GNOME programs and the Qt and KDE libraries to write KDE programs.

The window managers, and virtually all X applications, are designed to help users tailor their work environments in simple or complex ways. You can designate applications that start automatically, set such attributes as colors and fonts, and even alter the way keyboard strokes and mouse clicks are interpreted.

Built on top of the X Window System, the GNOME desktop manager can be used as is or customized to better suit your needs. It is a graphical user interface to system services (commands), the filesystem, applications, and more. Although not part of GNOME, the Metacity and Compiz window managers work closely with GNOME and are the default window managers for GNOME under Fedora. A window manager controls all aspects of the windows, including placement, decoration, grouping, minimizing and maximizing, sizing, and moving.

The Nautilus File Browser window is a critical part of GNOME; the desktop is a modified File Browser window. The File Browser View pane displays icons or a list of filenames you can work with. The Side pane, which can display six types of information, augments the information Nautilus displays in the View pane.



GNOME also provides many graphical utilities you can use to customize and work with the desktop. It supports MIME types; thus, when you double-click an object, GNOME generally knows which tool to use to display the data represented by the object. In sum, GNOME is a powerful desktop manager that can make your job both easier and more fun.

---

## EXERCISES

1. a. What is Nautilus?  
b. List four things you can do with Nautilus.  
c. How do you use Nautilus to search for a file?
2. What is a terminal emulator? What does it allow you to do from a GUI that you would not be able to do without one?
3. How would you search the entire filesystem for a file named **today.odt**?
4. a. List two ways you can open a file using Nautilus.  
b. How does Nautilus “know” which program to use to open different types of files?  
c. What are the three common Nautilus control bars? Which kinds of tools do you find on each?  
d. Discuss the use of the Nautilus location bar in textual mode.

---

## ADVANCED EXERCISES

5. Assume you are using a mouse with nine pointer buttons defined. How would you reverse the effects of using the mouse wheel?
6. a. How would you use Nautilus to connect to the FTP server at [mirrors.kernel.org/fedora](http://mirrors.kernel.org/fedora)?  
b. Find a small file in the directory hierarchy. How would you copy this file to the desktop?
7. Discuss the client/server environment set up by the X Window System. How does the X server work? List three X clients. Where is the client and where is the server when you log in on a local system? What is an advantage of this setup?
8. Run `xwininfo` from a terminal emulator window and answer these questions:
  - a. What does `xwininfo` do?

- b. What does `xwininfo` give as the name of the window you clicked? Does that agree with the name in the window's titlebar?
  - c. What is the size of the window? In which units does `xwininfo` display this size? What is the depth of a window?
  - d. How can you get `xwininfo` to display the same information without having to click the window?
9. Find and install `xeyes`. Write an `xeyes` command to display a window that is 600 pixels wide and 400 pixels tall, is located 200 pixels from the right edge of the screen and 300 pixels from the top of the screen, and contains orange eyes outlined in blue with red pupils. (*Hint:* Refer to the `xeyes` man page.)

# THE BOURNE AGAIN SHELL

## IN THIS CHAPTER

|                                                |     |
|------------------------------------------------|-----|
| Startup Files .....                            | 281 |
| Redirecting Standard Error.....                | 284 |
| Writing a Simple Shell Script ....             | 286 |
| Job Control.....                               | 294 |
| Parameters and Variables .....                 | 299 |
| Processes .....                                | 314 |
| History.....                                   | 316 |
| Reexecuting and Editing<br>Commands.....       | 318 |
| Aliases.....                                   | 332 |
| Functions.....                                 | 335 |
| Controlling bash Features and<br>Options ..... | 338 |
| Processing the Command Line...                 | 342 |

This chapter picks up where Chapter 7 left off. Chapter 27 expands on this chapter, exploring control flow commands and more advanced aspects of programming the Bourne Again Shell. The bash home page is [www.gnu.org/software/bash](http://www.gnu.org/software/bash). The bash info page is a complete Bourne Again Shell reference.

The Bourne Again Shell is a command interpreter and high-level programming language. As a command interpreter, it processes commands you enter on the command line in response to a prompt. When you use the shell as a programming language, it processes commands stored in files called *shell scripts*. Like other languages, shells have variables and control flow commands (for example, **for** loops and **if** statements).

When you use a shell as a command interpreter, you can customize the environment you work in. You can make your prompt display the name of the working directory, create a function or alias for **cp** that keeps it from overwriting certain kinds of files, take advantage of keyword variables to change aspects of how the shell works, and so on. You can also write shell scripts that do your bidding, from a one-line script that

stores a long, complex command to a longer script that runs a set of reports, prints them, and mails you a reminder when the job is done. More complex shell scripts are themselves programs; they do not just run other programs. Chapter 27 has some examples of these types of scripts.

Most system shell scripts are written to run under the Bourne Again Shell. If you will ever work in single-user mode—as when you boot your system or do system maintenance, administration, or repair work, for example—it is a good idea to become familiar with this shell.

This chapter expands on the interactive features of the shell described in Chapter 7, explains how to create and run simple shell scripts, discusses job control, introduces the basic aspects of shell programming, talks about history and aliases, and describes command-line expansion. Chapter 27 presents some more challenging shell programming problems.

---

## BACKGROUND

The Bourne Again Shell is based on the Bourne Shell (the early UNIX shell; this book refers to it as the *original Bourne Shell* to avoid confusion), which was written by Steve Bourne of AT&T's Bell Laboratories. Over the years the original Bourne Shell has been expanded but it remains the basic shell provided with many commercial versions of UNIX.

**sh Shell** Because of its long and successful history, the original Bourne Shell has been used to write many of the shell scripts that help manage UNIX systems. Some of these scripts appear in Linux as Bourne Again Shell scripts. Although the Bourne Again Shell includes many extensions and features not found in the original Bourne Shell, **bash** maintains compatibility with the original Bourne Shell so you can run Bourne Shell scripts under **bash**. On UNIX systems the original Bourne Shell is named **sh**. On Linux systems **sh** is a symbolic link to **bash** ensuring that scripts that require the presence of the Bourne Shell still run. When called as **sh**, **bash** does its best to emulate the original Bourne Shell.

**Korn Shell** System V UNIX introduced the Korn Shell (**ksh**), written by David Korn. This shell extended many features of the original Bourne Shell and added many new features. Some features of the Bourne Again Shell, such as command aliases and command-line editing, are based on similar features from the Korn Shell.

**POSIX standards** The POSIX (the Portable Operating System Interface) family of related standards is being developed by PASC (IEEE's Portable Application Standards Committee, [www.pasc.org](http://www.pasc.org)). A comprehensive FAQ on POSIX, including many links, appears at [www.opengroup.org/austin/papers/posix\\_faq.html](http://www.opengroup.org/austin/papers/posix_faq.html).

POSIX standard 1003.2 describes shell functionality. The Bourne Again Shell provides the features that match the requirements of this POSIX standard. Efforts are under way to make the Bourne Again Shell fully comply with the POSIX standard. In the meantime, if you invoke **bash** with the **--posix** option, the behavior of the Bourne Again Shell will more closely match the POSIX requirements.

## SHELL BASICS

This section covers writing and using startup files, redirecting standard error, writing and executing simple shell scripts, separating and grouping commands, implementing job control, and manipulating the directory stack.

## STARTUP FILES

When a shell starts, it runs startup files to initialize itself. Which files the shell runs depends on whether it is a login shell, an interactive shell that is not a login shell (such as you get by giving the command **bash**), or a noninteractive shell (one used to execute a shell script). You must have read access to a startup file to execute the commands in it. Fedora/RHEL puts appropriate commands in some of these files. This section covers **bash** startup files.

### LOGIN SHELLS

The files covered in this section are executed by login shells and shells that you start with the **--login** option. Login shells are, by their nature, interactive.

- /etc/profile** The shell first executes the commands in **/etc/profile**. Superuser can set up this file to establish systemwide default characteristics for **bash** users.
- .bash\_profile** Next the shell looks for **~/.bash\_profile**, **~/.bash\_login**, and **~/.profile** (**~/** is shorthand for your home directory), in that order, executing the commands in the first of these files it finds. You can put commands in one of these files to override the defaults set in **/etc/profile**.
- .bash\_login**
- .profile**
- .bash\_logout** When you log out, **bash** executes commands in the **~/.bash\_logout** file. Frequently commands that clean up after a session, such as those that remove temporary files, go in this file.

### INTERACTIVE NONLOGIN SHELLS

The commands in the preceding startup files are not executed by interactive, nonlogin shells. However, these shells inherit from the login shell variables that are set by these startup files.

- /etc/bashrc** Although not called by **bash** directly, many **~/.bashrc** files call **/etc/bashrc**. This setup allows Superuser to establish systemwide default characteristics for nonlogin **bash** shells.
- .bashrc** An interactive nonlogin shell executes commands in the **~/.bashrc** file. Typically a startup file for a login shell, such as **.bash\_profile**, runs this file, so that both login and nonlogin shells benefit from the commands in **.bashrc**.

### NONINTERACTIVE SHELLS

The commands in the previously described startup files are not executed by noninteractive shells, such as those that runs shell scripts. However, these shells inherit from the login shell variables that are set by these startup files.

**BASH\_ENV** Noninteractive shells look for the environment variable **BASH\_ENV** (or **ENV**, if the shell is called as **sh**) and execute commands in the file named by this variable.

## SETTING UP STARTUP FILES

Although many startup files and types of shells exist, usually all you need are the **.bash\_profile** and **.bashrc** files in your home directory. Commands similar to the following in **.bash\_profile** run commands from **.bashrc** for login shells (when **.bashrc** exists). With this setup, the commands in **.bashrc** are executed by login and non-login shells.

```
if [ -f ~/.bashrc ]; then source ~/.bashrc; fi
```

The `[ -f ~/.bashrc ]` tests whether the file named **.bashrc** in your home directory exists. See pages 889 and 891 for more information on **test** and its synonym `[ ]`.

### Use **.bash\_profile** to set **PATH**

**tip** Because commands in **.bashrc** may be executed many times, and because subshells inherit exported variables, it is a good idea to put commands that add to existing variables in the **.bash\_profile** file. For example, the following command adds the **bin** subdirectory of the **home** directory to **PATH** (page 306) and should go in **.bash\_profile**:

```
PATH=$PATH:$HOME/bin
```

When you put this command in **.bash\_profile** and not in **.bashrc**, the string is added to the **PATH** variable only once, when you log in.

Modifying a variable in **.bash\_profile** allows changes you make in an interactive session to propagate to subshells. In contrast, modifying a variable in **.bashrc** overrides changes inherited from a parent shell.

Sample **.bash\_profile** and **.bashrc** files follow. Some of the commands used in these files are not covered until later in this chapter. In any startup file, you must export variables and functions that you want to be available to child processes. For more information refer to “Locality of Variables” on page 926.

```
$ cat ~/.bash_profile
if [ -f ~/.bashrc ]; then
    source ~/.bashrc          # read local startup file if it exists
fi
PATH=$PATH:.                # add the working directory to PATH
export PS1='\h \W \!]\$ '    # set prompt
```

The first command in the preceding **.bash\_profile** file executes the commands in the user’s **.bashrc** file if it exists. The next command adds to the **PATH** variable (page 306). Typically **PATH** is set and exported in **/etc/profile** so it does not need to be exported in a user’s startup file. The final command sets and exports **PS1** (page 307), which controls the user’s prompt.

Next is a sample **.bashrc** file. The first command executes the commands in the **/etc/bashrc** file if it exists. Next the **LANG** (page 312) and **VIMINIT** (for vim initialization) variables are set and exported and several aliases (page 332) are established. The final command defines a function (page 335) that swaps the names of two files.

```

$ cat ~/.bashrc
if [ -f /etc/bashrc ]; then
    source /etc/bashrc      # read global startup file if it exists
fi

set -o noclobber            # prevent overwriting files
unset MAILCHECK            # turn off "you have new mail" notice
export LANG=C              # set LANG variable
export VIMINIT='set ai aw' # set vim options
alias df='df -h'           # set up aliases
alias rm='rm -i'           # always do interactive rm's
alias lt='ls -ltrh | tail'
alias h='history | tail'
alias ch='chmod 755 '

function switch()           # a function to exchange the names
{                           # of two files
    local tmp=$$switch
    mv "$1" $tmp
    mv "$2" "$1"
    mv $tmp "$2"
}

```

## . (DOT) OR source: RUNS A STARTUP FILE IN THE CURRENT SHELL

After you edit a startup file such as `.bashrc`, you do not have to log out and log in again to put the changes into effect. You can run the startup file using the `.` (dot) or `source` builtin (they are the same command). As with all other commands, the `.` must be followed by a `SPACE` on the command line. Using the `.` or `source` builtin is similar to running a shell script, except that these commands run the script as part of the current process. Consequently, when you use `.` or `source` to run a script, changes you make to variables from within the script affect the shell that you run the script from. You can use the `.` or `source` command to run any shell script—not just a startup file—but undesirable side effects (such as changes in the values of shell variables you rely on) may occur. If you ran a startup file as a regular shell script and did not use the `.` or `source` builtin, the variables created in the startup file would remain in effect only in the subshell running the script—not in the shell you ran the script from. For more information refer to “Locality of Variables” on page 926.

In the following example, `.bashrc` sets several variables and sets `PS1`, the prompt, to the name of the host. The `.` builtin puts the new values into effect.

```

$ cat ~/.bashrc
export TERM=vt100          # set the terminal type
export PS1="$(hostname -f): " # set the prompt string
export CDPATH=: $HOME       # add HOME to CDPATH string
stty kill '^u'              # set kill line to control-u

$ . ~/.bashrc
bravo.example.com:

```

## COMMANDS THAT ARE SYMBOLS

The Bourne Again Shell uses the symbols (, ), [, ], and \$ in a variety of ways. To minimize confusion, Table 9-1 lists the most common use of each of these symbols, even though some of them are not introduced until later.

**Table 9-1**    Builtin commands that are symbols

| Symbol   | Command                                                                                                  |
|----------|----------------------------------------------------------------------------------------------------------|
| ( )      | Subshell (page 293)                                                                                      |
| \$( )    | Command substitution (page 348)                                                                          |
| (( ))    | Arithmetic evaluation; a synonym for let (use when the enclosed value contains an equal sign) (page 950) |
| \$( ( )) | Arithmetic expansion (not for use with an enclosed equal sign) (page 346)                                |
| [ ]      | The test command (pages 889, 891, and 904)                                                               |
| [[ ]]    | Conditional expression; similar to [ ] but adds string comparisons (page 951)                            |

## REDIRECTING STANDARD ERROR

Chapter 7 covered the concept of standard output and explained how to redirect standard output of a command. In addition to standard output, commands can send output to *standard error*. A command can send error messages to standard error to keep them from getting mixed up with the information it sends to standard output.

Just as it does with standard output, by default the shell sends a command’s standard error to the screen. Unless you redirect one or the other, you may not know the difference between the output a command sends to standard output and the output it sends to standard error. This section covers the syntax used by the Bourne Again Shell.

**File descriptors**    A *file descriptor* is the place a program sends its output to and gets its input from. When you execute a program, the process running the program opens three file descriptors: 0 (standard input), 1 (standard output), and 2 (standard error). The redirect output symbol (> [page 232]) is shorthand for 1>, which tells the shell to redirect standard output. Similarly < (page 234) is short for 0<, which redirects standard input. The symbols 2> redirect standard error. For more information refer to “File Descriptors” on page 921.

The following examples demonstrate how to redirect standard output and standard error to different files and to the same file. When you run the cat utility with the name of a file that does not exist and the name of a file that does exist, cat sends an error message to standard error and copies the file that does exist to standard output. Unless you redirect them, both messages appear on the screen.

```
$ cat y
This is y.
$ cat x
cat: x: No such file or directory
```



```
$ cat x y
cat: x: No such file or directory
This is y.
```

When you redirect standard output of a command, output sent to standard error is not affected and still appears on the screen.

```
$ cat x y > hold
cat: x: No such file or directory
$ cat hold
This is y.
```

Similarly, when you send standard output through a pipe, standard error is not affected. The following example sends standard output of `cat` through a pipe to `tr`, which in this example converts lowercase characters to uppercase. (See the `tr` info page for more information.) The text that `cat` sends to standard error is not translated because it goes directly to the screen rather than through the pipe.

```
$ cat x y | tr "[a-z]" "[A-Z]"
cat: x: No such file or directory
THIS IS Y.
```

The following example redirects standard output and standard error to different files. The notation `2>` tells the shell where to redirect standard error (file descriptor 2). The `1>` tells the shell where to redirect standard output (file descriptor 1). You can use `>` in place of `1>`.

```
$ cat x y 1> hold1 2> hold2
$ cat hold1
This is y.
$ cat hold2
cat: x: No such file or directory
```

Duplicating a file  
descriptor

In the next example, `1>` redirects standard output to `hold`. Then `2>&1` declares file descriptor 2 to be a duplicate of file descriptor 1. As a result both standard output and standard error are redirected to `hold`.

```
$ cat x y 1> hold 2>&1
$ cat hold
cat: x: No such file or directory
This is y.
```

In the preceding example, `1> hold` precedes `2>&1`. If they had been listed in the opposite order, standard error would have been made a duplicate of standard output before standard output was redirected to `hold`. In that case only standard output would have been redirected to `hold`.

The next example declares file descriptor 2 to be a duplicate of file descriptor 1 and sends the output for file descriptor 1 through a pipe to the `tr` command.

```
$ cat x y 2>&1 | tr "[a-z]" "[A-Z]"
CAT: X: NO SUCH FILE OR DIRECTORY
THIS IS Y.
```

Sending errors to standard error    You can also use `1>&2` to redirect standard output of a command to standard error. This technique is used in shell scripts to send the output of `echo` to standard error. In the following script, standard output of the first `echo` is redirected to standard error:

```
$ cat message_demo
echo This is an error message. 1>&2
echo This is not an error message.
```

If you redirect standard output of `message_demo`, error messages such as the one produced by the first `echo` will still go to the screen because you have not redirected standard error. Because standard output of a shell script is frequently redirected to another file, you can use this technique to display on the screen error messages generated by the script. The `lnks` script (page 896) uses this technique. You can also use the `exec` builtin to create additional file descriptors and to redirect standard input, standard output, and standard error of a shell script from within the script (page 940).

The Bourne Again Shell supports the redirection operators shown in Table 9-2.

**Table 9-2**    Redirection operators

| Operator                       | Meaning                                                                                                                                                                                                                       |
|--------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>&lt; filename</code>     | Redirects standard input from <i>filename</i> .                                                                                                                                                                               |
| <code>&gt; filename</code>     | Redirects standard output to <i>filename</i> unless <i>filename</i> exists and <b>noclobber</b> (page 235) is set. If <b>noclobber</b> is not set, this redirection creates <i>filename</i> if it does not exist.             |
| <code>&gt;  filename</code>    | Redirects standard output to <i>filename</i> , even if the file exists and <b>noclobber</b> (page 235) is set.                                                                                                                |
| <code>&gt;&gt; filename</code> | Redirects and appends standard output to <i>filename</i> unless <i>filename</i> exists and <b>noclobber</b> (page 235) is set. If <b>noclobber</b> is not set, this redirection creates <i>filename</i> if it does not exist. |
| <code>&lt;&amp;m</code>        | Duplicates standard input from file descriptor <i>m</i> (page 922).                                                                                                                                                           |
| <code>[n]&gt;&amp;m</code>     | Duplicates standard output or file descriptor <i>n</i> if specified from file descriptor <i>m</i> (page 922).                                                                                                                 |
| <code>[n]&lt;&amp;-</code>     | Closes standard input or file descriptor <i>n</i> if specified (page 922).                                                                                                                                                    |
| <code>[n]&gt;&amp;-</code>     | Closes standard output or file descriptor <i>n</i> if specified.                                                                                                                                                              |

# WRITING A SIMPLE SHELL SCRIPT

A *shell script* is a file that contains commands that the shell can execute. The commands in a shell script can be any commands you can enter in response to a shell prompt. For example, a command in a shell script might run a Linux utility, a compiled program, or another shell script. Like the commands you give on the command line, a command in a shell script can use ambiguous file references and can have its input or output redirected from or to a file or sent through a pipe (page 238). You can also use pipes and redirection with the input and output of the script itself.

In addition to the commands you would ordinarily use on the command line, *control flow* commands (also called *control structures*) find most of their use in shell scripts. This group of commands enables you to alter the order of execution of commands in a script just as you would alter the order of execution of statements using a structured programming language. Refer to “Control Structures” on page 888 for specifics.

The shell interprets and executes the commands in a shell script, one after another. Thus a shell script enables you to simply and quickly initiate a complex series of tasks or a repetitive procedure.

## chmod: MAKES A FILE EXECUTABLE

To execute a shell script by giving its name as a command, you must have permission to read and execute the file that contains the script (refer to “Access Permissions” on page 202). Read permission enables you to read the file that holds the script. Execute permission tells the shell and the system that the owner, group, and/or public has permission to execute the file; it implies that the content of the file is executable.

When you create a shell script using an editor, the file does not typically have its execute permission set. The following example shows a file named **whoson** that contains a shell script:

```
$ cat whoson
date
echo "Users Currently Logged In"
who

$ whoson
bash: ./whoson: Permission denied
```

You cannot execute **whoson** by giving its name as a command because you do not have execute permission for the file. The shell does not recognize **whoson** as an executable file and issues an error message when you try to execute it. When you give the filename as an argument to **bash** (**bash whoson**), **bash** takes the argument to be a shell script and executes it. In this case **bash** is executable and **whoson** is an argument that **bash** executes so you do not need to have permission to execute **whoson**.

## Command not found?

**tip** If you get the message

```
$ whoson
bash: whoson: command not found
```

the shell is not set up to search for executable files in the working directory. Give this command instead:

```
$ ./whoson
```

The **./** tells the shell explicitly to look for an executable file in the working directory. To change the environment so that the shell searches the working directory automatically, see page 306.

```

$ ls -l whoson
-rw-rw-r-- 1 alex group 40 May 24 11:30 whoson

$ chmod u+x whoson
$ ls -l whoson
-rwxr--r-- 1 alex group 40 May 24 11:30 whoson

$ whoson
Sat May 24 11:40:49 PDT 2008
Users Currently Logged In
jenny pts/7 May 23 18:17
hls pts/1 May 24 09:59
scott pts/12 May 24 06:29 (bravo.example.com)
alex pts/4 May 24 09:08

```

**Figure 9-1** Using `chmod` to make a shell script executable

The `chmod` utility changes the access privileges associated with a file. Figure 9-1 shows `ls` with the `-l` option displaying the access privileges of `whoson` before and after `chmod` gives execute permission to the file's owner.

The first `ls` displays a hyphen (`-`) as the fourth character, indicating that the owner does not have permission to execute the file. Next `chmod` gives the owner execute permission: The `u+x` causes `chmod` to add (+) execute permission (`x`) for the owner (`u`). (The `u` stands for *user*, although it means the owner of the file who may be the user of the file at any given time.) The second argument is the name of the file. The second `ls` shows an `x` in the fourth position, indicating that the owner now has execute permission.

If other users will execute the file, you must also change group and/or public access permissions for the file. Any user must have execute access to use the file's name as a command. If the file is a shell script, the user trying to execute the file must also have read access to the file. You do not need read access to execute a binary executable (compiled program).

The final command in Figure 9-1 shows the shell executing the file when its name is given as a command. For more information refer to "Access Permissions" on page 202, `ls` (page 203), and `chmod` (page 204).

## #! SPECIFIES A SHELL

You can put a special sequence of characters on the first line of a file to tell the operating system which shell should execute the file. Because the operating system checks the initial characters of a program before attempting to `exec` it, these characters save the system from making an unsuccessful attempt. If `#!` are the first two characters of a script, the system interprets the characters that follow as the absolute pathname of the utility that should execute the script. This can be the pathname of any program, not just a shell. The following example specifies that `bash` should run the script:

```
$ cat bash_script
#!/bin/bash
echo "This is a Bourne Again Shell script."
```

The `#!` characters are useful if you have a script that you want to run with a shell other than the shell you are running the script from. The following example shows a script that should be executed by `tcsh`:

```
$ cat tcsh_script
#!/bin/tcsh
echo "This is a tcsh script."
set person = jenny
echo "person is $person"
```

Because of the `#!` line, the operating system ensures that `tcsh` executes the script no matter which shell you run it from.

You can use `ps -f` within a shell script to display the name of the shell that is executing the script. The three lines that `ps` displays in the following example show the process running the parent `bash` shell, the process running the `tcsh` script, and the process running the `ps` command:

```
$ cat tcsh_script2
#!/bin/tcsh
ps -f

$ tcsh_script2
UID          PID    PPID  C STIME TTY          TIME CMD
alex         3031   3030  0 Nov16 pts/4        00:00:00 -bash
alex         9358   3031  0 21:13 pts/4        00:00:00 /bin/tcsh ./tcsh_script2
alex         9375   9358  0 21:13 pts/4        00:00:00 ps -f
```

If you do not follow `#!` with the name of an executable program, the shell reports that it cannot find the command that you asked it to run. You can optionally follow `#!` with `SPACES`. If you omit the `#!` line and try to run, for example, a `tcsh` script from `bash`, the shell may generate error messages or the script may not run properly.

## # BEGINS A COMMENT

Comments make shell scripts and all code easier to read and maintain by you and others. If a pound sign (`#`) in the first character position of the first line of a script is not immediately followed by an exclamation point (`!`) or if a pound sign occurs in any other location in a script, the shell interprets it as the beginning of a comment. The shell then ignores everything between the pound sign and the end of the line (the next `NEWLINE` character).

## RUNNING A SHELL SCRIPT

**fork** and **exec**  
system calls

A command on the command line causes the shell to **fork** a new process, creating a duplicate of the shell process (a subshell). The new process attempts to **exec** (execute) the command. Like **fork**, the **exec** routine is executed by the operating system (a system call). If the command is a binary executable program, such as a compiled

C program, `exec` succeeds and the system overlays the newly created subshell with the executable program. If the command is a shell script, `exec` fails. When `exec` fails, the command is assumed to be a shell script, and the subshell runs the commands in the script. Unlike a login shell, which expects input from the command line, the subshell takes its input from a file: the shell script.

As discussed earlier, if you have a shell script in a file that you do not have execute permission for, you can run the commands in the script by using a `bash` command to `exec` a shell to run the script directly. In the following example, `bash` creates a new shell that takes its input from the file named `whoson`:

```
$ bash whoson
```

Because the `bash` command expects to read a file containing commands, you do not need execute permission for `whoson`. (You do need read permission.) Even though `bash` reads and executes the commands in `whoson`, standard input, standard output, and standard error remain connected to the terminal.

Although you can use `bash` to execute a shell script, this technique causes the script to run more slowly than giving yourself execute permission and directly invoking the script. Users typically prefer to make the file executable and run the script by typing its name on the command line. It is also easier to type the name, and this practice is consistent with the way other kinds of programs are invoked (so you do not need to know whether you are running a shell script or another kind of program). However, if `bash` is not your interactive shell or if you want to see how the script runs with different shells, you may want to run a script as an argument to `bash` or `tcsh`.

### **sh does not call the original Bourne Shell**

**caution** The original Bourne Shell was invoked with the command `sh`. Although you can call `bash` with an `sh` command, it is not the original Bourne Shell. The `sh` command (`/bin/sh`) is a symbolic link to `/bin/bash`, so it is simply another name for the `bash` command. When you call `bash` using the command `sh`, `bash` tries to mimic the behavior of the original Bourne Shell as closely as possible. It does not always succeed.

---

## **SEPARATING AND GROUPING COMMANDS**

Whether you give the shell commands interactively or write a shell script, you must separate commands from one another. This section reviews the ways to separate commands that were covered in Chapter 7 and introduces a few new ones.

### **; AND NEWLINE SEPARATE COMMANDS**

The NEWLINE character is a unique command separator because it initiates execution of the command preceding it. You have seen this throughout this book each time you press the RETURN key at the end of a command line.

The semicolon (;) is a command separator that *does not* initiate execution of a command and *does not* change any aspect of how the command functions. You can execute a series of commands sequentially by entering them on a single command line and separating each from the next with a semicolon (;). You initiate execution of the sequence of commands by pressing RETURN:

```
$ x ; y ; z
```

If `x`, `y`, and `z` are commands, the preceding command line yields the same results as the next three commands. The difference is that in the next example the shell issues a prompt after each of the commands (`x`, `y`, and `z`) finishes executing, whereas the preceding command line causes the shell to issue a prompt only after `z` is complete:

```
$ x
$ y
$ z
```

**Whitespace** Although the whitespace around the semicolons in the earlier example makes the command line easier to read, it is not necessary. None of the command separators needs to be surrounded by `SPACES` or `TABS`.

## \ CONTINUES A COMMAND

When you enter a long command line and the cursor reaches the right side of the screen, you can use a backslash (`\`) character to continue the command on the next line. The backslash quotes, or escapes, the `NEWLINE` character that follows it so that the shell does not treat the `NEWLINE` as a command terminator. Enclosing a backslash within single quotation marks turns off the power of a backslash to quote special characters such as `NEWLINE`. Enclosing a backslash within double quotation marks has no effect on the power of the backslash.

Although you can break a line in the middle of a word (token), it is typically easier to break a line just before or after whitespace.

**optional** You can enter a `RETURN` in the middle of a quoted string on a command line without using a backslash. The `NEWLINE` (`RETURN`) that you enter will then be part of the string:

```
$ echo "Please enter the three values
> required to complete the transaction."
Please enter the three values
required to complete the transaction.
```

In the three examples in this section, the shell does not interpret `RETURN` as a command terminator because it occurs within a quoted string. The `>` is a secondary prompt indicating that the shell is waiting for you to continue the unfinished command. In the next example, the first `RETURN` is quoted (escaped) so the shell treats it as a separator and does not interpret it literally.

```
$ echo "Please enter the three values \
> required to complete the transaction."
Please enter the three values required to complete the transaction.
```

Single quotation marks cause the shell to interpret a backslash literally:

```
$ echo 'Please enter the three values \
> required to complete the transaction.'
Please enter the three values \
required to complete the transaction.
```

## | AND & SEPARATE COMMANDS AND DO SOMETHING ELSE

The pipe symbol (`|`) and the background task symbol (`&`) are also command separators. They *do not* start execution of a command but *do* change some aspect of how the command functions. The pipe symbol alters the source of standard input or the destination of standard output. The background task symbol causes the shell to execute the task in the background so you get a prompt immediately and can continue working on other tasks.

Each of the following command lines initiates a single job comprising three tasks:

```
$ x | y | z
$ ls -l | grep tmp | less
```

In the first job, the shell redirects standard output of task `x` to standard input of task `y` and redirects `y`'s standard output to `z`'s standard input. Because it runs the entire job in the foreground, the shell does not display a prompt until task `z` runs to completion: Task `z` does not finish until task `y` finishes, and task `y` does not finish until task `x` finishes. In the second job, task `x` is an `ls -l` command, task `y` is `grep tmp`, and task `z` is the pager `less`. The shell displays a long (wide) listing of the files in the working directory that contain the string `tmp`, piped through `less`.

The next command line executes tasks `d` and `e` in the background and task `f` in the foreground:

```
$ d & e & f
[1] 14271
[2] 14272
```

The shell displays the job number between brackets and the PID (process identification) number for each process running in the background. You get a prompt as soon as `f` finishes, which may be before `d` or `e` finishes.

Before displaying a prompt for a new command, the shell checks whether any background jobs have completed. For each job that has completed, the shell displays its job number, the word **Done**, and the command line that invoked the job; then the shell displays a prompt. When the job numbers are listed, the number of the last job started is followed by a `+` character and the job number of the previous job is followed by a `-` character. Any other jobs listed show a `SPACE` character. After running the last command, the shell displays the following before issuing a prompt:

```
[1]- Done           d
[2]+ Done           e
```

The next command line executes all three tasks as background jobs. You get a shell prompt immediately:

```
$ d & e & f &
[1] 14290
[2] 14291
[3] 14292
```

You can use pipes to send the output from one task to the next task and an ampersand (`&`) to run the entire job as a background task. Again the prompt comes back immediately. The shell regards the commands joined by a pipe as being a single job. That is, it treats all pipes as single jobs, no matter how many tasks are connected



with the pipe (|) symbol or how complex they are. The Bourne Again Shell shows only one process placed in the background:

```
$ d | e | f &
[1] 14295
```

### optional ( ) GROUPS COMMANDS

You can use parentheses to group commands. The shell creates a copy of itself, called a *subshell*, for each group. It treats each group of commands as a job and creates a new process to execute each command (refer to “Process Structure” on page 314 for more information on creating subshells). Each subshell (job) has its own environment, meaning that it has its own set of variables with values that can differ from those of other subshells.

The following command line executes commands **a** and **b** sequentially in the background while executing **c** in the background. The shell prompt returns immediately.

```
$ ( a ; b ) & c &
[1] 15520
[2] 15521
```

The preceding example differs from the earlier example **d & e & f &** in that tasks **a** and **b** are initiated sequentially, not concurrently.

Similarly the following command line executes **a** and **b** sequentially in the background and, at the same time, executes **c** and **d** sequentially in the background. The subshell running **a** and **b** and the subshell running **c** and **d** run concurrently. The prompt returns immediately.

```
$ ( a ; b ) & ( c ; d ) &
[1] 15528
[2] 15529
```

The next script copies one directory to another. The second pair of parentheses creates a subshell to run the commands following the pipe. Because of these parentheses, the output of the first **tar** command is available for the second **tar** command despite the intervening **cd** command. Without the parentheses, the output of the first **tar** command would be sent to **cd** and lost because **cd** does not process input from standard input. The shell variables **\$1** and **\$2** represent the first and second command-line arguments (page 931), respectively. The first pair of parentheses, which creates a subshell to run the first two commands, allows users to call **cpdir** with relative pathnames. Without them the first **cd** command would change the working directory of the script (and consequently the working directory of the second **cd** command). With them only the working directory of the subshell is changed.

```
$ cat cpdir
(cd $1 ; tar -cf - . ) | (cd $2 ; tar -xvf - )
$ cpdir /home/alex/sources /home/alex/memo/biblio
```

The **cpdir** command line copies the files and directories in the **/home/alex/sources** directory to the directory named **/home/alex/memo/biblio**. This shell script is almost the same as using **cp** with the **-r** option. Refer to the **cp** and **tar** man pages for more information.

## JOB CONTROL

A job is a command pipeline. You run a simple job whenever you give the shell a command. For example, type **date** on the command line and press RETURN: You have run a job. You can also create several jobs with multiple commands on a single command line:

```
$ find . -print | sort | lpr & grep -l alex /tmp/* > alexfiles &
[1] 18839
[2] 18876
```

The portion of the command line up to the first **&** is one job consisting of three processes connected by pipes: **find**, **sort** (page 155), and **lpr** (page 153). The second job is a single process running **grep**. Both jobs have been put into the background by the trailing **&** characters, so **bash** does not wait for them to complete before displaying a prompt.

Using job control you can move commands from the foreground to the background (and vice versa), stop commands temporarily, and list all the commands that are running in the background or stopped.

### jobs: LISTS JOBS

The **jobs** builtin lists all background jobs. The following sequence demonstrates what happens when you give a **jobs** command. Here the **sleep** command runs in the background and creates a background job that **jobs** reports on:

```
$ sleep 60 &
[1] 7809
$ jobs
[1] + Running                  sleep 60 &
```

### fg: BRINGS A JOB TO THE FOREGROUND

The shell assigns job numbers to commands you run in the background (page 292). Several jobs are started in the background in the next example. For each job the shell lists the job number and PID number immediately, just before it issues a prompt.

```
$ gnome-calculator &
[1] 1246
$ date &
[2] 1247
$ Thu Dec 4 11:44:40 PST 2008
[2]+ Done                  date
$ find /usr -name ace -print > findout &
[2] 1269
$ jobs
[1]- Running               gnome-calculator &
[2]+ Running               find /usr -name ace -print > findout &
```

Job numbers, which are discarded when a job is finished, can be reused. When you start or put a job in the background, the shell assigns a job number that is one more than the highest job number in use.

In the preceding example, the `jobs` command lists the first job, `gnome-calculator`, as job 1. The `date` command does not appear in the jobs list because it finished before `jobs` was run. Because the `date` command was completed before `find` was run, the `find` command became job 2.

To move a background job into the foreground, use the `fg` builtin followed by the job number. Alternatively, you can give a percent sign (%) followed by the job number as a command. Either of the following commands moves job 2 into the foreground:

```
$ fg 2
```

*or*

```
$ %2
```

You can also refer to a job by following the percent sign with a string that uniquely identifies the beginning of the command line used to start the job. Instead of the preceding command, you could have used either `fg %find` or `fg %f` because both uniquely identify job 2. If you follow the percent sign with a question mark and a string, the string can match any part of the command line. In the preceding example, `fg %?ace` also brings job 2 into the foreground.

Often the job you wish to bring into the foreground is the only job running in the background or is the job that `jobs` lists with a plus (+). In these cases you can use `fg` without an argument.

## bg: SENDS A JOB TO THE BACKGROUND

To move the foreground job to the background, you must first suspend (temporarily stop) the job by pressing the suspend key (usually `CONTROL-Z`). Pressing the suspend key immediately suspends the job in the foreground. You can then use the `bg` builtin to resume execution of the job in the background.

```
$ bg
```

If a background job attempts to read from the terminal, the shell stops it and notifies you that the job has been stopped and is waiting for input. You must then move the job into the foreground so that it can read from the terminal. The shell displays the command line when it moves the job into the foreground.

```
$ (sleep 5; cat > mytext) &
[1] 1343
$ date
Thu Dec 4 11:58:20 PST 2008
[1]+ Stopped ( sleep 5; cat >mytext )
$ fg
( sleep 5; cat >mytext )
Remember to let the cat out!
CONTROL-D
$
```

In the preceding example, the shell displays the job number and PID number of the background job as soon as it starts, followed by a prompt. Demonstrating that you can give a command at this point, the user gives the command `date` and its output

appears on the screen. The shell waits until just before it issues a prompt (after `date` has finished) to notify you that job 1 is stopped. When you give an `fg` command, the shell puts the job in the foreground and you can enter the input that the command is waiting for. In this case the input needs to be terminated with a `CONTROL-D` to signify EOF (end of file). The shell then displays another prompt.

The shell keeps you informed about changes in the status of a job, notifying you when a background job starts, completes, or is stopped, perhaps waiting for input from the terminal. The shell also lets you know when a foreground job is suspended. Because notices about a job being run in the background can disrupt your work, the shell delays displaying these notices until just before it displays a prompt. You can set `notify` (page 341) to make the shell display these notices without delay.

If you try to exit from a shell while jobs are stopped, the shell issues a warning and does not allow you to exit. If you then use `jobs` to review the list of jobs or you immediately try to leave the shell again, the shell allows you to leave and terminates the stopped jobs. Jobs that are running (not stopped) in the background continue to run. In the following example, `find` (job 1) continues to run after the second `exit` terminates the shell, but `cat` (job 2) is terminated:

```
$ find / -size +100k > $HOME/bigfiles 2>&1 &
[1] 1426
$ cat > mytest &
[2] 1428
[2]+  Stopped                  cat >mytest
$ exit
exit
There are stopped jobs.
$ exit
exit
```

login:

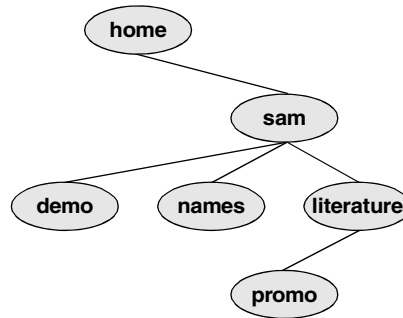
## MANIPULATING THE DIRECTORY STACK

The Bourne Again Shell allows you to store a list of directories you are working with, enabling you to move easily among them. This list is referred to as a *stack*. It is analogous to a stack of dinner plates: You typically add plates to and remove plates from the top of the stack, creating a last-in first-out (*LIFO*) stack.

### **dirs: DISPLAYS THE STACK**

The `dirs` builtin displays the contents of the directory stack. If you call `dirs` when the directory stack is empty, it displays the name of the working directory:

```
$ dirs
~/literature
```



**Figure 9-2** The directory structure in the examples

The `dirs` builtin uses a tilde (~) to represent the name of the home directory. The examples in the next several sections assume that you are referring to the directory structure shown in Figure 9-2.

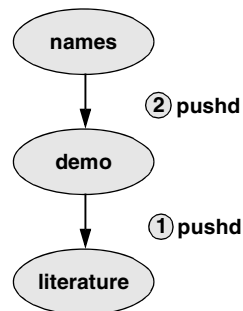
## pushd: PUSHES A DIRECTORY ON THE STACK

To change directories and at the same time add a new directory to the top of the stack, use the `pushd` (push directory) builtin. In addition to changing directories, the `pushd` builtin displays the contents of the stack. The following example is illustrated in Figure 9-3:

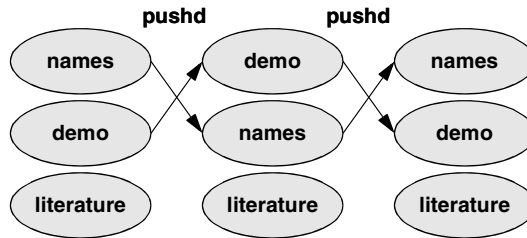
```

$ pushd ../demo
~/demo ~/literature
$ pwd
/home/sam/demo

$ pushd ../names
~/names ~/demo ~/literature
$ pwd
/home/sam/names
  
```



**Figure 9-3** Creating a directory stack



**Figure 9-4** Using `pushd` to change working directories

When you use `pushd` without an argument, it swaps the top two directories on the stack and makes the new top directory (which was the second directory) become the new working directory (Figure 9-4):

```
$ pushd
~/demo ~/names ~/literature
$ pwd
/home/sam/demo
```

Using `pushd` in this way, you can easily move back and forth between two directories. You can also use `cd -` to change to the previous directory, whether or not you have explicitly created a directory stack. To access another directory in the stack, call `pushd` with a numeric argument preceded by a plus sign. The directories in the stack are numbered starting with the top directory, which is number 0. The following `pushd` command continues with the previous example, changing the working directory to **literature** and moving **literature** to the top of the stack:

```
$ pushd +2
~/literature ~/demo ~/names
$ pwd
/home/sam/literature
```

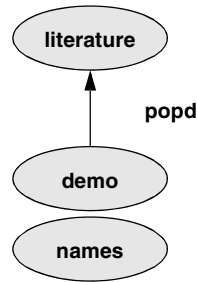
## popd: POPS A DIRECTORY OFF THE STACK

To remove a directory from the stack, use the `popd` (pop directory) builtin. As the following example and Figure 9-5 show, `popd` used without an argument removes the top directory from the stack and changes the working directory to the new top directory:

```
$ dirs
~/literature ~/demo ~/names
$ popd
~/demo ~/names
$ pwd
/home/sam/demo
```

To remove a directory other than the top one from the stack, use `popd` with a numeric argument preceded by a plus sign. The following example removes directory number 1, **demo**:

```
$ dirs
~/literature ~/demo ~/names
$ popd +1
~/literature ~/names
```



**Figure 9-5** Using `popd` to remove a directory from the stack

Removing a directory other than directory number 0 does not change the working directory.

## PARAMETERS AND VARIABLES

**Variables** Within a shell, a *shell parameter* is associated with a value that is accessible to the user. There are several kinds of shell parameters. Parameters whose names consist of letters, digits, and underscores are often referred to as *shell variables*, or simply *variables*. A variable name must start with a letter or underscore, not with a number. Thus `A76`, `MY_CAT`, and `___X___` are valid variable names, whereas `69TH_STREET` (starts with a digit) and `MY-NAME` (contains a hyphen) are not.

**User-created variables** Shell variables that you name and assign values to are *user-created variables*. You can change the values of user-created variables at any time, or you can make them *readonly* so that their values cannot be changed. You can also make user-created variables *global*. A global variable (also called an *environment variable*) is available to all shells and other programs you fork from the original shell. One naming convention is to use only uppercase letters for global variables and to use mixed-case or lowercase letters for other variables. Refer to “Locality of Variables” on page 926 for more information on global variables.

To assign a value to a variable in the Bourne Again Shell, use the following syntax:

**`VARIABLE=value`**

There can be no whitespace on either side of the equal sign (`=`). An example assignment follows:

**`$ myvar=abc`**

The Bourne Again Shell permits you to put variable assignments on a command line. These assignments are local to the command shell—that is, they apply to the command only. The `my_script` shell script displays the value of `TEMPDIR`. The following command runs `my_script` with `TEMPDIR` set to `/home/sam/temp`. The `echo` builtin shows that the interactive shell has no value for `TEMPDIR` after running `my_script`. If `TEMPDIR` had been set in the interactive shell, running `my_script` in this manner would have had no effect on its value.

```
$ cat my_script
echo $TEMPDIR
$ TEMPDIR=/home/sam/temp my_script
/home/sam/temp
$ echo $TEMPDIR

$
```

Keyword variables *Keyword shell variables* (or simply *keyword variables*) have special meaning to the shell and usually have short, mnemonic names. When you start a shell (by logging in, for example), the shell inherits several keyword variables from the environment. Among these variables are **HOME**, which identifies your home directory, and **PATH**, which determines which directories the shell searches and in what order to locate commands that you give the shell. The shell creates and initializes (with default values) other keyword variables when you start it. Still other variables do not exist until you set them.

You can change the values of most of the keyword shell variables at any time but it is usually not necessary to change the values of keyword variables initialized in the */etc/profile* or */etc/csh.cshrc* systemwide startup files. If you need to change the value of a **bash** keyword variable, do so in one of your startup files (page 281). Just as you can make user-created variables global, so you can make keyword variables global; this is usually done automatically in the startup files. You can also make a keyword variable readonly.

Positional and special parameters The names of positional and special parameters do not resemble variable names. Most of these parameters have one-character names (for example, **1**, **?**, and **#**) and are referenced (as are all variables) by preceding the name with a dollar sign (**\$1**, **\$?**, and **\$#**). The values of these parameters reflect different aspects of your ongoing interaction with the shell.

Whenever you give a command, each argument on the command line becomes the value of a *positional parameter*. Positional parameters (page 930) enable you to access command-line arguments, a capability that you will often require when you write shell scripts. The **set** builtin (page 934) enables you to assign values to positional parameters.

Other frequently needed shell script values, such as the name of the last command executed, the number of command-line arguments, and the status of the most recently executed command, are available as *special parameters*. You cannot assign values to special parameters.

## USER-CREATED VARIABLES

The first line in the following example declares the variable named **person** and initializes it with the value **alex**:

```
$ person=alex
$ echo person
person
$ echo $person
alex
```



Because the `echo` builtin copies its arguments to standard output, you can use it to display the values of variables. The second line of the preceding example shows that `person` does not represent `alex`. Instead, the string `person` is echoed as `person`. The shell substitutes the value of a variable only when you precede the name of the variable with a dollar sign (`$`). The command `echo $person` displays the value of the variable `person`; it does not display `$person` because the shell does not pass `$person` to `echo` as an argument. Because of the leading `$`, the shell recognizes that `$person` is the name of a variable, *substitutes* the value of the variable, and passes that value to `echo`. The `echo` builtin displays the value of the variable—not its name—never knowing that you called it with a variable.

Quoting the `$` You can prevent the shell from substituting the value of a variable by quoting the leading `$`. Double quotation marks do not prevent the substitution; single quotation marks or a backslash (`\`) do.

```
$ echo $person
alex
$ echo "$person"
alex
$ echo '$person'
$person
$ echo \ $person
$person
```

SPACES Because they do not prevent variable substitution but do turn off the special meanings of most other characters, double quotation marks are useful when you assign values to variables and when you use those values. To assign a value that contains SPACES or TABS to a variable, use double quotation marks around the value. Although double quotation marks are not required in all cases, using them is a good habit.

```
$ person="alex and jenny"
$ echo $person
alex and jenny

$ person=alex and jenny
bash: and: command not found
```

When you reference a variable that contains TABS or multiple adjacent SPACES, you need to use quotation marks to preserve the spacing. If you do not quote the variable, the shell collapses each string of blank characters into a single SPACE before passing the variable to the utility:

```
$ person="alex  and  jenny"
$ echo $person
alex and jenny
$ echo "$person"
alex  and  jenny
```

When you execute a command with a variable as an argument, the shell replaces the name of the variable with the value of the variable and passes that value to the program being executed. If the value of the variable contains a special character, such as `*` or `?`, the shell *may* expand that variable.

Pathname expansion in assignments The first line in the following sequence of commands assigns the string **alex\*** to the variable **memo**. The Bourne Again Shell does *not expand the string* because bash does not perform pathname expansion (page 243) when assigning a value to a variable. All shells process a command line in a specific order. Within this order bash expands variables before it interprets commands. In the following **echo** command line, the double quotation marks quote the asterisk (\*) in the expanded value of **\$memo** and prevent bash from performing pathname expansion on the expanded **memo** variable before passing its value to the **echo** command:

```
$ memo=alex*
$ echo "$memo"
alex*
```

All shells interpret special characters as special when you reference a variable that contains an unquoted special character. In the following example, the shell expands the value of the **memo** variable because it is not quoted:

```
$ ls
alex.report
alex.summary
$ echo $memo
alex.report alex.summary
```

Here the shell expands the **\$memo** variable to **alex\***, expands **alex\*** to **alex.report** and **alex.summary**, and passes these two values to **echo**.

## optional

Braces The **\$VARIABLE** syntax is a special case of the more general syntax **\${VARIABLE}**, in which the variable name is enclosed by **{}**. The braces insulate the variable name. Braces are necessary when concatenating a variable value with a string:

```
$ PREF=counter
$ WAY=$PREFclockwise
$ FAKE=$PREFfeit
$ echo $WAY $FAKE

$
```

The preceding example does not work as planned. Only a blank line is output because, although the symbols **PREFclockwise** and **PREFfeit** are valid variable names, they are not set. By default bash evaluates an unset variable as an empty (null) string and displays this value. To achieve the intent of these statements, refer to the **PREF** variable using braces:

```
$ PREF=counter
$ WAY=${PREF}clockwise
$ FAKE=${PREF}feit
$ echo $WAY $FAKE
counterclockwise counterfeit
```

The Bourne Again Shell refers to the arguments on its command line by position, using the special variables \$1, \$2, \$3, and so forth up to \$9. If you wish to refer to arguments past the ninth argument, you must use braces: \${10}. The name of the command is held in \$0 (page 931).

### unset: REMOVES A VARIABLE

Unless you remove a variable, it exists as long as the shell in which it was created exists. To remove the *value* of a variable but not the variable itself, set the value to null:

```
$ person=
$ echo $person

$
```

You can remove a variable with the unset builtin. To remove the variable **person**, give the following command:

```
$ unset person
```

## VARIABLE ATTRIBUTES

This section discusses attributes and explains how to assign them to variables.

### readonly: MAKES THE VALUE OF A VARIABLE PERMANENT

You can use the **readonly** builtin to ensure that the value of a variable cannot be changed. The next example declares the variable **person** to be readonly. You must assign a value to a variable *before* you declare it to be readonly; you cannot change its value after the declaration. When you attempt to unset or change the value of a readonly variable, the shell displays an error message:

```
$ person=jenny
$ echo $person
jenny
$ readonly person
$ person=helen
bash: person: readonly variable
```

If you use the **readonly** builtin without an argument, it displays a list of all readonly shell variables. This list includes keyword variables that are automatically set as readonly as well as keyword or user-created variables that you have declared as readonly. See “Listing variable attributes” on page 304 for an example (**readonly** and **declare -r** produce the same output).

### declare AND typeset: ASSIGN ATTRIBUTES TO VARIABLES

The **declare** and **typeset** builtins (two names for the same command) set attributes and values for shell variables. Table 9-3 (next page) lists five of these attributes.

**Table 9-3** Variable attributes (typeset or declare)

| Attribute | Meaning                                                      |
|-----------|--------------------------------------------------------------|
| <b>-a</b> | Declares a variable as an array (page 924)                   |
| <b>-f</b> | Declares a variable to be a function name (page 335)         |
| <b>-i</b> | Declares a variable to be of type integer (page 305)         |
| <b>-r</b> | Makes a variable readonly; also readonly (page 303)          |
| <b>-x</b> | Exports a variable (makes it global); also export (page 926) |

The following commands declare several variables and set some attributes. The first line declares **person1** and assigns it a value of **alex**. This command has the same effect with or without the word **declare**.

```
$ declare person1=alex
$ declare -r person2=jenny
$ declare -rx person3=helen
$ declare -x person4
```

The readonly and export builtins are synonyms for the commands **declare -r** and **declare -x**, respectively. It is legal to declare a variable without assigning a value to it, as the preceding declaration of the variable **person4** illustrates. This declaration makes **person4** available to all subshells (makes it global). Until an assignment is made to the variable, it has a null value.

You can list the options to **declare** separately in any order. The following is equivalent to the preceding declaration of **person3**:

```
$ declare -x -r person3=helen
```

Use the **+** character in place of **-** when you want to remove an attribute from a variable. You cannot remove a readonly attribute however. After the following command is given, the variable **person3** is no longer exported but it is still readonly.

```
$ declare +x person3
```

You can also use **typeset** instead of **declare**.

Listing variable attributes

Without any arguments or options, the **declare** builtin lists all shell variables. The same list is output when you run **set** (page 934) without any arguments.

If you use a **declare** builtin with options but no variable names as arguments, the command lists all shell variables that have the indicated attributes set. For example, the option **-r** with **declare** gives a list of all readonly shell variables. This list is the same as that produced by a **readonly** command without any arguments. After the declarations in the preceding example have been given, the results are as follows:

```
$ declare -r
declare -ar BASH_VERSION='([0]="4" [1]="0" [2]="33" [3]="1" ... )'
declare -ir EUID="500"
declare -ir PPID="936"
```

```
declare -r SHELLOPTS="braceexpand:emacs:hashall:histexpand:history:..."
declare -ir UID="500"
declare -r person2="jenny"
declare -rx person3="helen"
```

The first five entries are keyword variables that are automatically declared as read-only. Some of these variables are stored as integers (**-i**). The **-a** option indicates that **BASH\_VERSINFO** is an array variable; the value of each element of the array is listed to the right of an equal sign.

**Integer** By default the values of variables are stored as strings. When you perform arithmetic on a string variable, the shell converts the variable into a number, manipulates it, and then converts it back to a string. A variable with the integer attribute is stored as an integer. Assign the integer attribute as follows:

```
$ typeset -i COUNT
```

## KEYWORD VARIABLES

Keyword variables either are inherited or are declared and initialized by the shell when it starts. You can assign values to these variables from the command line or from a startup file. Typically you want these variables to apply to all subshells you start as well as to your login shell. For those variables not automatically exported by the shell, you must use **export** (page 926) to make them available to child shells.

### HOME: YOUR HOME DIRECTORY

By default your home directory is your working directory when you log in. Your home directory is determined when you establish your account; its name is stored in the **/etc/passwd** file.

```
$ grep sam /etc/passwd
sam:x:501:501:Sam S. x301:/home/sam:/bin/bash
```

When you log in, the shell inherits the pathname of your home directory and assigns it to the variable **HOME**. When you give a **cd** command without an argument, **cd** makes the directory whose name is stored in **HOME** the working directory:

```
$ pwd
/home/alex/laptop
$ echo $HOME
/home/alex
$ cd
$ pwd
/home/alex
```

This example shows the value of the **HOME** variable and the effect of the **cd** builtin. After you execute **cd** without an argument, the pathname of the working directory is the same as the value of **HOME**: your home directory.

**Tilde (~)** The shell uses the value of **HOME** to expand pathnames that use the shorthand tilde (**~**) notation (page 193) to denote a user's home directory. The following example

uses `echo` to display the value of this shortcut and then uses `ls` to list the files in Alex's `laptop` directory, which is a subdirectory of his home directory:

```
$ echo ~
/home/alex
$ ls ~/laptop
tester      count      lineup
```

## PATH: WHERE THE SHELL LOOKS FOR PROGRAMS

When you give the shell an absolute or relative pathname rather than a simple filename as a command, it looks in the specified directory for an executable file with the specified filename. If the file with the pathname you specified does not exist, the shell reports **command not found**. If the file exists as specified but you do not have execute permission for it, or in the case of a shell script you do not have read and execute permission for it, the shell reports **Permission denied**.

If you give a simple filename as a command, the shell searches through certain directories for the program you want to execute. It looks in several directories for a file that has the same name as the command and that you have execute permission for (a compiled program) or read and execute permission for (a shell script). The `PATH` shell variable controls this search.

The default value of `PATH` is determined when `bash` is compiled. It is not set in a startup file, although it may be modified there. Normally the default specifies that the shell search several system directories used to hold common commands and then search the working directory. These system directories include `/bin` and `/usr/bin` and other directories appropriate to the local system. When you give a command, if the shell does not find the executable—and, in the case of a shell script, readable—file named by the command in any of the directories listed in `PATH`, the shell generates one of the aforementioned error messages.

**Working directory** The `PATH` variable specifies the directories in the order the shell should search them. Each directory must be separated from the next by a colon. The following command sets `PATH` so that a search for an executable file starts with the `/usr/local/bin` directory. If it does not find the file in this directory, the shell first looks in `/bin`, and then in `/usr/bin`. If the search fails in those directories, the shell looks in the `bin` directory, a subdirectory of the user's home directory. Finally the shell looks in the working directory. Exporting `PATH` makes its value accessible to subshells:

```
$ export PATH=/usr/local/bin:/bin:/usr/bin:~/bin:
```

A null value in the string indicates the working directory. In the preceding example, a null value (nothing between the colon and the end of the line) appears as the last element of the string. The working directory is represented by a leading colon (not recommended; see the following security tip), a trailing colon (as in the example), or two colons next to each other anywhere in the string. You can also represent the working directory explicitly with a period (`.`).

Because Linux stores many executable files in directories named `bin` (*binary*), users typically put their own executable files in their own `~/bin` directories. If you put

your own **bin** directory at the end of your **PATH**, as in the preceding example, the shell looks there for any commands that it cannot find in directories listed earlier in **PATH**.

### PATH and security

**security** Do not put the working directory first in **PATH** when security is a concern. If you are running as Superuser, you should *never* put the working directory first in **PATH**. It is common for Superuser **PATH** to omit the working directory entirely. You can always execute a file in the working directory by prepending **./** to the name: **./ls**.

Putting the working directory first in **PATH** can create a security hole. Most people type **ls** as the first command when entering a directory. If the owner of a directory places an executable file named **ls** in the directory, and the working directory appears first in a user's **PATH**, the user giving an **ls** command from the directory executes the **ls** program in the working directory instead of the system **ls** utility, possibly with undesirable results.

If you want to add directories to **PATH**, you can reference the old value of the **PATH** variable while you are setting **PATH** to a new value (but see the preceding security tip). The following command adds **/usr/local/bin** to the beginning of the current **PATH** and the **bin** directory in the user's home directory (**~/bin**) to the end:

```
$ PATH=/usr/local/bin:$PATH:~/bin
```

### MAIL: WHERE YOUR MAIL IS KEPT

The **MAIL** variable contains the pathname of the file that holds your mail (your *mailbox*, usually **/var/spool/mail/name**, where *name* is your username). If **MAIL** is set and **MAILPATH** (next) is not set, the shell informs you when mail arrives in the file specified by **MAIL**. In a graphical environment you can unset **MAIL** so that the shell does not display mail reminders in a terminal emulator window (assuming you are using a graphical mail program).

The **MAILPATH** variable contains a list of filenames separated by colons. If this variable is set, the shell informs you when any one of the files is modified (for example, when mail arrives). You can follow any of the filenames in the list with a question mark (**?**), followed by a message. The message replaces the **you have mail** message when you get mail while you are logged in.

The **MAILCHECK** variable specifies how often, in seconds, the shell checks for new mail. The default is 60 seconds. If you set this variable to zero, the shell checks before each prompt.

### PS1: USER PROMPT (PRIMARY)

The default Bourne Again Shell prompt is a dollar sign (**\$**). When you run **bash** as **root**, you may have a pound sign (**#**) prompt. The **PS1** variable holds the prompt string that the shell uses to let you know that it is waiting for a command. When you change the value of **PS1**, you change the appearance of your prompt.

You can customize the prompt displayed by **PS1**. For example, the assignment

```
$ PS1="[u@\h \W \!]$ "
```

displays the following prompt:

```
[user@host directory event]$
```

where *user* is the username, *host* is the hostname up to the first period, *directory* is the basename of the working directory, and *event* is the event number of the current command.

If you are working on more than one system, it can be helpful to incorporate the system name into your prompt. For example, you might change the prompt to the name of the system you are using, followed by a colon and a SPACE (a SPACE at the end of the prompt makes the commands that you enter after the prompt easier to read):

```
$ PS1="$(hostname): "  
bravo.example.com: echo test  
test  
bravo.example.com:
```

The first example that follows changes the prompt to the name of the local host, a SPACE, and a dollar sign (or, if the user is running as **root**, a pound sign). The second example changes the prompt to the time followed by the name of the user. The third example changes the prompt to the one used in this book (a pound sign for **root** and a dollar sign otherwise):

```
$ PS1='\h \$ '  
bravo $  
  
$ PS1='\@ \u $ '  
09:44 PM alex $  
  
$ PS1='\$ '  
$
```

Table 9-4 describes some of the symbols you can use in **PS1**. For a complete list of special characters you can use in the prompt strings, open the **bash man** page and search for the second occurrence of **PROMPTING** (give the command **/PROMPTING** and then press **n**).

**Table 9-4** PS1 symbols

| Symbol | Display in prompt                                       |
|--------|---------------------------------------------------------|
| \\$    | # if the user is running as <b>root</b> ; otherwise, \$ |
| \w     | Pathname of the working directory                       |
| \W     | Basename of the working directory                       |
| \!     | Current event (history) number (page 321)               |
| \d     | Date in Weekday Month Date format                       |



**Table 9-4 PS1 symbols (continued)**

| Symbol | Display in prompt                              |
|--------|------------------------------------------------|
| \h     | Machine hostname, without the domain           |
| \H     | Full machine hostname, including the domain    |
| \u     | Username of the current user                   |
| \@     | Current time of day in 12-hour, AM/PM format   |
| \T     | Current time of day in 12-hour HH:MM:SS format |
| \A     | Current time of day in 24-hour HH:MM format    |
| \t     | Current time of day in 24-hour HH:MM:SS format |

## PS2: USER PROMPT (SECONDARY)

Prompt String 2 is a secondary prompt that the shell stores in **PS2**. On the first line of the next example, an unclosed quoted string follows **echo**. The shell assumes that the command is not finished and, on the second line, gives the default secondary prompt (**>**). This prompt indicates that the shell is waiting for the user to continue the command line. The shell waits until it receives the quotation mark that closes the string and then executes the command:

```
$ echo "demonstration of prompt string
> 2"
demonstration of prompt string
2
$ PS2="secondary prompt: "
$ echo "this demonstrates
secondary prompt: prompt string 2"
this demonstrates
prompt string 2
```

The second command changes the secondary prompt to **secondary prompt:** followed by a **SPACE**. A multiline **echo** demonstrates the new prompt.

## PS3: MENU PROMPT

**PS3** holds the menu prompt for the **select** control structure (page 918).

## PS4: DEBUGGING PROMPT

**PS4** holds the bash debugging symbol (page 900).

## IFS: SEPARATES INPUT FIELDS (WORD SPLITTING)

The **IFS** (Internal Field Separator) shell variable specifies the characters that you can use to separate arguments on a command line and has the default value of **SPACE** **TAB** **NEWLINE**. Regardless of the value of **IFS**, you can always use one or more **SPACE** or **TAB** characters to separate arguments on the command line, provided that these characters are not quoted or escaped. When you assign **IFS** character values, these characters can also separate fields but only if they undergo expansion. This type of interpretation of the command line is called *word splitting*.

## Be careful when changing IFS

**caution** Changing **IFS** has a variety of side effects so work cautiously. You may find it useful to first save the value of **IFS** before changing it; you can easily then restore the original value if you get unexpected results. Alternatively, you can fork a new shell with a **bash** command before experimenting with **IFS**; if you get into trouble, you can **exit** back to the old shell, where **IFS** is working properly. You can also set **IFS** to its default value with the following command:

```
$ IFS=' \t\n'
```

---

The following example demonstrates how setting **IFS** can affect the interpretation of a command line:

```
$ a=w:x:y:z
$ cat $a
cat: w:x:y:z: No such file or directory
$ IFS=":"
$ cat $a
cat: w: No such file or directory
cat: x: No such file or directory
cat: y: No such file or directory
cat: z: No such file or directory
```

The first time **cat** is called, the shell expands the variable **a**, interpreting the string **w:x:y:z** as a single word to be used as the argument to **cat**. The **cat** utility cannot find a file named **w:x:y:z** and reports an error for that filename. After **IFS** is set to a colon (:), the shell expands the variable **a** into four words, each of which is an argument to **cat**. Now **cat** reports an error for four separate files: **w**, **x**, **y**, and **z**. Word splitting based on the colon (:) takes place only *after* the variable **a** is expanded.

The shell splits all *expanded* words on a command line according to the separating characters found in **IFS**. When there is no expansion, there is no splitting. Consider the following commands:

```
$ IFS="p"
$ export VAR
```

Although **IFS** is set to **p**, the **p** on the **export** command line is not expanded so the word **export** is not split.

The following example uses variable expansion in an attempt to produce an **export** command:

```
$ IFS="p"
$ aa=export
$ echo $aa
ex ort
```

This time expansion occurs so that the character **p** in the token **export** is interpreted as a separator as the preceding **echo** command shows. Now when you try to use the value of the **aa** variable to export the **VAR** variable, the shell parses the **\$aa VAR** command line as **ex ort VAR**. The effect is that the command line starts the **ex** editor with two filenames: **ort** and **VAR**.

```

$ $aa VAR
2 files to edit
"ort" [New File]
Entering Ex mode. Type "visual" to go to Normal mode.
:q
E173: 1 more file to edit
:q
$

```

If you unset **IFS**, only **SPACES** and **TABS** work as field separators.

### Multiple separator characters

**tip** Although sequences of multiple **SPACE** or **TAB** characters are treated as single separators, *each occurrence* of another field-separator character acts as a separator.

## CDPATH: BROADENS THE SCOPE OF **cd**

The **CDPATH** variable allows you to use a simple filename as an argument to the **cd** builtin to change the working directory to a directory other than a child of the working directory. If you have several directories you like to work out of, this variable can speed things up and save you the tedium of using **cd** with longer pathnames to switch among them.

When **CDPATH** is not set and you specify a simple filename as an argument to **cd**, **cd** searches the working directory for a subdirectory with the same name as the argument. If the subdirectory does not exist, **cd** displays an error message. When **CDPATH** is set, **cd** searches for an appropriately named subdirectory in the directories in the **CDPATH** list. If **cd** finds one, that directory becomes the working directory. With **CDPATH** set, you can use **cd** and a simple filename to change the working directory to a child of any of the directories listed in **CDPATH**.

The **CDPATH** variable takes on the value of a colon-separated list of directory pathnames (similar to the **PATH** variable). It is usually set in the `~/.bash_profile` startup file with a command line such as the following:

```
export CDPATH=$HOME:$HOME/literature
```

This command causes **cd** to search your home directory, the **literature** directory, and then the working directory when you give a **cd** command. If you do not include the working directory in **CDPATH**, **cd** searches the working directory if the search of all the other directories in **CDPATH** fails. If you want **cd** to search the working directory first (which you should never do when you are logged in as **root**—refer to the tip on page 307), include a null string, represented by two colons (`::`), as the first entry in **CDPATH**:

```
export CDPATH=::$HOME:$HOME/literature
```

If the argument to the **cd** builtin is an absolute pathname—one starting with a slash (`/`)—the shell does not consult **CDPATH**.

## KEYWORD VARIABLES: A SUMMARY

Table 9-5 lists the bash keyword variables.

**Table 9-5** bash keyword variables

| Variable              | Value                                                                                                                                                                                                          |
|-----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>BASH_ENV</b>       | The pathname of the startup file for noninteractive shells (page 282)                                                                                                                                          |
| <b>CDPATH</b>         | The cd search path (page 311)                                                                                                                                                                                  |
| <b>COLUMNS</b>        | The width of the display used by <b>select</b> (page 917)                                                                                                                                                      |
| <b>FCEDIT</b>         | The name of the editor that fc uses by default (page 319)                                                                                                                                                      |
| <b>HISTFILE</b>       | The pathname of the file that holds the history list (default: <code>~/.bash_history</code> ; page 316)                                                                                                        |
| <b>HISTFILESIZE</b>   | The maximum number of entries saved in <b>HISTFILE</b> (default: 500; page 316)                                                                                                                                |
| <b>HISTSIZE</b>       | The maximum number of entries saved in the history list (default: 500; page 316)                                                                                                                               |
| <b>HOME</b>           | The pathname of the user's home directory (page 305); used as the default argument for cd and in tilde expansion (page 193)                                                                                    |
| <b>IFS</b>            | Internal Field Separator (page 309); used for word splitting (page 349)                                                                                                                                        |
| <b>INPUTRC</b>        | The pathname of the Readline startup file (default: <code>~/.inputrc</code> ; page 329)                                                                                                                        |
| <b>LANG</b>           | The locale category when that category is not specifically set with an <b>LC_*</b> variable                                                                                                                    |
| <b>LC_*</b>           | A group of variables that specify locale categories including <b>LC_COLLATE</b> , <b>LC_CTYPE</b> , <b>LC_MESSAGES</b> , and <b>LC_NUMERIC</b> ; use the locale builtin to display a complete list with values |
| <b>LINES</b>          | The height of the display used by <b>select</b> (page 917)                                                                                                                                                     |
| <b>MAIL</b>           | The pathname of the file that holds a user's mail (page 307)                                                                                                                                                   |
| <b>MAILCHECK</b>      | How often, in seconds, bash checks for mail (page 307)                                                                                                                                                         |
| <b>MAILPATH</b>       | A colon-separated list of file pathnames that bash checks for mail in (page 307)                                                                                                                               |
| <b>PATH</b>           | A colon-separated list of directory pathnames that bash looks for commands in (page 306)                                                                                                                       |
| <b>PROMPT_COMMAND</b> | A command that bash executes just before it displays the primary prompt                                                                                                                                        |
| <b>PS1</b>            | Prompt String 1; the primary prompt (default: <code>\s-\v\$</code> ; page 307)                                                                                                                                 |
| <b>PS2</b>            | Prompt String 2; the secondary prompt (default: <code>&gt;</code> ; page 309)                                                                                                                                  |
| <b>PS3</b>            | The prompt issued by <b>select</b> (page 917)                                                                                                                                                                  |
| <b>PS4</b>            | The bash debugging symbol (page 900)                                                                                                                                                                           |
| <b>REPLY</b>          | Holds the line that read accepts (page 938); also used by <b>select</b> (page 917)                                                                                                                             |

## SPECIAL CHARACTERS

Table 9-6 lists most of the characters that are special to the bash shell.

**Table 9-6** Shell special characters

| Character           | Use                                                                                                |
|---------------------|----------------------------------------------------------------------------------------------------|
| NEWLINE             | Initiates execution of a command (page 290)                                                        |
| ;                   | Separates commands (page 290)                                                                      |
| ( )                 | Groups commands (page 293) for execution by a subshell or identifies a function (page 335)         |
| &                   | Executes a command in the background (pages 241 and 292)                                           |
|                     | Sends standard output of preceding command to standard input of following command (pipe; page 292) |
| >                   | Redirects standard output (page 232)                                                               |
| >>                  | Appends standard output (page 236)                                                                 |
| <                   | Redirects standard input (page 234)                                                                |
| <<                  | Here document (page 919)                                                                           |
| *                   | Any string of zero or more characters in an ambiguous file reference (page 244)                    |
| ?                   | Any single character in an ambiguous file reference (page 243)                                     |
| \                   | Quotes the following character (page 148)                                                          |
| '                   | Quotes a string, preventing all substitution (page 148)                                            |
| "                   | Quotes a string, allowing only variable and command substitution (pages 148 and 301)               |
| `...`               | Performs command substitution (page 348)                                                           |
| [ ]                 | Character class in an ambiguous file reference (page 245)                                          |
| \$                  | References a variable (page 299)                                                                   |
| . (dot builtin)     | Executes a command (only at the beginning of a line, page 283)                                     |
| #                   | Begins a comment (page 289)                                                                        |
| { }                 | Used to surround the contents of a function (page 335)                                             |
| : (null builtin)    | Returns <i>true</i> (page 945)                                                                     |
| &&<br>(Boolean AND) | Executes command on right only if command on left succeeds (returns a zero exit status, page 956)  |
| (Boolean OR)        | Executes command on right only if command on left fails (returns a nonzero exit status; page 956)  |
| ! (Boolean NOT)     | Reverses exit status of a command                                                                  |
| \$( )               | Performs command substitution (preferred form; page 348)                                           |
| [ ]                 | Evaluates an arithmetic expression (page 346)                                                      |

## PROCESSES

A *process* is the execution of a command by Linux. The shell that starts when you log in is a command, or a process, like any other. When you give the name of a Linux utility on the command line, you initiate a process. When you run a shell script, another shell process is started and additional processes are created for each command in the script. Depending on how you invoke the shell script, the script is run either by the current shell or, more typically, by a subshell (child) of the current shell. A process is not started when you run a shell builtin, such as `cd`.

## PROCESS STRUCTURE

**fork** system call Like the file structure, the process structure is hierarchical, with parents, children, and even a *root*. A parent process *forks* a child process, which in turn can fork other processes. (The term *fork* indicates that, as with a fork in the road, one process turns into two. Initially the two forks are identical except that one is identified as the parent and one as the child. You can also use the term *spawn*; the words are interchangeable.) The operating system routine, or *system call*, that creates a new process is named **fork**.

When Linux begins execution when a system is started, it starts `init`, a single process called a *spontaneous process*, with PID number 1. This process holds the same position in the process structure as the root directory does in the file structure: It is the ancestor of all processes that the system and users work with. When the system is in multiuser mode, `init` runs `getty` or `mingetty` processes, which display **login:** prompts on terminals and virtual consoles. When someone responds to the prompt and presses RETURN, `getty` hands control over to a utility named `login`, which checks the username and password combination. After the user logs in, the `login` process becomes the user's shell process.

## PROCESS IDENTIFICATION

**PID number** Linux assigns a unique PID (process identification) number at the inception of each process. As long as a process exists, it keeps the same PID number. During one session the same process is always executing the login shell. When you fork a new process—for example, when you use an editor—the PID number of the new (child) process is different from that of its parent process. When you return to the login shell, it is still being executed by the same process and has the same PID number as when you logged in.

The following example shows that the process running the shell forked (is the parent of) the process running `ps` (page 242). When you call it with the `-f` option, `ps` displays a full listing of information about each process. The line of the `ps` display with **bash** in the **CMD** column refers to the process running the shell. The column headed by **PID** identifies the PID number. The column headed **PPID** identifies the PID number of the *parent* of the process. From the PID and PPID columns you can see that the process running the shell (PID 21341) is the parent of the process running `sleep`

(PID 22789). The parent PID number of `sleep` is the same as the PID number of the shell (21341).

```
$ sleep 10 &
[1] 22789
$ ps -f
UID          PID  PPID  C  STIME TTY          TIME CMD
alex        21341 21340  0  10:42 pts/16      00:00:00 bash
alex        22789 21341  0  17:30 pts/16      00:00:00 sleep 10
alex        22790 21341  0  17:30 pts/16      00:00:00 ps -f
```

Refer to the `ps` man page for more information on `ps` and the columns it displays with the `-f` option. A second pair of `sleep` and `ps -f` commands shows that the shell is still being run by the same process but that it forked another process to run `sleep`:

```
$ sleep 10 &
[1] 22791
$ ps -f
UID          PID  PPID  C  STIME TTY          TIME CMD
alex        21341 21340  0  10:42 pts/16      00:00:00 bash
alex        22791 21341  0  17:31 pts/16      00:00:00 sleep 10
alex        22792 21341  0  17:31 pts/16      00:00:00 ps -f
```

You can also use `pstree` (or `ps --forest`, with or without the `-e` option) to see the parent-child relationship of processes. The next example shows the `-p` option to `pstree`, which causes it to display PID numbers:

```
$ pstree -p
init(1)---acpid(1395)
|---atd(1758)
|---crond(1702)
...
|-kdeinit(2223)---firefox(8914)---run-mozilla.sh(8920)---firefox-bin(8925)
|
|   |--gaim(2306)
|   |--gqview(14062)
|   |--kdeinit(2228)
|   |--kdeinit(2294)
|   |--kdeinit(2314)---bash(2329)---ssh(2561)
|   |   |--bash(2339)
|   |   '--bash(15821)---bash(16778)
|   |--kdeinit(16448)
|   |--kdeinit(20888)
|   |--oclock(2317)
|   '--pam-panel-icon(2305)---pam_timestamp_c(2307)
...
|-login(1823)---bash(20986)---pstree(21028)
|   '--sleep(21026)
...
```

The preceding output is abbreviated. The line that starts with `-kdeinit` shows a graphical user running many processes, including `firefox`, `gaim`, and `oclock`. The line that starts with `-login` shows a textual user running `sleep` in the background while running `pstree` in the foreground. Refer to “`$$: PID Number`” on page 929 for a description of how to instruct the shell to report on PID numbers.

## EXECUTING A COMMAND

- fork and sleep** When you give the shell a command, it usually forks (spawns) a child process to execute the command. While the child process is executing the command, the parent process *sleeps*. While a process is sleeping, it does not use any computer time but remains inactive, waiting to wake up. When the child process finishes executing the command, it tells its parent of its success or failure via its exit status and then dies. The parent process (which is running the shell) wakes up and prompts for another command.
- Background process** When you run a process in the background by ending a command with an ampersand (&), the shell forks a child process without going to sleep and without waiting for the child process to run to completion. The parent process, which is executing the shell, reports the job number and PID number of the child and prompts for another command. The child process runs in the background, independent of its parent.
- Builtins** Although the shell forks a process to run most of the commands you give it, some commands are built into the shell. The shell does not need to fork a process to run builtins. For more information refer to “Builtins” on page 247.
- Variables** Within a given process, such as your login shell or a subshell, you can declare, initialize, read, and change variables. By default however, a variable is local to a process. When a process forks a child process, the parent does not pass the value of a variable to the child. You can make the value of a variable available to child processes (global) by using the `export` builtin (page 926).

---

## HISTORY

The history mechanism, a feature adapted from the C Shell, maintains a list of recently issued command lines, also called *events*, providing a quick way to reexecute any of the events in the list. This mechanism also enables you to execute variations of previous commands and to reuse arguments from them. You can replicate complicated commands and arguments that you used earlier in this login session or in a previous one and enter a series of commands that differ from one another in minor ways. The history list also serves as a record of what you have done. It can prove helpful when you have made a mistake and are not sure what you did or when you want to keep a record of a procedure that involved a series of commands.

The history builtin displays the history list. If it does not, read on—you need to set some variables.

## VARIABLES THAT CONTROL HISTORY

The value of the `HISTSIZE` variable determines the number of events preserved in the history list during a session. A value in the range of 100 to 1,000 is normal.

When you exit from the shell, the most recently executed commands are saved in the file given by the `HISTFILE` variable (the default is `~/.bash_history`). The next time you start the shell, this file initializes the history list. The value of the `HISTFILESIZE`



## history can help track down mistakes

**tip** When you have made a command-line mistake (not an error within a script or program) and are not sure what you did wrong, look at the history list to review your recent commands. Sometimes this list can help you figure out what went wrong and how to fix things.

variable determines the number of lines of history saved in **HISTFILE** (not necessarily the same as **HISTSIZE**). **HISTSIZE** holds the number of events remembered during a session, **HISTFILESIZE** holds the number remembered between sessions, and the file designated by **HISTFILE** holds the history list. See Table 9-7.

**Table 9-7** History variables

| Variable            | Default                | Function                                        |
|---------------------|------------------------|-------------------------------------------------|
| <b>HISTSIZE</b>     | 500 events             | Maximum number of events saved during a session |
| <b>HISTFILE</b>     | <b>~/.bash_history</b> | Location of the history file                    |
| <b>HISTFILESIZE</b> | 500 events             | Maximum number of events saved between sessions |

Event number The Bourne Again Shell assigns a sequential *event number* to each command line. You can display this event number as part of the bash prompt by including **\!** in **PS1** (page 307). Examples in this section show numbered prompts when they help to illustrate the behavior of a command.

Give the following command manually or place it in **~/.bash\_profile** (to affect future sessions) to establish a history list of the 100 most recent events:

```
$ HISTSIZE=100
```

The following command causes bash to save the 100 most recent events across login sessions:

```
$ HISTFILESIZE=100
```

After you set **HISTFILESIZE**, you can log out and log in again, and the 100 most recent events from the previous login session will appear in your history list.

Give the command **history** to display the events in the history list. The list of events is ordered with oldest events at the top of the list. The following history list includes a command to modify the bash prompt so that it displays the history event number. The last event in the history list is the **history** command that displayed the list.

```
32 $ history | tail
23 PS1="\! bash$ "
24 ls -l
25 cat temp
26 rm temp
27 vim memo
28 lpr memo
29 vim memo
30 lpr memo
31 rm memo
32 history | tail
```

As you run commands and your history list becomes longer, it may run off the top of the screen when you use the `history` builtin. Pipe the output of `history` through `less` to browse through it, or give the command `history 10` to look at the ten most recent commands.

## REEXECUTING AND EDITING COMMANDS

You can reexecute any event in the history list. This feature can save you time, effort, and aggravation. Not having to reenter long command lines allows you to reexecute events more easily, quickly, and accurately than you could if you had to retype the entire command line. You can recall, modify, and reexecute previously executed events in three ways: You can use the `fc` builtin (covered next); the exclamation point commands (page 320); or the Readline Library, which uses a one-line `vi`- or `emacs`-like editor to edit and execute events (page 326).

### Which method to use?

**tip** If you are more familiar with `vi` or `emacs` and less familiar with the C or TC Shell, use `fc` or the Readline Library. If you are more familiar with the C or TC Shell and less familiar with `vi` and `emacs`, use the exclamation point commands. If it is a toss-up, try the Readline Library; it will benefit you in other areas of Linux more than learning the exclamation point commands will.

---

## fc: DISPLAYS, EDITS, AND REEXECUTES COMMANDS

The `fc` (fix command) builtin enables you to display the history list and to edit and reexecute previous commands. It provides many of the same capabilities as the command-line editors.

### VIEWING THE HISTORY LIST

When you call `fc` with the `-l` option, it displays commands from the history list. Without any arguments, `fc -l` lists the 16 most recent commands in a numbered list, with the oldest appearing first:

```
$ fc -l
1024    cd
1025    view calendar
1026    vim letter.adams01
1027    aspell -c letter.adams01
1028    vim letter.adams01
1029    lpr letter.adams01
1030    cd ../memos
1031    ls
1032    rm *0405
1033    fc -l
1034    cd
1035    whereis aspell
1036    man aspell
1037    cd /usr/share/doc/*aspell*
1038    pwd
1039    ls
1040    ls man-html
```

The `fc` builtin can take zero, one, or two arguments with the `-l` option. The arguments specify the part of the history list to be displayed:

```
fc -l [first [last]]
```

The `fc` builtin lists commands beginning with the most recent event that matches *first*. The argument can be an event number, the first few characters of the command line, or a negative number, which is taken to be the *n*th previous command. If you provide *last*, `fc` displays commands from the most recent event that matches *first* through the most recent event that matches *last*. The next command displays the history list from event 1030 through event 1035:

```
$ fc -l 1030 1035
1030      cd ../memos
1031      ls
1032      rm *0405
1033      fc -l
1034      cd
1035      whereis aspell
```

The following command lists the most recent event that begins with **view** through the most recent command line that begins with **whereis**:

```
$ fc -l view whereis
1025      view calendar
1026      vim letter.adams01
1027      aspell -c letter.adams01
1028      vim letter.adams01
1029      lpr letter.adams01
1030      cd ../memos
1031      ls
1032      rm *0405
1033      fc -l
1034      cd
1035      whereis aspell
```

To list a single command from the history list, use the same identifier for the first and second arguments. The following command lists event 1027:

```
$ fc -l 1027 1027
1027      aspell -c letter.adams01
```

## EDITING AND REEXECUTING PREVIOUS COMMANDS

You can use `fc` to edit and reexecute previous commands.

```
fc [-e editor] [first [last]]
```

When you call `fc` with the `-e` option followed by the name of an editor, `fc` calls the editor with event(s) in the Work buffer. Without *first* and *last*, `fc` defaults to the most recent command. The next example invokes the `vi(m)` editor to edit the most recent command:

```
$ fc -e vi
```

The `fc` builtin uses the stand-alone `vi(m)` editor. If you set the `FCEDIT` variable, you do not need to use the `-e` option to specify an editor on the command line. Because the value of `FCEDIT` has been changed to `/usr/bin/emacs` and `fc` has no arguments, the following command edits the most recent command with the `emacs` editor:

```
$ export FCEDIT=/usr/bin/emacs
$ fc
```

If you call it with a single argument, `fc` invokes the editor on the specified command. The following example starts the editor with event 21 in the Work buffer. When you exit from the editor, the shell executes the command:

```
$ fc 21
```

Again you can identify commands with numbers or by specifying the first few characters of the command name. The following example calls the editor to work on events from the most recent event that begins with the letters `vim` through event 206:

```
$ fc vim 206
```

### Clean up the `fc` buffer

**caution** When you execute an `fc` command, the shell executes whatever you leave in the editor buffer, possibly with unwanted results. If you decide you do not want to execute a command, delete everything from the buffer before you exit from the editor.

---

### REEXECUTING COMMANDS WITHOUT CALLING THE EDITOR

You can reexecute previous commands without going into an editor. If you call `fc` with the `-s` option, it skips the editing phase and reexecutes the command. The following example reexecutes event 1029:

```
$ fc -s 1029
lpr letter.adams01
```

The next example reexecutes the previous command:

```
$ fc -s
```

When you reexecute a command you can tell `fc` to substitute one string for another. The next example substitutes the string `john` for the string `adams` in event 1029 and executes the modified event:

```
$ fc -s adams=john 1029
lpr letter.john01
```

### USING AN EXCLAMATION POINT (!) TO REFERENCE EVENTS

The C Shell history mechanism uses an exclamation point to reference events and is available under `bash`. It is frequently more cumbersome to use than `fc` but nevertheless

has some useful features. For example, the **!!** command reexecutes the previous event, and the **!\$** token represents the last word on the previous command line.

You can reference an event by using its absolute event number, its relative event number, or the text it contains. All references to events, called event designators, begin with an exclamation point (**!**). One or more characters follow the exclamation point to specify an event.

You can put history events anywhere on a command line. To escape an exclamation point so that it is treated literally instead of as the start of a history event, precede it with a backslash (**\**) or enclose it within single quotation marks.

## EVENT DESIGNATORS

An event designator specifies a command in the history list. See Table 9-8 on page 322 for a list of event designators.

**!!** reexecutes the previous event You can always reexecute the previous event by giving a **!!** command. In the following example, event 45 reexecutes event 44:

```
44 $ ls -l text
-rw-rw-r-- 1 alex group 45 Apr 30 14:53 text
45 $ !!
ls -l text
-rw-rw-r-- 1 alex group 45 Apr 30 14:53 text
```

The **!!** command works whether or not your prompt displays an event number. As this example shows, when you use the history mechanism to reexecute an event, the shell displays the command it is reexecuting.

**!n** event number A number following an exclamation point refers to an event. If that event is in the history list, the shell executes it. Otherwise, the shell displays an error message. A negative number following an exclamation point references an event relative to the current event. For example, the command **!-3** refers to the third preceding event. After you issue a command, the relative event number of a given event changes (event **-3** becomes event **-4**). Both of the following commands reexecute event 44:

```
51 $ !44
ls -l text
-rw-rw-r-- 1 alex group 45 Nov 30 14:53 text
52 $ !-8
ls -l text
-rw-rw-r-- 1 alex group 45 Nov 30 14:53 text
```

**!string** event text When a string of text follows an exclamation point, the shell searches for and executes the most recent event that *began* with that string. If you enclose the string between question marks, the shell executes the most recent event that *contained* that string. The final question mark is optional if a RETURN would immediately follow it.

```
68 $ history 10
59 ls -l text*
60 tail text5
61 cat text1 text5 > letter
62 vim letter
63 cat letter
64 cat memo
65 lpr memo
66 pine jenny
67 ls -l
68 history
69 $ !l
ls -l
...
70 $ !lpr
lpr memo
71 $ !?letter?
cat letter
...
```

Table 9-8 Event designators

| Designator  | Meaning                                                                                                                                                                                             |
|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| !           | Starts a history event unless followed immediately by SPACE, NEWLINE, =, or (.                                                                                                                      |
| !!          | The previous command.                                                                                                                                                                               |
| !n          | Command number <i>n</i> in the history list.                                                                                                                                                        |
| !-n         | The <i>n</i> th preceding command.                                                                                                                                                                  |
| !string     | The most recent command line that started with <i>string</i> .                                                                                                                                      |
| !?string[?] | The most recent command that contained <i>string</i> . The last <i>?</i> is optional.                                                                                                               |
| !#          | The current command (as you have it typed so far).                                                                                                                                                  |
| !{event}    | The <i>event</i> is an event designator. The braces isolate <i>event</i> from the surrounding text. For example, <b>!{-3}3</b> is the third most recently executed command followed by a <b>3</b> . |

optional WORD DESIGNATORS

A *word designator* specifies a word or series of words from an event. Table 9-9 on page 324 lists word designators.

The words are numbered starting with 0 (the first word on the line—usually the command), continuing with 1 (the first word following the command), and going through *n* (the last word on the line).

To specify a particular word from a previous event, follow the event designator (such as **!14**) with a colon and the number of the word in the previous event. For

example, **!14:3** specifies the third word following the command from event 14. You can specify the first word following the command (word number 1) by using a caret (^) and the last word by using a dollar sign (\$). You can specify a range of words by separating two word designators with a hyphen.

```
72 $ echo apple grape orange pear
apple grape orange pear
73 $ echo !72:2
echo grape
grape
74 $ echo !72:^
echo apple
apple
75 $ !72:0 !72:$
echo pear
pear
76 $ echo !72:2-4
echo grape orange pear
grape orange pear
77 $ !72:0-$
echo apple grape orange pear
apple grape orange pear
```

As the next example shows, **!\$** refers to the last word of the previous event. You can use this shorthand to edit, for example, a file you just displayed with **cat**:

```
$ cat report.718
...

$ vim !$
vim report.718
...
```

If an event contains a single command, the word numbers correspond to the argument numbers. If an event contains more than one command, this correspondence does not hold true for commands after the first. In the following example event 78 contains two commands separated by a semicolon so that the shell executes them sequentially; the semicolon is word number 5.

```
78 $ !72 ; echo helen jenny barbara
echo apple grape orange pear ; echo helen jenny barbara
apple grape orange pear
helen jenny barbara
79 $ echo !78:7
echo helen
helen
80 $ echo !78:4-7
echo pear ; echo helen
pear
helen
```

Table 9-9 Word designators

| Designator | Meaning                                                                                                                  |
|------------|--------------------------------------------------------------------------------------------------------------------------|
| <i>n</i>   | The <i>n</i> th word. Word 0 is normally the command name.                                                               |
| <i>^</i>   | The first word (after the command name).                                                                                 |
| <i>\$</i>  | The last word.                                                                                                           |
| <i>m–n</i> | All words from word number <i>m</i> through word number <i>n</i> ; <i>m</i> defaults to 0 if you omit it (0– <i>n</i> ). |
| <i>n*</i>  | All words from word number <i>n</i> through the last word.                                                               |
| <i>*</i>   | All words except the command name. The same as <i>1*</i> .                                                               |
| <i>%</i>   | The word matched by the most recent <i>?string?</i> search.                                                              |

MODIFIERS

On occasion you may want to change an aspect of an event you are reexecuting. Perhaps you entered a complex command line with a typo or incorrect pathname or you want to specify a different argument. You can modify an event or a word of an event by putting one or more modifiers after the word designator, or after the event designator if there is no word designator. Each modifier must be preceded by a colon (:).

Substitute modifier The *substitute modifier* is more complex than the other modifiers. The following example shows the substitute modifier correcting a typo in the previous event:

```
$ car /home/jenny/memo.0507 /home/alex/letter.0507
bash: car: command not found
$ !!:s/car/cat
cat /home/jenny/memo.0507 /home/alex/letter.0507
...
```

The substitute modifier has the following syntax:

```
[g]s/old/new/
```

where *old* is the original string (not a regular expression), and *new* is the string that replaces *old*. The substitute modifier substitutes the first occurrence of *old* with *new*. Placing a *g* before the *s* (as in *gs/old/new/*) causes a global substitution, replacing all occurrences of *old*. The */* is the delimiter in the examples but you can use any character that is not in either *old* or *new*. The final delimiter is optional if a RETURN would immediately follow it. As with the vim Substitute command, the history mechanism replaces an ampersand (&) in *new* with *old*. The shell replaces a null old string (*s/new/*) with the previous old string or string within a command that you searched for with *?string?*.



**Quick substitution** An abbreviated form of the substitute modifier is *quick substitution*. Use it to reexecute the most recent event while changing some of the event text. The quick substitution character is the caret (^). For example, the command

```
$ ^old^new^
```

produces the same results as

```
$ !!:s/old/new/
```

Thus substituting **cat** for **car** in the previous event could have been entered as

```
$ ^car^cat
cat /home/jenny/memo.0507 /home/alex/letter.0507
...
```

You can omit the final caret if it would be followed immediately by a RETURN. As with other command-line substitutions, the shell displays the command line as it appears after the substitution.

**Other modifiers** Modifiers (other than the substitute modifier) perform simple edits on the part of the event that has been selected by the event designator and the optional word designators. You can use multiple modifiers, each preceded by a colon (:).

The following series of commands uses **ls** to list the name of a file, repeats the command without executing it (**p** modifier), and repeats the last command, removing the last part of the pathname (**h** modifier) again without executing it:

```
$ ls /etc/sysconfig/harddisks
/etc/sysconfig/harddisks
$ !!:p
ls /etc/sysconfig/harddisks
$ !!:h:p
ls /etc/sysconfig
$
```

Table 9-10 lists event modifiers other than the substitute modifier.

**Table 9-10** Modifiers

| Modifier             | Function                                                            |
|----------------------|---------------------------------------------------------------------|
| <b>e</b> (extension) | Removes all but the filename extension                              |
| <b>h</b> (head)      | Removes the last part of a pathname                                 |
| <b>p</b> (print-not) | Displays the command, but does not execute it                       |
| <b>q</b> (quote)     | Quotes the substitution to prevent further substitutions on it      |
| <b>r</b> (root)      | Removes the filename extension                                      |
| <b>t</b> (tail)      | Removes all elements of a pathname except the last                  |
| <b>x</b>             | Like <b>q</b> but quotes each word in the substitution individually |

## THE READLINE LIBRARY

Command-line editing under the Bourne Again Shell is implemented through the *Readline Library*, which is available to any application written in C. Any application that uses the Readline Library supports line editing that is consistent with that provided by `bash`. Programs that use the Readline Library, including `bash`, read `~/inputrc` (page 329) for key binding information and configuration settings. The `--noediting` command line option turns off command-line editing in `bash`.

**vi mode** You can choose one of two editing modes when using the Readline Library in `bash`: `emacs` or `vi(m)`. Both modes provide many of the commands available in the stand-alone versions of the `vi(m)` and `emacs` editors. You can also use the `ARROW` keys to move around. Up and down movements move you backward and forward through the history list. In addition, Readline provides several types of interactive word completion (page 328). The default mode is `emacs`; you can switch to `vi` mode with the following command:

```
$ set -o vi
```

**emacs mode** The next command switches back to `emacs` mode:

```
$ set -o emacs
```

### vi EDITING MODE

Before you start make sure you are in `vi` mode.

When you enter `bash` commands while in `vi` editing mode, you are in Input mode (page 176). As you enter a command, if you discover an error before you press `RETURN`, you can press `ESCAPE` to switch to `vi` Command mode. This setup is different from the stand-alone `vi(m)` editor's initial mode. While in Command mode you can use many `vi(m)` commands to edit the command line. It is as though you were using `vi(m)` to edit a copy of the history file with a screen that has room for only one command. When you use the `k` command or the `UP ARROW` to move up a line, you access the previous command. If you then use the `j` command or the `DOWN ARROW` to move down a line, you will return to the original command. To use the `k` and `j` keys to move between commands you must be in Command mode; you can use the `ARROW` keys in both Command and Input modes.

### The stand-alone editor starts in Command mode

---

**tip** The stand-alone `vim` editor starts in Command mode, whereas the command-line `vi(m)` editor starts in Input mode. If commands display characters and do not work properly, you are in Input mode. Press `ESCAPE` and enter the command again.

---

In addition to cursor-positioning commands, you can use the search-backward (`?`) command followed by a search string to look *back* through your history list for the most recent command containing that string. If you have moved back in your history list, use a forward slash (`/`) to search *forward* toward your most recent command. Unlike the search strings in the stand-alone `vi(m)` editor, these search strings cannot

contain regular expressions. You can, however, start the search string with a caret (^) to force the shell to locate commands that start with the search string. As in `vi(m)`, pressing `n` after a successful search looks for the next occurrence of the same string.

You can also access events in the history list by using event numbers. While you are in Command mode (press `ESCAPE`), enter the event number followed by a `G` to go to the command with that event number.

When you use `/`, `?`, or `G` to move to a command line, you are in Command mode, not Input mode. Now you can edit the command as you like or press `RETURN` to execute it.

Once the command you want to edit is displayed, you can modify the command line using `vi(m)` Command mode editing commands such as `x` (delete character), `r` (replace character), `~` (change case), and `.` (repeat last change). To change to Input mode, use an Insert (`i`, `I`), Append (`a`, `A`), Replace (`R`), or Change (`c`, `C`) command. You do not have to return to Command mode to run a command; simply press `RETURN`, even if the cursor is in the middle of the command line.

## emacs EDITING MODE

Unlike the `vi(m)` editor, `emacs` is modeless. You need not switch between Command mode and Input mode because most `emacs` commands are control characters, allowing `emacs` to distinguish between input and commands. Like `vi(m)`, the `emacs` command-line editor provides commands for moving the cursor on the command line and through the command history list and for modifying part or all of a command. The `emacs` command-line editor commands differ in a few cases from the commands in the stand-alone `emacs` editor.

In `emacs` you perform cursor movement by using both `CONTROL` and `ESCAPE` commands. To move the cursor one character backward on the command line, press `CONTROL-B`. Press `CONTROL-F` to move one character forward. As in `vi`, you may precede these movements with counts. To use a count you must first press `ESCAPE`; otherwise, the numbers you type will appear on the command line.

Like `vi(m)`, `emacs` provides word and line movement commands. To move backward or forward one word on the command line, press `ESCAPE b` or `ESCAPE f`. To move several words by using a count, press `ESCAPE` followed by the number and the appropriate escape sequence. To get to the beginning of the line, press `CONTROL-A`; to the end of the line, press `CONTROL-E`; and to the next instance of the character `c`, press `CONTROL-X CONTROL-F` followed by `c`.

You can add text to the command line by moving the cursor to the correct place and typing the desired text. To delete text, move the cursor just to the right of the characters that you want to delete and press the erase key (page 139) once for each character you want to delete.

### **CONTROL-D can terminate your screen session**

---

**tip** If you want to delete the character directly under the cursor, press `CONTROL-D`. If you enter `CONTROL-D` at the beginning of the line, it may terminate your shell session.

---

If you want to delete the entire command line, type the line kill character (page 139). You can type this character while the cursor is anywhere in the command line. If you want to delete from the cursor to the end of the line, use `CONTROL-K`.

## READLINE COMPLETION COMMANDS

You can use the `TAB` key to complete words you are entering on the command line. This facility, called *completion*, works in both `vi` and `emacs` editing modes. Several types of completion are possible, and which one you use depends on which part of a command line you are typing when you press `TAB`.

### COMMAND COMPLETION

If you are typing the name of a command (the first word on the command line), pressing `TAB` results in *command completion*. That is, `bash` looks for a command whose name starts with the part of the word you have typed. If no command starts with what you have entered, `bash` beeps. If there is one such command, `bash` completes the command name for you. If there is more than one choice, `bash` does nothing in `vi` mode and beeps in `emacs` mode. Pressing `TAB` a second time causes `bash` to display a list of commands whose names start with the prefix you typed and allows you to finish typing the command name.

In the following example, the user types `bz` and presses `TAB`. The shell beeps (the user is in `emacs` mode) to indicate that several commands start with the letters `bz`. The user enters another `TAB` to cause the shell to display a list of commands that start with `bz` followed by the command line as the user had entered it so far:

```
$ bz →TAB (beep) →TAB
bzcat      bzdiff      bzip2      bzless
bzcmp      bzgrep      bzip2recover  bzmore
$ bz■
```

Next the user types `c` and presses `TAB` twice. The shell displays the two commands that start with `bzc`. The user types `a` followed by `TAB` and the shell then completes the command because only one command starts with `bzca`.

```
$ bzc →TAB (beep) →TAB
bzcat  bzcmp
$ bzca →TAB →t ■
```

### PATHNAME COMPLETION

*Pathname completion*, which also uses `TABS`, allows you to type a portion of a pathname and have `bash` supply the rest. If the portion of the pathname that you have typed is sufficient to determine a unique pathname, `bash` displays that pathname. If more than one pathname would match it, `bash` completes the pathname up to the point where there are choices so that you can type more.

When you are entering a pathname, including a simple filename, and press `TAB`, the shell beeps (if the shell is in `emacs` mode—in `vi` mode there is no beep). It then extends the command line as far as it can.

```
$ cat films/dar →TAB (beep) cat films/dark_■
```

In the **films** directory every file that starts with **dar** has **k\_** as the next characters, so **bash** cannot extend the line further without making a choice among files. You are left with the cursor just past the **\_** character. At this point you can continue typing the pathname or press **TAB** twice. In the latter case **bash** beeps, displays your choices, redisplay the command line, and again leaves the cursor just after the **\_** character.

```
$ cat films/dark_ →TAB (beep) →TAB
dark_passage dark_victory
$ cat films/dark_■
```

When you add enough information to distinguish between the two possible files and press **TAB**, **bash** displays the unique pathname. If you enter **p** followed by **TAB** after the **\_** character, the shell completes the command line:

```
$ cat films/dark_p →TAB →assage
```

Because there is no further ambiguity, the shell appends a **SPACE** so you can finish typing the command line or just press **RETURN** to execute the command. If the complete pathname is that of a directory, **bash** appends a slash (**/**) in place of a **SPACE**.

## VARIABLE COMPLETION

When typing a variable name, pressing **TAB** results in *variable completion*, where **bash** tries to complete the name of the variable. In case of an ambiguity, pressing **TAB** twice displays a list of choices:

```
$ echo $HO →TAB →TAB
$HOME      $HOSTNAME $HOSTTYPE
$ echo $HOM →TAB →E
```

## Pressing RETURN executes the command

**caution** Pressing **RETURN** causes the shell to execute the command regardless of where the cursor is on the command line.

## .inputrc: CONFIGURING READLINE

The Bourne Again Shell and other programs that use the Readline Library read the file specified by the **INPUTRC** environment variable to obtain initialization information. If **INPUTRC** is not set, these programs read the **~/.inputrc** file. They ignore lines of **.inputrc** that are blank or that start with a pound sign (**#**).

## VARIABLES

You can set variables in **.inputrc** to control the behavior of the Readline Library using the following syntax:

*set variable value*

Table 9-11 (next page) lists some variables and values you can use. See **Readline Variables** in the **bash** man or info page for a complete list.

Table 9-11 Readline variables

| Variable               | Effect                                                                                                                                                                                                                                                                                                                                                                                                              |
|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| editing-mode           | Set to <b>vi</b> to start Readline in vi mode. Set to <b>emacs</b> to start Readline in emacs mode (the default). Similar to the <b>set -o vi</b> and <b>set -o emacs</b> shell commands (page 326).                                                                                                                                                                                                                |
| horizontal-scroll-mode | Set to <b>on</b> to cause long lines to extend off the right edge of the display area. Moving the cursor to the right when it is at the right edge of the display area shifts the line to the left so you can see more of the line. You can shift the line back by moving the cursor back past the left edge. The default value is <b>off</b> , which causes long lines to wrap onto multiple lines of the display. |
| mark-directories       | Set to <b>off</b> to cause Readline not to place a slash (/) at the end of directory names it completes. Normally it is <b>on</b> .                                                                                                                                                                                                                                                                                 |
| mark-modified-lines    | Set to <b>on</b> to cause Readline to precede modified history lines with an asterisk. The default value is <b>off</b> .                                                                                                                                                                                                                                                                                            |

KEY BINDINGS

You can specify bindings that map keystroke sequences to Readline commands, allowing you to change or extend the default bindings. As in **emacs**, the Readline Library includes many commands that are not bound to a keystroke sequence. To use an unbound command, you must map it using one of the following forms:

```
keyname: command_name
"keystroke_sequence": command_name
```

In the first form, you spell out the name for a single key. For example, **CONTROL-U** would be written as **control-u**. This form is useful for binding commands to single keys.

In the second form, you specify a string that describes a sequence of keys that will be bound to the command. You can use the **emacs**-style backslash escape sequences to represent the special keys **CONTROL** (**\C**), **META** (**\M**), and **ESCAPE** (**\e**). Specify a backslash by escaping it with another backslash: **\\**. Similarly, a double or single quotation mark can be escaped with a backslash: **\"** or **\'**.

The **kill-whole-line** command, available in **emacs** mode only, deletes the current line. Put the following command in **.inputrc** to bind the **kill-whole-line** command (which is unbound by default) to the keystroke sequence **CONTROL-R**.

```
control-r: kill-whole-line
```

bind Give the command **bind -P** to display a list of all Readline commands. If a command is bound to a key sequence, that sequence is shown. Commands you can use in **vi** mode start with **vi**. For example, **vi-next-word** and **vi-prev-word** move the cursor to the beginning of the next and previous words, respectively. Commands that do not begin with **vi** are generally available in **emacs** mode.

Use **bind -q** to determine which key sequence is bound to a command:

```
$ bind -q kill-whole-line
kill-whole-line can be invoked via "\C-r".
```

You can also bind text by enclosing it within double quotation marks (emacs mode only):

```
"QQ": "The Linux Operating System"
```

This command causes `bash` to insert the string **The Linux Operating System** when you type `QQ`.

## CONDITIONAL CONSTRUCTS

You can conditionally select parts of the `.inputrc` file using the `$if` directive. The syntax of the conditional construct is

```
$if test[=value]
    commands
[$else
    commands]
$endif
```

where *test* is **mode**, **term**, or **bash**. If *test* equals *value* or if *test* is *true*, this structure executes the first set of *commands*. If *test* does not equal *value* or if *test* is *false*, it executes the second set of *commands* if they are present or exits from the structure if they are not present.

The power of the `$if` directive lies in the three types of tests it can perform.

1. You can test to see which mode is currently set.

```
$if mode=vi
```

The preceding test is *true* if the current Readline mode is `vi` and *false* otherwise. You can test for `vi` or `emacs`.

2. You can test the type of terminal.

```
$if term=xterm
```

The preceding test is *true* if the `TERM` variable is set to `xterm`. You can test for any value of `TERM`.

3. You can test the application name.

```
$if bash
```

The preceding test is *true* when you are running `bash` and not another program that uses the Readline Library. You can test for any application name.

These tests can customize the Readline Library based on the current mode, the type of terminal, and the application you are using. They give you a great deal of power and flexibility when using the Readline Library with `bash` and other programs.

The following commands in **.inputrc** cause CONTROL-Y to move the cursor to the beginning of the next word regardless of whether **bash** is in **vi** or **emacs** mode:

```
$ cat ~/.inputrc
set editing-mode vi
$if mode=vi
    "\C-y": vi-next-word
$else
    "\C-y": forward-word
$endif
```

Because **bash** reads the preceding conditional construct when it is started, you must set the editing mode in **.inputrc**. Changing modes interactively using **set** will not change the binding of CONTROL-Y.

For more information on the Readline Library, open the **bash** man page and give the command **/^READLINE**, which searches for the word **READLINE** at the beginning of a line.

---

### If Readline commands do not work, log out and log in again

---

**tip** The Bourne Again Shell reads **~/.inputrc** when you log in. After you make changes to this file, you should log out and log in again before testing the changes.

---

---

## ALIASES

An *alias* is a (usually short) name that the shell translates into another (usually longer) name or (complex) command. Aliases allow you to define new commands by substituting a string for the first token of a simple command. They are typically placed in the **~/.bashrc** startup files so that they are available to interactive subshells.

The syntax of the **alias** builtin is

```
alias [name[=value]]
```

No SPACES are permitted around the equal sign. If *value* contains SPACES or TABS, you must enclose *value* between quotation marks. An alias does not accept an argument from the command line in *value*. Use a function (page 335) when you need to use an argument.

An alias does not replace itself, which avoids the possibility of infinite recursion in handling an alias such as the following:

```
$ alias ls='ls -F'
```

You can nest aliases. Aliases are disabled for noninteractive shells (that is, shell scripts). To see a list of the current aliases, give the command **alias**. To view the alias for a particular name, use **alias** followed by the name and nothing else. You can use the **unalias** builtin to remove an alias.



When you give an `alias` builtin command without any arguments, the shell displays a list of all defined aliases:

```
$ alias
alias ll='ls -l'
alias l='ls -ltr'
alias ls='ls -F'
alias zap='rm -i'
```

Fedora/RHEL defines some aliases. Give an `alias` command to see which aliases are in effect. You can delete the aliases you do not want from the appropriate startup file.

## SINGLE VERSUS DOUBLE QUOTATION MARKS IN ALIASES

The choice of single or double quotation marks is significant in the `alias` syntax when the alias includes variables. If you enclose *value* within double quotation marks, any variables that appear in *value* are expanded when the alias is created. If you enclose *value* within single quotation marks, variables are not expanded until the alias is used. The following example illustrates the difference.

The `PWD` keyword variable holds the pathname of the working directory. Alex creates two aliases while he is working in his home directory. Because he uses double quotation marks when he creates the `dirA` alias, the shell substitutes the value of the working directory when he creates this alias. The `alias dirA` command displays the `dirA` alias and shows that the substitution has already taken place:

```
$ echo $PWD
/home/alex
$ alias dirA="echo Working directory is $PWD"
$ alias dirA
alias dirA='echo Working directory is /home/alex'
```

When Alex creates the `dirB` alias, he uses single quotation marks, which prevent the shell from expanding the `$PWD` variable. The `alias dirB` command shows that the `dirB` alias still holds the unexpanded `$PWD` variable:

```
$ alias dirB='echo Working directory is $PWD'
$ alias dirB
alias dirB='echo Working directory is $PWD'
```

After creating the `dirA` and `dirB` aliases, Alex uses `cd` to make `cars` his working directory and gives each of the aliases as commands. The alias that he created with double quotation marks displays the name of the directory that he created the alias in as the working directory (which is wrong) and the `dirB` alias displays the proper name of the working directory:

```
$ cd cars
$ dirA
Working directory is /home/alex
$ dirB
Working directory is /home/alex/cars
```

## How to prevent the shell from invoking an alias

**tip** The shell checks only simple, unquoted commands to see if they are aliases. Commands given as relative or absolute pathnames and quoted commands are not checked. When you want to give a command that has an alias but do not want to use the alias, precede the command with a backslash, specify the command's absolute pathname, or give the command as `./command`.

## EXAMPLES OF ALIASES

The following alias allows you to type `r` to repeat the previous command or `r abc` to repeat the last command line that began with `abc`:

```
$ alias r='fc -s'
```

If you use the command `ls -ltr` frequently, you can create an alias that substitutes `ls -ltr` when you give the command `l`:

```
$ alias l='ls -ltr'
$ l
total 41
-rw-r--r-- 1 alex group 30015 Mar 1 2007 flute.ps
-rw-r----- 1 alex group 3089 Feb 11 2008 XTerm.ad
-rw-r--r-- 1 alex group 641 Apr 1 2008 fixtax.icn
-rw-r--r-- 1 alex group 484 Apr 9 2008 maptax.icn
drwxrwxr-x 2 alex group 1024 Aug 9 17:41 Tiger
drwxrwxr-x 2 alex group 1024 Sep 10 11:32 testdir
-rwxr-xr-x 1 alex group 485 Oct 21 08:03 floor
drwxrwxr-x 2 alex group 1024 Oct 27 20:19 Test_Emacs
```

Another common use of aliases is to protect yourself from mistakes. The following example substitutes the interactive version of the `rm` utility when you give the command `zap`:

```
$ alias zap='rm -i'
$ zap f*
rm: remove 'fixtax.icn'? n
rm: remove 'flute.ps'? n
rm: remove 'floor'? n
```

The `-i` option causes `rm` to ask you to verify each file that would be deleted, to help you avoid accidentally deleting the wrong file. You can also alias `rm` with the `rm -i` command: `alias rm='rm -i'`.

The aliases in the next example cause the shell to substitute `ls -l` each time you give an `ll` command and `ls -F` when you use `ls`:

```
$ alias ls='ls -F'
$ alias ll='ls -l'
$ ll
total 41
drwxrwxr-x 2 alex group 1024 Oct 27 20:19 Test_Emacs/
drwxrwxr-x 2 alex group 1024 Aug 9 17:41 Tiger/
-rw-r----- 1 alex group 3089 Feb 11 2008 XTerm.ad
-rw-r--r-- 1 alex group 641 Apr 1 2008 fixtax.icn
-rw-r--r-- 1 alex group 30015 Mar 1 2007 flute.ps
-rwxr-xr-x 1 alex group 485 Oct 21 08:03 floor*
-rw-r--r-- 1 alex group 484 Apr 9 2008 maptax.icn
drwxrwxr-x 2 alex group 1024 Sep 10 11:32 testdir/
```

The `-F` option causes `ls` to print a slash (/) at the end of directory names and an asterisk (\*) at the end of the names of executable files. In this example, the string that replaces the alias `ll` (`ls -l`) itself contains an alias (`ls`). When it replaces an alias with its value, the shell looks at the first word of the replacement string to see whether it is an alias. In the preceding example, the replacement string contains the alias `ls`, so a second substitution occurs to produce the final command `ls -F -l`. (To avoid a *recursive plunge*, the `ls` in the replacement text, although an alias, is not expanded a second time.)

When given a list of aliases without the `=value` or `value` field, the `alias` builtin responds by displaying the value of each defined alias. The `alias` builtin reports an error if an alias has not been defined:

```
$ alias ll l ls zap wx
alias ll='ls -l'
alias l='ls -ltr'
alias ls='ls -F'
alias zap='rm -i'
bash: alias: wx: not found
```

You can avoid alias substitution by preceding the aliased command with a backslash (\):

```
$ \ls
Test_Emacs XTerm.ad flute.ps maptax.icn
Tiger      fixtax.icn floor      testdir
```

Because the replacement of an alias name with the alias value does not change the rest of the command line, any arguments are still received by the command that gets executed:

```
$ ll f*
-rw-r--r-- 1 alex group 641 Apr 1 2008 fixtax.icn
-rw-r--r-- 1 alex group 30015 Mar 1 2007 flute.ps
-rwxr-xr-x 1 alex group 485 Oct 21 08:03 floor*
```

You can remove an alias with the `unalias` builtin. When the `zap` alias is removed, it is no longer displayed with the `alias` builtin and its subsequent use results in an error message:

```
$ unalias zap
$ alias
alias ll='ls -l'
alias l='ls -ltr'
alias ls='ls -F'
$ zap maptax.icn
bash: zap: command not found
```

---

## FUNCTIONS

A shell function is similar to a shell script in that it stores a series of commands for execution at a later time. However, because the shell stores a function in the computer's main memory (RAM) instead of in a file on the disk, the shell can access it more quickly than the shell can access a script. The shell also preprocesses (pares) a function so that it starts up more quickly than a script. Finally the shell executes a

shell function in the same shell that called it. If you define too many functions, the overhead of starting a subshell (as when you run a script) can become unacceptable.

You can declare a shell function in the `~/.bash_profile` startup file, in the script that uses it, or directly from the command line. You can remove functions with the `unset` builtin. The shell does not keep functions once you log out.

### Removing variables and functions

**tip** If you have a shell variable and a function with the same name, using `unset` removes the shell variable. If you then use `unset` again with the same name, it removes the function.

The syntax that declares a shell function is

```
[function] function-name ()
{
    commands
}
```

where the word *function* is optional, *function-name* is the name you use to call the function, and *commands* comprise the list of commands the function executes when you call it. The *commands* can be anything you would include in a shell script, including calls to other functions.

The first brace (`{}`) can appear on the same line as the function name. Aliases and variables are expanded when a function is read, not when it is executed. You can use the `break` statement (page 910) within a function to terminate its execution.

Shell functions are useful as a shorthand as well as to define special commands. The following function starts a process named `process` in the background, with the output normally displayed by `process` being saved in `.process.out`:

```
start_process() {
process > .process.out 2>&1 &
}
```

The next example shows how to create a simple function that displays the date, a header, and a list of the people who are using the system. This function runs the same commands as the `whoson` script described on page 287. In this example the function is being entered from the keyboard. The greater-than (`>`) signs are secondary shell prompts (`PS2`); do not enter them.

```
$ function whoson ()
> {
>   date
>   echo "Users Currently Logged On"
>   who
> }

$ whoson
Thu Aug  7 15:44:58 PDT 2008
Users Currently Logged On
hls      console      Aug  6 08:59  (:0)
alex     pts/4             Aug  6 09:33  (0.0)
jenny    pts/7             Aug  6 09:23  (bravo.example.com)
```

Functions in startup files If you want to have the **whoson** function always be available without having to enter it each time you log in, put its definition in **~/.bash\_profile**. Then run **.bash\_profile**, using the **.** (dot) command to put the changes into effect immediately:

```
$ cat ~/.bash_profile
export TERM=vt100
stty kill '^u'
whoson ()
{
    date
    echo "Users Currently Logged On"
    who
}
$ . ~/.bash_profile
```

You can specify arguments when you call a function. Within the function these arguments are available as positional parameters (page 930). The following example shows the **arg1** function entered from the keyboard.

```
$ arg1 ( ) {
> echo "$1"
> }

$ arg1 first_arg
first_arg
```

See the function **switch** () on page 283 for another example of a function. “Functions” on page 927 discusses the use of local and global variables within a function.

**optional** The following function allows you to export variables using **tcsh** syntax. The **env** builtin lists all environment variables and their values and verifies that **setenv** worked correctly:

```
$ cat .bash_profile
...
# setenv - keep tcsh users happy
function setenv()
{
    if [ $# -eq 2 ]
    then
        eval $1=$2
        export $1
    else
        echo "Usage: setenv NAME VALUE" 1>&2
    fi
}
$ . ~/.bash_profile
$ setenv TCL_LIBRARY /usr/local/lib/tcl
$ env | grep TCL_LIBRARY
TCL_LIBRARY=/usr/local/lib/tcl
```

eval The **\$#** special parameter (page 931) takes on the value of the number of command-line arguments. This function uses the **eval** builtin to force **bash** to scan the command **\$1=\$2** *twice*. Because **\$1=\$2** begins with a dollar sign (**\$**), the shell treats the

entire string as a single token—a command. With variable substitution performed, the command name becomes `TCL_LIBRARY=/usr/local/lib/tcl`, which results in an error. Using `eval`, a second scanning splits the string into the three desired tokens, and the correct assignment occurs.

## CONTROLLING bash FEATURES AND OPTIONS

This section explains how to control bash features and options using command-line options and the `set` and `shopt` builtins.

### COMMAND-LINE OPTIONS

Two kinds of command-line options are available: short and long. Short options consist of a hyphen followed by a letter; long options have two hyphens followed by multiple characters. Long options must appear before short options on a command line that calls `bash`. Table 9-12 lists some commonly used command-line options.

**Table 9-12** Command-line options

| Option         | Explanation                                                                                                                                                            | Syntax                          |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|
| Help           | Displays a usage message.                                                                                                                                              | <code>--help</code>             |
| No edit        | Prevents users from using the Readline Library (page 326) to edit command lines in an interactive shell.                                                               | <code>--noediting</code>        |
| No profile     | Prevents reading these startup files (page 281): <code>/etc/profile</code> , <code>~/.bash_profile</code> , <code>~/.bash_login</code> , and <code>~/.profile</code> . | <code>--noprofile</code>        |
| No rc          | Prevents reading the <code>~/.bashrc</code> startup file (page 281). This option is on by default if the shell is called as <code>sh</code> .                          | <code>--norc</code>             |
| POSIX          | Runs bash in POSIX mode.                                                                                                                                               | <code>--posix</code>            |
| Version        | Displays bash version information and exits.                                                                                                                           | <code>--version</code>          |
| Login          | Causes bash to run as though it were a login shell.                                                                                                                    | <code>-l</code> (lowercase “l”) |
| shopt          | Runs a shell with the <i>opt</i> shopt option (page 339). A <code>-O</code> (uppercase “O”) sets the option; <code>+O</code> unsets it.                                | <code>[±]O [opt]</code>         |
| End of options | On the command line, signals the end of options. Subsequent tokens are treated as arguments even if they begin with a hyphen ( <code>-</code> ).                       | <code>--</code>                 |

### SHELL FEATURES

You can control the behavior of the Bourne Again Shell by turning features on and off. Different features use different methods to turn features on and off. The `set`

builtin controls one group of features, while the `shopt` builtin controls another group. You can also control many features from the command line you use to call `bash`.

### Features, options, variables?

**tip** To avoid confusing terminology, this book refers to the various shell behaviors that you can control as *features*. The `bash` info page refers to them as “options” and “values of variables controlling optional shell behavior.”

### set ±o: TURNS SHELL FEATURES ON AND OFF

The `set` builtin, when used with the `-o` or `+o` option, enables, disables, and lists certain `bash` features. For example, the following command turns on the `noclobber` feature (page 235):

```
$ set -o noclobber
```

You can turn this feature off (the default) by giving the command

```
$ set +o noclobber
```

The command `set -o` without an option lists each of the features controlled by `set` followed by its state (on or off). The command `set +o` without an option lists the same features in a form that you can use as input to the shell. Table 9-13 lists `bash` features.

### shopt: TURNS SHELL FEATURES ON AND OFF

The `shopt` (shell option) builtin enables, disables, and lists certain `bash` features that control the behavior of the shell. For example, the following command causes `bash` to include filenames that begin with a period (.) when it expands ambiguous file references (the `-s` stands for *set*):

```
$ shopt -s dotglob
```

You can turn this feature off (the default) by giving the command (the `-u` stands for *unset*)

```
$ shopt -u dotglob
```

The shell displays how a feature is set if you give the name of the feature as the only argument to `shopt`:

```
$ shopt dotglob
dotglob      off
```

The command `shopt` without any options or arguments lists the features controlled by `shopt` and their state. The command `shopt -s` without an argument lists the features controlled by `shopt` that are set or on. The command `shopt -u` lists the features that are unset or off. Table 9-13 (next page) lists `bash` features.

### Setting set ±o features using shopt

**tip** You can use `shopt` to set/unset features that are otherwise controlled by `set ±o`. Use the regular `shopt` syntax with `-s` or `-u` and include the `-o` option. For example, the following command turns on the `noclobber` feature:

```
$ shopt -o -s noclobber
```

**Table 9-13** bash features

| Feature        | Description                                                                                                                                                                                                                                                                                                             | Syntax                       | Alternate syntax |
|----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|------------------|
| allexport      | Automatically exports all variables and functions that you create or modify after giving this command.                                                                                                                                                                                                                  | <b>set -o allexport</b>      | <b>set -a</b>    |
| braceexpand    | Causes bash to perform brace expansion (the default; page 344).                                                                                                                                                                                                                                                         | <b>set -o braceexpand</b>    | <b>set -B</b>    |
| cdspell        | Corrects minor spelling errors in directory names used as arguments to <code>cd</code> .                                                                                                                                                                                                                                | <b>shopt -s cdspell</b>      |                  |
| cmdhist        | Saves all lines of a multiline command in the same history entry, adding semicolons as needed.                                                                                                                                                                                                                          | <b>shopt -s cmdhist</b>      |                  |
| dotglob        | Causes shell special characters (wildcards; page 243) in an ambiguous file reference to match a leading period in a filename. By default special characters do not to match a leading period. You must always specify the filenames <code>.</code> and <code>..</code> explicitly because no pattern ever matches them. | <b>shopt -s dotglob</b>      |                  |
| emacs          | Specifies emacs editing mode for command-line editing (the default; page 327).                                                                                                                                                                                                                                          | <b>set -o emacs</b>          |                  |
| errexit        | Causes bash to exit when a simple command (not a control structure) fails.                                                                                                                                                                                                                                              | <b>set -o errexit</b>        | <b>set -e</b>    |
| execfail       | Causes a shell script to continue running when it cannot find the file that is given as an argument to <code>exec</code> . By default a script terminates when <code>exec</code> cannot find the file that is given as its argument.                                                                                    | <b>shopt -s execfail</b>     |                  |
| expand_aliases | Causes aliases (page 332) to be expanded (by default it is on for interactive shells and off for noninteractive shells).                                                                                                                                                                                                | <b>shopt -s expand_alias</b> |                  |
| hashall        | Causes bash to remember where commands it has found using <b>PATH</b> (page 306) are located (default).                                                                                                                                                                                                                 | <b>set -o hashall</b>        | <b>set -h</b>    |
| histappend     | Causes bash to append the history list to the file named by <b>HISTFILE</b> (page 316) when the shell exits. By default bash overwrites this file.                                                                                                                                                                      | <b>shopt -s histappend</b>   |                  |
| histexpand     | Causes the history mechanism (which uses exclamation points; page 320) to work (default). Turn this feature off to turn off history expansion.                                                                                                                                                                          | <b>set -o histexpand</b>     | <b>set -H</b>    |



**Table 9-13** bash features (continued)

| Feature    | Description                                                                                                                                                                    | Syntax                     | Alternate syntax |
|------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|------------------|
| history    | Enable command history (on by default; page 316).                                                                                                                              | <b>set -o history</b>      |                  |
| ignoreeof  | Specifies that bash must receive ten EOF characters before it exits. Useful on noisy dial-up lines.                                                                            | <b>set -o ignoreeof</b>    |                  |
| monitor    | Enables job control (on by default, page 294).                                                                                                                                 | <b>set -o monitor</b>      | <b>set -m</b>    |
| nocaseglob | Causes ambiguous file references (page 243) to match filenames without regard to case (off by default).                                                                        | <b>shopt -s nocaseglob</b> |                  |
| noclobber  | Helps prevent overwriting files (off by default; page 235).                                                                                                                    | <b>set -o noclobber</b>    | <b>set -C</b>    |
| noglob     | Disables pathname expansion (off by default; page 243).                                                                                                                        | <b>set -o noglob</b>       | <b>set -f</b>    |
| notify     | With job control (page 294) enabled, reports the termination status of background jobs immediately. The default behavior is to display the status just before the next prompt. | <b>set -o notify</b>       | <b>set -b</b>    |
| nounset    | Displays an error and exits from a shell script when you use an unset variable in an interactive shell. The default is to display a null value for an unset variable.          | <b>set -o nounset</b>      | <b>set -u</b>    |
| nullglob   | Causes bash to expand ambiguous file references (page 243) that do not match a filename to a null string. By default bash passes these file references without expanding them. | <b>shopt -s nullglob</b>   |                  |
| posix      | Runs bash in POSIX mode.                                                                                                                                                       | <b>set -o posix</b>        |                  |
| verbose    | Displays command lines as bash reads them.                                                                                                                                     | <b>set -o verbose</b>      | <b>set -v</b>    |
| vi         | Specifies vi editing mode for command-line editing (page 326).                                                                                                                 | <b>set -o vi</b>           |                  |
| xpg_echo   | Causes the echo builtin to expand backslash escape sequences without the need for the <b>-e</b> option (page 914).                                                             | <b>shopt -s xpg_echo</b>   |                  |
| xtrace     | Turns on shell debugging (page 900).                                                                                                                                           | <b>set -o xtrace</b>       | <b>set -x</b>    |

## PROCESSING THE COMMAND LINE

Whether you are working interactively or running a shell script, **bash** needs to read a command line before it can start processing it—**bash** always reads at least one line before processing a command. Some **bash** builtins, such as **if** and **case**, as well as functions and quoted strings, span multiple lines. When **bash** recognizes a command that covers more than one line, it reads the entire command before processing it. In interactive sessions **bash** prompts you with the secondary prompt (**PS2**, **>** by default; page 309) as you type each line of a multiline command until it recognizes the end of the command:

```
$ echo 'hi
> end'
hi
end
$ function hello () {
> echo hello there
> }
$
```

After reading a command line, **bash** applies history expansion and alias substitution to the line.

## HISTORY EXPANSION

“Reexecuting and Editing Commands” on page 318 discusses the commands you can give to modify and reexecute command lines from the history list. History expansion is the process that **bash** uses to turn a history command into an executable command line. For example, when you give the command **!!**, history expansion changes that command line so it is the same as the previous one. History expansion is turned on by default for interactive shells; **set +o histexpand** turns it off. History expansion does not apply to noninteractive shells (shell scripts).

## ALIAS SUBSTITUTION

Aliases (page 332) substitute a string for the first word of a simple command. By default aliases are turned on for interactive shells and off for noninteractive shells. Give the command **shopt -u expand\_aliases** to turn aliases off.

## PARSING AND SCANNING THE COMMAND LINE

After processing history commands and aliases, **bash** does not execute the command immediately. One of the first things the shell does is to *parse* (isolate strings of characters in) the command line into tokens or words. The shell then scans each token for special characters and patterns that instruct the shell to take certain actions. These actions can involve substituting one word or words for another. When the shell parses the following command line, it breaks it into three tokens (**cp**, **~/letter**, and **.**):

```
$ cp ~/letter .
```

After separating tokens and before executing the command, the shell scans the tokens and performs *command-line expansion*.

## COMMAND-LINE EXPANSION

In both interactive and noninteractive use, the shell transforms the command line using *command-line expansion* before passing the command line to the program being called. You can use a shell without knowing much about command-line expansion, but you can use what a shell has to offer to a better advantage with an understanding of this topic. This section covers Bourne Again Shell command-line expansion.

The Bourne Again Shell scans each token for the various types of expansion and substitution in the following order. Most of these processes expand a word into a single word. Only brace expansion, word splitting, and pathname expansion can change the number of words in a command (except for the expansion of the variable "\$@"—page 932).

1. Brace expansion (page 344)
2. Tilde expansion (page 345)
3. Parameter and variable expansion (page 346)
4. Arithmetic expansion (page 346)
5. Command substitution (page 348)
6. Word splitting (page 349)
7. Pathname expansion (page 349)
8. Process substitution (page 351)

**Quote removal** After `bash` finishes with the preceding list, it removes from the command line single quotation marks, double quotation marks, and backslashes that are not a result of an expansion. This process is called *quote removal*.

## ORDER OF EXPANSION

The order in which `bash` carries out these steps affects the interpretation of commands. For example, if you set a variable to a value that looks like the instruction for output redirection and then enter a command that uses the variable's value to perform redirection, you might expect `bash` to redirect the output.

```
$ SENDIT="> /tmp/saveit"
$ echo xxx $SENDIT
xxx > /tmp/saveit
$ cat /tmp/saveit
cat: /tmp/saveit: No such file or directory
```

In fact, the shell does *not* redirect the output—it recognizes input and output redirection before it evaluates variables. When it executes the command line, the shell checks for redirection and, finding none, evaluates the `SENDIT` variable. After

replacing the variable with `> /tmp/saveit`, `bash` passes the arguments to `echo`, which dutifully copies its arguments to standard output. No `/tmp/saveit` file is created.

The following sections provide more detailed descriptions of the steps involved in command processing. Keep in mind that double and single quotation marks cause the shell to behave differently when performing expansions. Double quotation marks permit parameter and variable expansion but suppress other types of expansion. Single quotation marks suppress all types of expansion.

## BRACE EXPANSION

*Brace expansion*, which originated in the C Shell, provides a convenient way to specify filenames when pathname expansion does not apply. Although brace expansion is almost always used to specify filenames, the mechanism can be used to generate arbitrary strings; the shell does not attempt to match the brace notation with the names of existing files.

Brace expansion is turned on in interactive and noninteractive shells by default; you can turn it off with `set +o braceexpand`. The shell also uses braces to isolate variable names (page 302).

The following example illustrates how brace expansion works. The `ls` command does not display any output because there are no files in the working directory. The `echo` builtin displays the strings that the shell generates with brace expansion. In this case the strings do not match filenames (there are no files in the working directory.)

```
$ ls
$ echo chap_{one,two,three}.txt
chap_one.txt chap_two.txt chap_three.txt
```

The shell expands the comma-separated strings inside the braces in the `echo` command into a SPACE-separated list of strings. Each string from the list is prepended with the string `chap_`, called the *preamble*, and appended with the string `.txt`, called the *postscript*. Both the preamble and the postscript are optional. The left-to-right order of the strings within the braces is preserved in the expansion. For the shell to treat the left and right braces specially and for brace expansion to occur, at least one comma and no unquoted whitespace characters must be inside the braces. You can nest brace expansions.

Brace expansion is useful when there is a long preamble or postscript. The following example copies the four files `main.c`, `f1.c`, `f2.c`, and `tmp.c` located in the `/usr/local/src/C` directory to the working directory:

```
$ cp /usr/local/src/C/{main,f1,f2,tmp}.c .
```

You can also use brace expansion to create directories with related names:

```
$ ls -F
file1 file2 file3
$ mkdir vrs{A,B,C,D,E}
$ ls -F
file1 file2 file3 vrsA/ vrsB/ vrsC/ vrsD/ vrsE/
```

The `-F` option causes `ls` to display a slash (/) after a directory and an asterisk (\*) after an executable file.

If you tried to use an ambiguous file reference instead of braces to specify the directories, the result would be different (and not what you wanted):

```
$ rmdir vrs*
$ mkdir vrs[A-E]
$ ls -F
file1 file2 file3 vrs[A-E]/
```

An ambiguous file reference matches the names of existing files. Because it found no filenames matching `vrs[A-E]`, `bash` passed the ambiguous file reference to `mkdir`, which created a directory with that name. Page 245 has a discussion of brackets in ambiguous file references.

## TILDE EXPANSION

Chapter 6 showed a shorthand notation to specify your home directory or the home directory of another user. This section provides a more detailed explanation of *tilde expansion*.

The tilde (~) is a special character when it appears at the start of a token on a command line. When it sees a tilde in this position, `bash` looks at the following string of characters—up to the first slash (/) or to the end of the word if there is no slash—as a possible username. If this possible username is null (that is, if the tilde appears as a word by itself or if it is immediately followed by a slash), the shell substitutes the value of the `HOME` variable for the tilde. The following example demonstrates this expansion, where the last command copies the file named `letter` from Alex’s home directory to the working directory:

```
$ echo $HOME
/home/alex
$ echo ~
/home/alex
$ echo ~/letter
/home/alex/letter
$ cp ~/letter .
```

If the string of characters following the tilde forms a valid username, the shell substitutes the path of the home directory associated with that username for the tilde and name. If it is not null and not a valid username, the shell does not make any substitution:

```
$ echo ~jenny
/home/jenny
$ echo ~root
/root
$ echo ~xx
~xx
```

Tildes are also used in directory stack manipulation (page 296). In addition, `~+` is a synonym for `PWD` (the name of the working directory), and `~-` is a synonym for `OLDPWD` (the name of the previous working directory).

## PARAMETER AND VARIABLE EXPANSION

On a command line a dollar sign (\$) that is not followed by an open parenthesis introduces parameter or variable expansion. *Parameters* include command line, or positional, parameters (page 930) and special parameters (page 928). *Variables* include user-created variables (page 300) and keyword variables (page 305). The `bash` man and info pages do not make this distinction, however.

Parameters and variables are not expanded if they are enclosed within single quotation marks or if the leading dollar sign is escaped (preceded with a backslash). If they are enclosed within double quotation marks, the shell expands parameters and variables.

## ARITHMETIC EXPANSION

The shell performs *arithmetic expansion* by evaluating an arithmetic expression and replacing it with the result. Under `bash` the syntax for arithmetic expansion is

```
$((expression))
```

The shell evaluates *expression* and replaces `$((expression))` with the result of the evaluation. This syntax is similar to the syntax used for command substitution [`$(...)`] and performs a parallel function. You can use `$((expression))` as an argument to a command or in place of any numeric value on a command line.

The rules for forming *expression* are the same as those found in the C programming language; all standard C arithmetic operators are available (see Table 27-8 on page 953). Arithmetic in `bash` is done using integers. Unless you use variables of type integer (page 305) or actual integers, however, the shell must convert string-valued variables to integers for the purpose of the arithmetic evaluation.

You do not need to precede variable names within *expression* with a dollar sign (\$). In the following example, an arithmetic expression determines how many years are left until age 60:

```
$ cat age_check
#!/bin/bash
echo -n "How old are you? "
read age
echo "Wow, in $((60-age)) years, you'll be 60!"

$ age_check
How old are you? 55
Wow, in 5 years, you'll be 60!
```

You do not need to enclose the *expression* within quotation marks because `bash` does not perform filename expansion on it. This feature makes it easier for you to use an asterisk (\*) for multiplication, as the following example shows:

```
$ echo There are $((60*60*24*365)) seconds in a non-leap year.
There are 31536000 seconds in a non-leap year.
```

The next example uses `wc`, `cut`, arithmetic expansion, and command substitution to estimate the number of pages required to print the contents of the file `letter.txt`. The output of the `wc` (word count) utility used with the `-l` option is the number of lines in the file, in columns 1 through 4, followed by a `SPACE` and the name of the file (the first command following). The `cut` utility with the `-c1-4` option extracts the first four columns.

```
$ wc -l letter.txt
351 letter.txt
$ wc -l letter.txt | cut -c1-4
351
```

The dollar sign and single parenthesis instruct the shell to perform command substitution; the dollar sign and double parentheses indicate arithmetic expansion:

```
$ echo $(( $(wc -l letter.txt | cut -c1-4)/66 + 1))
6
```

The preceding example sends standard output from `wc` to standard input of `cut` via a pipe. Because of command substitution, the output of both commands replaces the commands between the `$()` and the matching `)` on the command line. Arithmetic expansion then divides this number by 66, the number of lines on a page. A 1 is added at the end because the integer division results in any remainder being discarded.

### Fewer dollar signs (\$)

**tip** When you use variables within `$(( and ))`, the dollar signs that precede individual variable references are optional:

```
$ x=23 y=37
$ echo $((2*$x + 3*$y))
157
$ echo $((2*x + 3*y))
157
```

Another way to get the same result without using `cut` is to redirect the input to `wc` instead of having `wc` get its input from a file you name on the command line. When you redirect its input, `wc` does not display the name of the file:

```
$ wc -l < letter.txt
351
```

It is common practice to assign the result of arithmetic expansion to a variable:

```
$ numpages=$(( $(wc -l < letter.txt)/66 + 1))
```

**let builtin** The `let` builtin evaluates arithmetic expressions just as the `$(( ))` syntax does. The following command is equivalent to the preceding one:

```
$ let "numpages=$(wc -l < letter.txt)/66 + 1"
```

The double quotation marks keep the SPACES (both those you can see and those that result from the command substitution) from separating the expression into separate arguments to `let`. The value of the last expression determines the exit status of `let`. If the value of the last expression is 0, the exit status of `let` is 1; otherwise, the exit status is 0.

You can give multiple arguments to `let` on a single command line:

```
$ let a=5+3 b=7+2
$ echo $a $b
8 9
```

When you refer to variables when doing arithmetic expansion with `let` or `$( )`, the shell does not require you to begin the variable name with a dollar sign (`$`). Nevertheless, it is a good practice to do so, as in most places you must include this symbol.

## COMMAND SUBSTITUTION

*Command substitution* replaces a command with the output of that command. The preferred syntax for command substitution under `bash` follows:

```
$(command)
```

Under `bash` you can also use the following syntax:

```
`command`
```

The shell executes *command* within a subshell and replaces *command*, along with the surrounding punctuation, with standard output of *command*.

In the following example, the shell executes `pwd` and substitutes the output of the command for the command and surrounding punctuation. Then the shell passes the output of the command, which is now an argument, to `echo`, which displays it.

```
$ echo $(pwd)
/home/alex
```

The next script assigns the output of the `pwd` builtin to the variable `where` and displays a message containing the value of this variable:

```
$ cat where
where=$(pwd)
echo "You are using the $where directory."
$ where
You are using the /home/jenny directory.
```

Although it illustrates how to assign the output of a command to a variable, this example is not realistic. You can more directly display the output of `pwd` without using a variable:

```
$ cat where2
echo "You are using the $(pwd) directory."
$ where2
You are using the /home/jenny directory.
```



The following command uses `find` to locate files with the name `README` in the directory tree with its root at the working directory. This list of files is standard output of `find` and becomes the list of arguments to `ls`.

```
$ ls -l $(find . -name README -print)
```

The next command line shows the older `'command'` syntax:

```
$ ls -l `find . -name README -print`
```

One advantage of the newer syntax is that it avoids the rather arcane rules for token handling, quotation mark handling, and escaped back ticks within the old syntax. Another advantage of the new syntax is that it can be nested, unlike the old syntax. For example, you can produce a long listing of all `README` files whose size exceeds the size of `./README` with the following command:

```
$ ls -l $(find . -name README -size +$(echo $(cat ./README | wc -c)c ) -print )
```

Try giving this command after giving a `set -x` command (page 900) to see how `bash` expands it. If there is no `README` file, you just get the output of `ls -l`.

For additional scripts that use command substitution, see pages 896, 915, and 945.

### **`$(` Versus `$()`**

**tip** The symbols `$(` constitute a separate token. They introduce an arithmetic expression, not a command substitution. Thus, if you want to use a parenthesized subshell (page 293) within `$()`, you must insert a `SPACE` between the `$()` and the next `(`.

## **WORD SPLITTING**

The results of parameter and variable expansion, command substitution, and arithmetic expansion are candidates for word splitting. Using each character of `IFS` (page 309) as a possible delimiter, `bash` splits these candidates into words or tokens. If `IFS` is unset, `bash` uses its default value (`SPACE-TAB-NEWLINE`). If `IFS` is null, `bash` does not split words.

## **PATHNAME EXPANSION**

*Pathname expansion* (page 243), also called *filename generation* or *globbing*, is the process of interpreting ambiguous file references and substituting the appropriate list of filenames. Unless `noglob` (page 341) is set, the shell performs this function when it encounters an ambiguous file reference—a token containing any of the unquoted characters `*`, `?`, `[`, or `]`. If `bash` cannot locate any files that match the specified pattern, the token with the ambiguous file reference is left alone. The shell does not delete the token or replace it with a null string but rather passes it to the program as is (except see `nullglob` on page 341).

In the first `echo` command in the following example, the shell expands the ambiguous file reference `tmp*` and passes three tokens (`tmp1`, `tmp2`, and `tmp3`) to `echo`. The `echo` builtin displays the three filenames it was passed by the shell. After `rm`

removes the three **tmp\*** files, the shell finds no filenames that match **tmp\*** when it tries to expand it. Thus it passes the unexpanded string to the **echo** builtin, which displays the string it was passed.

```
$ ls
tmp1 tmp2 tmp3
$ echo tmp*
tmp1 tmp2 tmp3
$ rm tmp*
$ echo tmp*
tmp*
```

A period that either starts a pathname or follows a slash (/) in a pathname must be matched explicitly unless you have set **dotglob** (page 340). The option **nocaseglob** (page 341) causes ambiguous file references to match filenames without regard to case.

Quotation marks Putting double quotation marks around an argument causes the shell to suppress pathname and all other expansion except parameter and variable expansion. Putting single quotation marks around an argument suppresses all types of expansion. The second **echo** command in the following example shows the variable **\$alex** between double quotation marks, which allow variable expansion. As a result the shell expands the variable to its value: **sonar**. This expansion does not occur in the third **echo** command, which uses single quotation marks. Because neither single nor double quotation marks allow pathname expansion, the last two commands display the unexpanded argument **tmp\***.

```
$ echo tmp* $alex
tmp1 tmp2 tmp3 sonar
$ echo "tmp* $alex"
tmp* sonar
$ echo 'tmp* $alex'
tmp* $alex
```

The shell distinguishes between the value of a variable and a reference to the variable and does not expand ambiguous file references if they occur in the value of a variable. As a consequence you can assign to a variable a value that includes special characters, such as an asterisk (\*).

Levels of expansion In the next example, the working directory has three files whose names begin with **letter**. When you assign the value **letter\*** to the variable **var**, the shell does not expand the ambiguous file reference because it occurs in the value of a variable (in the assignment statement for the variable). No quotation marks surround the string **letter\***; context alone prevents the expansion. After the assignment the **set** builtin (with the help of **grep**) shows the value of **var** to be **letter\***.

The three **echo** commands demonstrate three levels of expansion. When **\$var** is quoted with single quotation marks, the shell performs no expansion and passes the character string **\$var** to **echo**, which displays it. When you use double quotation marks, the shell performs variable expansion only and substitutes the value of the **var** variable for its name, preceded by a dollar sign. No pathname expansion is performed

on this command because double quotation marks suppress it. In the final command, the shell, without the limitations of quotation marks, performs variable substitution and then pathname expansion before passing the arguments to `echo`.

```
$ ls letter*
letter1 letter2 letter3
$ var=letter*
$ set | grep var
var='letter*'
$ echo "$var"
$var
$ echo "$var"
letter*
$ echo $var
letter1 letter2 letter3
```

## PROCESS SUBSTITUTION

A special feature of the Bourne Again Shell is the ability to replace filename arguments with processes. An argument with the syntax `<(command)` causes *command* to be executed and the output written to a named pipe (FIFO). The shell replaces that argument with the name of the pipe. If that argument is then used as the name of an input file during processing, the output of *command* is read. Similarly an argument with the syntax `>(command)` is replaced by the name of a pipe that *command* reads as standard input.

The following example uses `sort` (page 155) with the `-m` (merge, which works correctly only if the input files are already sorted) option to combine two word lists into a single list. Each word list is generated by a pipe that extracts words matching a pattern from a file and sorts the words in that list.

```
$ sort -m -f <(grep "[^A-Z]..$" memo1 | sort) <(grep ".*aba.*" memo2 | sort)
```

---

## CHAPTER SUMMARY

The shell is both a command interpreter and a programming language. As a command interpreter, the shell executes commands you enter in response to its prompt. As a programming language, the shell executes commands from files called shell scripts. When you start a shell, it typically runs one or more startup files.

Running a shell script Assuming that the file holding a shell script is in the working directory, there are three basic ways to execute the shell script from the command line.

1. Type the simple filename of the file that holds the script.
2. Type a relative pathname, including the simple filename preceded by `./`.
3. Type **bash** followed by the name of the file.

Technique 1 requires that the working directory be in the **PATH** variable. Techniques 1 and 2 require that you have execute and read permission for the file holding the script. Technique 3 requires that you have read permission for the file holding the script.

**Job control** A job is one or more commands connected by pipes. You can bring a job running in the background into the foreground by using the **fg** builtin. You can put a foreground job into the background by using the **bg** builtin, provided that you first suspend the job by pressing the suspend key (typically **CONTROL-Z**). Use the **jobs** builtin to see which jobs are running or suspended.

**Variables** The shell allows you to define variables. You can declare and initialize a variable by assigning a value to it; you can remove a variable declaration by using **unset**. Variables are local to a process unless they are exported using the **export** builtin to make them available to child processes. Variables you declare are called *user-created* variables. The shell also defines *keyword* variables. Within a shell script you can work with the command line (*positional*) parameters the script was called with.

**Process** Each process has a unique identification (PID) number and is the execution of a single Linux command. When you give it a command, the shell forks a new (child) process to execute the command, unless the command is built into the shell (page 247). While the child process is running, the shell is in a state called sleep. By ending a command line with an ampersand (&), you can run a child process in the background and bypass the sleep state so that the shell prompt returns immediately after you press **RETURN**. Each command in a shell script forks a separate process, each of which may in turn fork other processes. When a process terminates, it returns its exit status to its parent process. An exit status of zero signifies success and nonzero signifies failure.

**History** The history mechanism, a feature adapted from the C Shell, maintains a list of recently issued command lines, also called *events*, that provides a way to reexecute previous commands quickly. There are several ways to work with the history list; one of the easiest is to use a command-line editor.

**Command-line editors** When using an interactive Bourne Again Shell, you can edit your command line and commands from the history file, using either of the Bourne Again Shell's command-line editors (**vi[m]** or **emacs**). When you use the **vi(m)** command-line editor, you start in Input mode, unlike the way you normally enter **vi(m)**. You can switch between Command and Input modes. The **emacs** editor is modeless and distinguishes commands from editor input by recognizing control characters as commands.

**Aliases** An alias is a name that the shell translates into another name or (complex) command. Aliases allow you to define new commands by substituting a string for the first token of a simple command.

**Functions** A shell function is a series of commands that, unlike a shell script, are parsed prior to being stored in memory so that they run faster than shell scripts. Shell scripts are parsed at runtime and are stored on disk. A function can be defined on the command line or within a shell script. If you want the function definition to remain in effect across login sessions, you can define it in a startup file. Like the functions of a

programming language, a shell function is called by giving its name followed by any arguments.

**Shell features** There are several ways to customize the shell's behavior. You can use options on the command line when you call **bash** and you can use the **bash** **set** and **shopt** builtins to turn features on and off.

**Command-line expansion** When it processes a command line, the Bourne Again Shell may replace some words with expanded text. Most types of command-line expansion are invoked by the appearance of a special character within a word (for example, a leading dollar sign denotes a variable). See Table 9-6 on page 313 for a list of special characters. The expansions take place in a specific order. Following the history and alias expansions, the common expansions are parameter and variable expansion, command substitution, and pathname expansion. Surrounding a word with double quotation marks suppresses all types of expansion except parameter and variable expansion. Single quotation marks suppress all types of expansion, as does quoting (escaping) a special character by preceding it with a backslash.

## EXERCISES

1. Explain the following unexpected result:

```
$ whereis date
date: /bin/date ...
$ echo $PATH
.: /usr/local/bin: /usr/bin: /bin
$ cat > date
echo "This is my own version of date."
$ date
Sat May 24 11:45:49 PDT 2008
```

2. What are two ways you can execute a shell script when you do not have execute access permission for the file containing the script? Can you execute a shell script if you do not have read access permission for the file containing the script?
3. What is the purpose of the **PATH** variable?
  - a. Set the **PATH** variable so that it causes the shell to search the following directories in order:
    - /usr/local/bin
    - /usr/bin
    - /bin
    - /usr/kerberos/bin
    - The **bin** directory in your home directory
    - The working directory

- b. If there is a file named **doit** in **/usr/bin** and another file with the same name in your **~/bin**, which one will be executed? (Assume that you have execute permission for both files.)
  - c. If your **PATH** variable is not set to search the working directory, how can you execute a program located there?
  - d. Which command can you use to add the directory **/usr/games** to the end of the list of directories in **PATH**?
4. Assume that you have made the following assignment:

```
$ person=jenny
```

Give the output of each of the following commands:

- a. **echo \$person**
  - b. **echo '\$person'**
  - c. **echo "\$person"**
5. The following shell script adds entries to a file named **journal-file** in your home directory. This script helps you keep track of phone conversations and meetings.

```
$ cat journal
# journal: add journal entries to the file
# $HOME/journal-file

file=$HOME/journal-file
date >> $file
echo -n "Enter name of person or group: "
read name
echo "$name" >> $file
echo >> $file
cat >> $file
echo "-----" >> $file
echo >> $file
```

- a. What do you have to do to the script to be able to execute it?
  - b. Why does the script use the **read** builtin (page 937) the first time it accepts input from the terminal and the **cat** utility the second time?
6. Assume that the **/home/jenny/grants/biblios** and **/home/jenny/biblios** directories exist. Give Jenny's working directory after she executes each sequence of commands given. Explain what happens in each case.
- a.

```
$ pwd
/home/jenny/grants
$ CDPATH=$(pwd)
$ cd
$ cd biblios
```

b.

```
$ pwd
/home/jenny/grants
$ CDPATH=$(pwd)
$ cd $HOME/biblios
```

7. Name two ways you can identify the PID number of your login shell.
8. Give the following command:

```
$ sleep 30 | cat /etc/passwd
```

Is there any output from `sleep`? Where does `cat` get its input from? What has to happen before the shell displays another prompt?

## ADVANCED EXERCISES

9. Write a sequence of commands or a script that demonstrates that variable expansion occurs before pathname expansion.
10. Write a shell script that outputs the name of the shell that is executing it.
11. Explain the behavior of the following shell script:

```
$ cat quote_demo
twoliner="This is line 1.
This is line 2."
echo "$twoliner"
echo $twoliner
```

- a. How many arguments does each `echo` command see in this script? Explain.
  - b. Redefine the `IFS` shell variable so that the output of the second `echo` is the same as the first.
12. Add the exit status of the previous command to your prompt so that it behaves similarly to the following:

```
$ [0] ls xxx
ls: xxx: No such file or directory
$ [1]
```

13. The `dirname` utility treats its argument as a pathname and writes to standard output the path prefix—that is, everything up to but not including the last component:

```
$ dirname a/b/c/d
a/b/c
```

If you give **dirname** a simple filename (no / characters) as an argument, **dirname** writes a **.** to standard output:

```
$ dirname simple
.
```

Implement **dirname** as a bash function. Make sure that it behaves sensibly when given such arguments as **/**.

14. Implement the **basename** utility, which writes the last component of its pathname argument to standard output, as a bash function. For example, given the pathname **a/b/c/d**, **basename** writes **d** to standard output:

```
$ basename a/b/c/d
d
```

15. The Linux **basename** utility has an optional second argument. If you give the command **basename *path suffix***, **basename** removes the *suffix* and the prefix from *path*:

```
$ basename src/shellfiles/prog.bash .bash
prog
$ basename src/shellfiles/prog.bash .c
prog.bash
```

Add this feature to the function you wrote for exercise 14.



# 10

## NETWORKING AND THE INTERNET

### IN THIS CHAPTER

|                                                    |     |
|----------------------------------------------------|-----|
| Types of Networks and How They Work. . . . .       | 359 |
| Network Protocols. . . . .                         | 365 |
| Network Utilities. . . . .                         | 376 |
| ping: Tests a Network Connection. . . . .          | 379 |
| tracert: Traces a Route Over the Internet. . . . . | 380 |
| nslookup: Query Internet Nameservers. . . . .      | 382 |
| Distributed Computing. . . . .                     | 383 |
| Usenet. . . . .                                    | 392 |
| WWW: World Wide Web. . . . .                       | 395 |

The communications facilities linking computers are continually improving, allowing faster and more economical connections. The earliest computers were unconnected stand-alone systems. To transfer information from one system to another, you had to store it in some form (usually magnetic tape, paper tape, or punch cards—called IBM or Hollerith cards), carry it to a compatible system, and read it back in. A notable advance occurred when computers began to exchange data over serial lines, although the transfer rate was slow (hundreds of bits per second). People quickly invented new ways to take advantage of this computing power, such as email, news retrieval, and bulletin board services. With the speed of today's networks, a piece of email can cross the country or even travel halfway around the world in a few seconds.

Today it would be difficult to find a computer facility that does not include a LAN to link its systems. Linux systems are typically attached to an *Ethernet* (page 1081) network. Wireless networks are also prevalent. Large computer facilities usually maintain several networks, often of different types, and almost certainly have connections to larger networks (companywide or campuswide and beyond).

**Internet** The Internet is a loosely administered network of networks (an *internetwork*) that links computers on diverse LANs around the globe. An internet (small *i*) is a generic network of networks that may share some parts in common with the public Internet. It is the Internet that makes it possible to send an email message to a colleague thousands of miles away and receive a reply within minutes. A related term, *intranet*, refers to the networking infrastructure within a company or other institution. Intranets are usually private; access to them from external networks may be limited and carefully controlled, typically using firewalls (page 363).

**Network services** Over the past decade many network services have emerged and become standardized. On Linux and UNIX systems, special processes called *daemons* (page 1078) support such services by exchanging specialized messages with other systems over the network. Several software systems have been created to allow computers to share filesystems with one another, making it appear as though remote files are stored on local disks. Sharing remote filesystems allows users to share information without knowing where the files physically reside, without making unnecessary copies, and without learning a new set of utilities to manipulate them. Because the files appear to be stored locally, you can use standard utilities (such as `cat`, `vim`, `lpr`, `mv`, or their graphical counterparts) to work with them.

Developers have created new tools and extended existing ones to take advantage of higher network speeds and to work within more crowded networks. The `rlogin`, `rsh`, and `telnet` utilities, which were designed long ago, have largely been supplanted by `ssh` (secure shell, page 621) in recent years. The `ssh` utility allows a user to log in on or execute commands securely on a remote computer. Users rely on such utilities as `scp` and `ftp` to transfer files from one system to another across the network. Communication utilities, including email utilities and chat programs (e.g., `talk`, Internet Relay Chat [IRC], ICQ, and instant messenger [IM] programs, such as AOL's AIM and `gaim`) have become so prevalent that many people with very little computer expertise use them on a daily basis to keep in touch with friends, family, and colleagues.

**Intranet** An *intranet* is a network that connects computing resources at a school, company, or other organization but, unlike the Internet, typically restricts access to internal users. An intranet is very similar to a LAN (local area network) but is based on Internet technology. An intranet can provide database, email, and Web page access to a limited group of people, regardless of their geographic location.

The ability of an intranet to connect dissimilar machines is one of its strengths. Think of all the machines you can find on the Internet: Macintosh systems, PCs running different versions of Windows, machines running UNIX and Linux, and so on. Each of these machines can communicate via IP (page 365), a common protocol. So it is with an intranet: Dissimilar machines can all talk to one another.

Another key difference between the Internet and an intranet is that the Internet transmits only one protocol suite: IP. In contrast, an intranet can be set up to use a number of protocols, such as IP, IPX, AppleTalk, DECnet, XNS, or other protocols developed by vendors over the years. Although these protocols cannot be transmitted directly over the Internet, you can set up special gateway boxes at remote sites that tunnel or encapsulate these protocols into IP packets and then use the Internet to pass them.

You can use an *extranet* (also called a *partner net*) or a virtual private network (VPN) to improve security. These terms describe ways to connect remote sites securely to a local site, typically by using the public Internet as a carrier and employing encryption as a means of protecting data in transit.

Following are some terms you may want to become familiar with before you read the rest of this chapter:

|                             |                             |                               |
|-----------------------------|-----------------------------|-------------------------------|
| <i>ASP</i> (page 1069)      | <i>hub</i> (page 1086)      | <i>packet</i> (page 1098)     |
| <i>bridge</i> (page 1072)   | <i>internet</i> (page 1088) | <i>router</i> (page 1104)     |
| <i>extranet</i> (page 1081) | <i>Internet</i> (page 1088) | <i>sneakernet</i> (page 1107) |
| <i>firewall</i> (page 1082) | <i>intranet</i> (page 1088) | <i>switch</i> (page 1110)     |
| <i>gateway</i> (page 1083)  | <i>ISP</i> (page 1089)      | <i>VPN</i> (page 1114)        |

## TYPES OF NETWORKS AND HOW THEY WORK

Computers communicate over networks using unique addresses assigned by system software. A computer message, called a *packet*, *frame*, or *datagram*, includes the address of the destination computer and the sender's return address. The three most common types of networks are *broadcast*, *point-to-point*, and *switched*. Once popular token-based networks (such as FDDI and token ring) are rarely seen anymore.

Speed is critical to the proper functioning of the Internet. Newer specifications (cat 6 and cat 7) are being standardized for 1000BaseT (1 gigabit per second, called gigabit Ethernet, or GIG-E) and faster networking. Some of the networks that form the backbone of the Internet run at speeds of almost 10 gigabits per second (OC192) to accommodate the ever-increasing demand for network services. Table 10-1 lists some of the specifications in use today.

**Table 10-1** Network specifications

| Specification | Speed                                                                            |
|---------------|----------------------------------------------------------------------------------|
| DS0           | 64 kilobits per second                                                           |
| ISDN          | Two DS0 lines plus signaling (16 kilobits per second) or 128 kilobits per second |
| T-1           | 1.544 megabits per second (24 DS0 lines)                                         |
| T-3           | 43.232 megabits per second (28 T-1s)                                             |
| OC3           | 155 megabits per second (100 T-1s)                                               |
| OC12          | 622 megabits per second (4 OC3s)                                                 |
| OC48          | 2.5 gigabits per seconds (4 OC12s)                                               |
| OC192         | 9.6 gigabits per second (4 OC48s)                                                |

## BROADCAST NETWORKS

On a *broadcast network*, such as Ethernet, any of the many systems attached to the network cable can send a message at any time; each system examines the address in each message and responds only to messages addressed to it. A problem occurs on a broadcast network when multiple systems send data at the same time, resulting in a collision of the messages on the cable. When messages collide, they can become garbled. The sending system notices the garbled message and resends it after waiting a short but random amount of time. Waiting a random amount of time helps prevent those same systems from resending the data at the same moment and experiencing yet another collision. The extra traffic that results from collisions can strain the network; if the collision rate gets too high, retransmissions may result in more collisions. Ultimately the network may become unusable.

## POINT-TO-POINT NETWORKS

A point-to-point link does not seem like much of a network because only two endpoints are involved. However, most connections to WANs (wide area networks) go through point-to-point links, using wire cable, radio, or satellite links. The advantage of a point-to-point link is its simplicity: Because only two systems are involved, the traffic on the link is limited and well understood. A disadvantage is that each system can typically be equipped for only a small number of such links; it is impractical and costly to establish point-to-point links that connect each computer to all the rest.

Point-to-point links often use serial lines and modems. The combination of a modem with a point-to-point link allows an isolated system to connect inexpensively to a larger network.

The most common types of point-to-point links are the ones used to connect to the Internet. When you use DSL<sup>1</sup> (digital subscriber line), you are using a point-to-point link to connect to the Internet. Serial lines, such as T-1, T-3, ATM links, and ISDN, are all point-to-point. Although it might seem like a point-to-point link, a cable modem is based on broadcast technology and in that way is similar to Ethernet.

## SWITCHED NETWORKS

A *switch* is a device that establishes a virtual path between source and destination hosts in such a way that each path appears to be a point-to-point link, much like a railroad roundhouse. The switch creates and tears down virtual paths as hosts seek to communicate with each other. Each host thinks it has a direct point-to-point path to the host it is talking to. Contrast this approach with a broadcast network, where each host also sees traffic bound for other hosts. The advantage of a switched network over a pure point-to-point network is that each host requires only one connection: the connection to the switch. Using pure point-to-point connections, each host must have a connection to every other host. Scalability is provided by further linking switches.

---

1. The term *DSL* incorporates the xDSL suite of technologies, which includes ADSL, XDSL, SDSL, and HDSL.

## LAN: LOCAL AREA NETWORK

Local area networks (LANs) are confined to a relatively small area—a single computer facility, building, or campus. Today most LANs run over copper or fiberoptic (glass or plastic) cable, but other wireless technologies, such as infrared (similar to most television remote control devices) and radio wave (wireless, or Wi-Fi), are becoming more popular.

If its destination address is not on the local network, a packet must be passed on to another network by a router (page 362). A router may be a general-purpose computer or a special-purpose device attached to multiple networks to act as a gateway among them.

### ETHERNET

A Linux system connected to a LAN usually connects to a network using Ethernet. A typical Ethernet connection can support data transfer rates from 10 megabits per second to 1 gigabit per second, with further speed enhancements planned for the future. As a result of computer load, competing network traffic, and network overhead, file transfer rates on an Ethernet are always slower than the maximum, theoretical transfer rate.

**Cables** An Ethernet network transfers data using copper or fiberoptic cable or wireless transmitters and receivers. Originally, each computer was attached to a thick coaxial cable (called *thicknet*) at tap points spaced at six-foot intervals along the cable. The thick cable was awkward to deal with, so other solutions, including a thinner coaxial cable called *thinnet*, or 10Base2,<sup>2</sup> were developed. Today most Ethernet connections are either wireless or made over unshielded twisted pair (referred to as UTP, Category 5 [cat 5], Category 5e [cat 5e], Category 6 [cat 6], 10BaseT, or 100BaseT) wire—similar to the type of wire used for telephone lines and serial data communications.

**Switch** A *switched Ethernet* network is a special case of a broadcast network that works with a *network switch* (or just *switch*), which is a type of intelligent hub. Instead of having a dumb repeater (passive hub) that broadcasts every packet it receives out of every port, a switch learns which devices are connected to which of its ports. A switch sorts packets and then sends the traffic to only the machine it is intended for. A switch also has buffers for holding and queuing packets.

Some Ethernet switches have enough bandwidth to communicate simultaneously, in full-duplex mode, with all the devices connected to them. A nonswitched (hub-based) broadcast network can run in only half-duplex mode. Full-duplex Ethernet further improves things by eliminating collisions. Each host on a switched network can transmit and receive simultaneously at 10/100/1,000 megabits per second for an effective bandwidth between hosts of 20/200/2,000 megabits per second, depending on the capacity of the switch.

---

2. Versions of Ethernet are classified as **XBaseY**, where **X** is the data rate in megabits per second, **Base** means baseband (as opposed to radio frequency), and **Y** is the category of cabling.

## WIRELESS

Wireless networks are becoming increasingly common. They are found in offices, homes, and public places, such as universities, coffee shops, and airports. Wireless access points provide functionality similar to an Ethernet hub. They allow multiple users to interact via a common radio frequency spectrum. A wireless, point-to-point connection allows you to wander about your home or office with a laptop, using an antenna to link to a LAN or to the Internet via an in-house base station. Linux includes drivers for many of the common wireless boards. A wireless access point, or base station, connects a wireless network to a wired network so that no special protocol is required for a wireless connection. Refer to page 605 and to the *Linux Wireless LAN HOWTO* at [www.hpl.hp.com/personal/Jean\\_Tourrilhes/Linux](http://www.hpl.hp.com/personal/Jean_Tourrilhes/Linux).

## WAN: WIDE AREA NETWORK

A wide area network (WAN) covers a large geographic area. In contrast, the technologies (such as Ethernet) used for LANs were designed to work over limited distances and for a certain number of host connections. A WAN may span long distances over dedicated data lines (leased from a telephone company) or radio or satellite links. Such networks are often used to interconnect LANs. Major Internet service providers rely on WANs to connect to their customers within a country and around the globe.

**MAN** Some networks do not fit into either the LAN or the WAN designation. A MAN (metropolitan area network) is a network that is contained in a smaller geographic area, such as a city. Like WANs, MANs are typically used to interconnect LANs.

## INTERNETWORKING THROUGH GATEWAYS AND ROUTERS

**Gateway** A LAN connects to a WAN through a *gateway*, a generic term for a computer or a special device with multiple network connections that passes data from one network to another. A gateway converts the data traffic from the format used on the LAN to that used on the WAN. Data that crosses the country from one Ethernet to another over a WAN, for example, is repackaged from the Ethernet format to a different format that can be processed by the communications equipment that makes up the WAN backbone. When it reaches the end of its journey over the WAN, the data is converted by another gateway to a format appropriate for the receiving network. For the most part, these details are of concern only to the network administrators; the end user does not need to know anything about how the data transfer takes place.

**Router** A *router* is the most popular form of gateway. Routers play an important role in internetworking. Just as you might study a map to plan your route when you need to drive to an unfamiliar place, so a computer needs to know how to deliver a message to a system attached to a distant network by passing through intermediary systems and networks along the way. Although you might envision using a giant network road map to choose the route that your data should follow, a static map of computer routes is usually a poor choice for a large network. Computers and

networks along the route you choose may be overloaded or down, without providing a detour for your message.

Routers instead communicate dynamically, keeping each other informed about which routes are open for use. To extend the analogy, this situation would be like heading out on a car trip without consulting a map to find a route to your destination; instead you head for a nearby gas station and ask directions. Throughout the journey you continue to stop at one gas station after another, getting directions at each to find the next one. Although it would take a while to make the stops, the owner of each gas station would advise you of bad traffic, closed roads, alternative routes, and shortcuts.

The stops made by the data are much quicker than those you would make in your car, but each message leaves each router on a path chosen based on the most current information. Think of this system as a GPS (global positioning system) setup that automatically gets updates at each intersection and tells you where to go next, based on traffic and highway conditions.

Figure 10-1 (next page) shows an example of how LANs might be set up at three sites interconnected by a WAN (the Internet). In this type of network diagram, Ethernet LANs are drawn as straight lines, with devices attached at right angles; WANs are represented as clouds, indicating that the details have been left out; and wireless connections are drawn as zigzag lines with breaks, indicating that the connection may be intermittent.

In Figure 10-1, a gateway or a router relays messages between each LAN and the Internet. Three of the routers in the Internet are shown (for example, the one closest to each site). Site A has a server, a workstation, a network computer, and a PC sharing a single Ethernet LAN. Site B has an Ethernet LAN that serves a printer and four Linux workstations. A firewall permits only certain traffic to pass between the Internet router and the site's local router. Site C has three LANs linked by a single router, perhaps to reduce the traffic load that would result if the LANs were combined or to keep workgroups or locations on separate networks. Site C also includes a wireless access point that enables wireless communication with nearby computers.

## FIREWALL

A firewall in a car separates the engine compartment from the passenger compartment, protecting the driver and passengers from engine fires, noise, and fumes. In much the same way, computer firewalls separate computers from malicious and unwanted users.

A *firewall* prevents certain types of traffic from entering or leaving a network. For example, a firewall might prevent traffic from your IP address from leaving the network and prevent anyone except users from selected domains from using FTP to retrieve data from the network. The implementations of firewalls vary widely—from Linux machines with two *interfaces* (page 1088) running custom software to a *router* (page 1104) with simple access lists to esoteric, vendor-supplied firewall

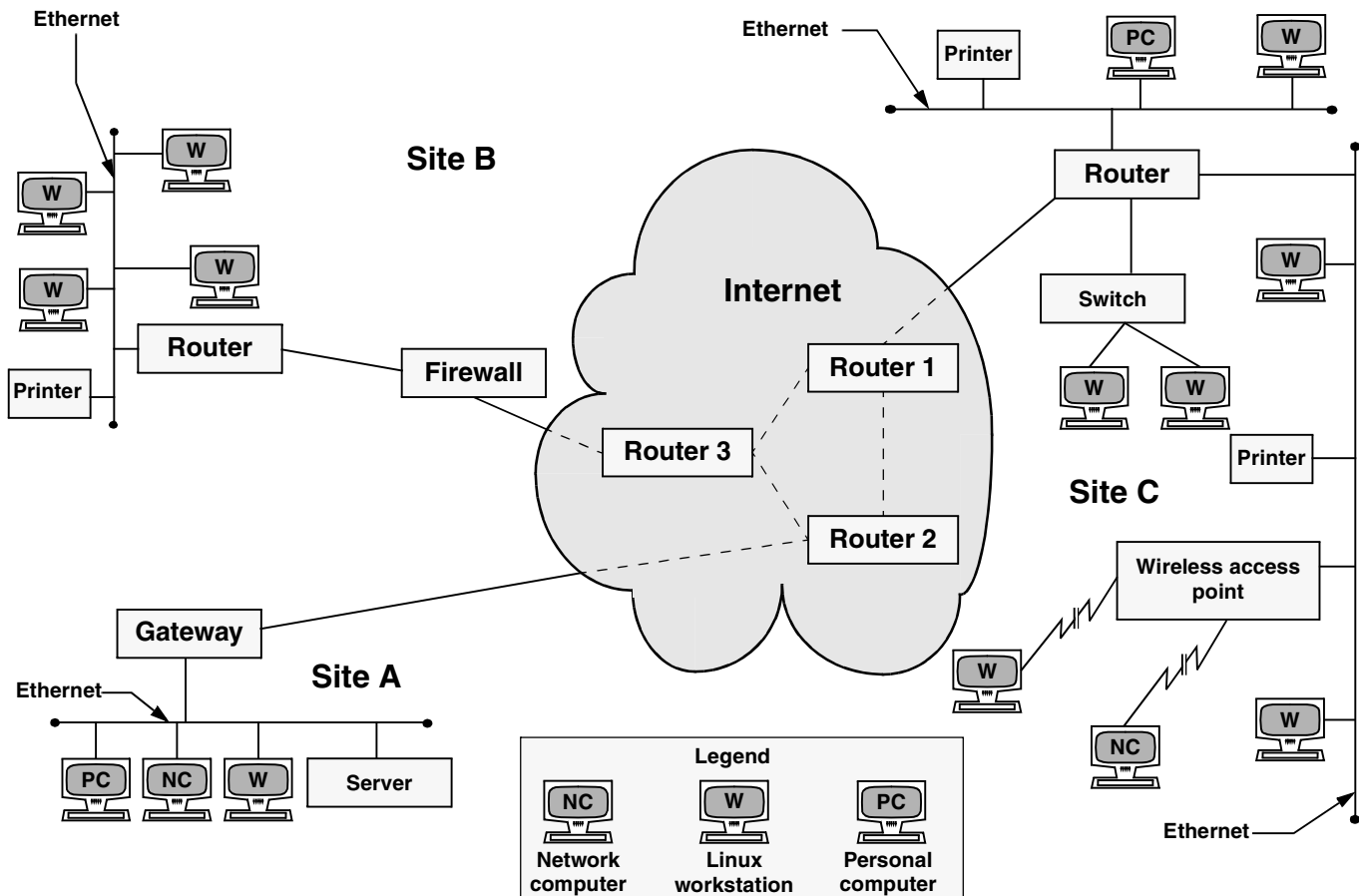


Figure 10-1 A slice of the Internet



appliances. Most larger installations have at least one kind of firewall in place. A firewall is often accompanied by a proxy server/gateway (page 391) that provides an intermediate point between you and the host you are communicating with.

In addition to the firewalls found in multipurpose computers, firewalls are becoming increasingly common in consumer appliances. For example, they are built into cable modems, wireless gateways, routers, and stand-alone devices.

Typically a single Linux machine will include a minimal firewall. A small group of Linux systems may have an inexpensive Linux machine with two network interfaces and packet-filtering software functioning as a dedicated firewall. One of the interfaces connects to the Internet, modems, and other outside data sources. The other connects, normally through a hub or switch, to the local network. Refer to Chapter 25 for information on `iptables` and setting up a firewall and to Appendix C for a discussion of security.

## NETWORK PROTOCOLS

To exchange information over a network, computers must communicate using a common language, or *protocol* (page 1100). The protocol determines the format of message packets. The predominant network protocols used by Linux systems are TCP and IP,<sup>3</sup> collectively referred to as TCP/IP (Transmission Control Protocol and Internet Protocol). Network services that need highly reliable connections, such as `ssh` and `scp`, tend to use TCP/IP. Another protocol used for some system services is UDP (User Datagram Protocol). Network services that do not require guaranteed delivery, such as RealAudio and RealVideo, operate satisfactorily with the simpler UDP.<sup>4</sup>

### IP: INTERNET PROTOCOL

Layering was introduced to facilitate protocol design: Layers distinguish functional differences between adjacent protocols. A grouping of layers can be standardized into a protocol model. IP has a model that distinguishes protocol layers. The IP model differs from the ISO seven-layer protocol model (also called the OSI model) that is often illustrated in networking textbooks. Specifically IP uses the following simplified five-layer model:

1. The first layer of the IP protocol, called the *physical layer*, describes the physical medium (copper, fiber, wireless) and the data encoding used to transmit signals on that medium (pulses of light, electrical waves, or radio waves, for instance).

---

3. All references to IP imply *IPv4* (page 1089).

4. Voice and video protocols are delay sensitive, not integrity sensitive. The human ear and eye accept and interpolate loss in an audio or video stream but cannot deal with variable delay. The guaranteed delivery that TCP provides introduces a delay on a busy network when packets get retransmitted. This delay is not acceptable for video and audio transmissions, whereas less than 100 percent integrity is acceptable.

2. The second layer, called the *data link layer*, covers media access by network devices and describes how to put data into packets, transmit the data, and check it for errors. Ethernet is found at this layer, as is 802.11 (page 1068) wireless.
3. The third layer, called the *network layer*, frequently uses IP and addresses and routes packets.
4. The fourth layer, called the *transport layer*, is where TCP and UDP exist. This layer provides a means for applications to communicate with each other. Functions commonly performed by the transport layer include guaranteed delivery, delivery of packets in the order of their transmission, flow control, error detection, and error correction. The transport layer is responsible for dividing data streams into packets. In addition, this layer performs port addressing, which allows it to distinguish among different services using the same transport protocol. Port addressing keeps the data from multiple applications using the same protocol (for example, TCP) separate.
5. Anything above the transport layer is the domain of the application and is part of the fifth layer. Unlike the ISO model, the Internet model does not distinguish among application, presentation, and session layers. All of the upper-layer characteristics, such as character encoding, encryption, and GUIs, are part of the application. Applications choose the transport characteristics they require as well as the corresponding transport layer protocol with which to send and receive data.

## TCP: TRANSMISSION CONTROL PROTOCOL

TCP is most frequently run on top of IP in a combination referred to as TCP/IP. This protocol provides error recovery and guaranteed delivery in packet transmission order; it also works with multiple ports so that it can handle more than one application. TCP is a *connection-oriented protocol* (page 1076), also known as a stream-based protocol. Once established, a TCP connection looks like a stream of data, not individual IP packets. The connection is assumed to remain up and be uniquely addressable. Every piece of information you write to the connection always goes to the same destination and arrives in the order it was sent. Because TCP is connection oriented and establishes a *virtual circuit* between two systems, this protocol is not suitable for one-to-many transmissions (see the discussion of UDP, following). TCP has builtin mechanisms for dealing with congestion (or flow) control over busy networks and throttles back (slows the speed of data flow) when it has to retransmit dropped packets. TCP can also deal with acknowledgments, wide area links, high-delay links, and other situations.

## UDP: USER DATAGRAM PROTOCOL

UDP runs at layer 4 of the IP stack, just as TCP does, but is much simpler. Like TCP, UDP works with multiple ports and multiple applications. It has checksums for error detection but does not automatically retransmit *datagrams* (page 1078) that fail the

checksum test. UDP is a datagram-oriented protocol: Each datagram must carry its own address and port information. Each router along the way examines each datagram to determine the destination, one hop at a time. You can broadcast or multicast UDP datagrams to many destinations at the same time by using special addresses.

## PPP: POINT-TO-POINT PROTOCOL

PPP provides serial line point-to-point connections that support IP. This protocol compresses data to make the most of the limited bandwidth available on serial connections. PPP, which replaces SLIP<sup>5</sup> (Serial Line IP), acts as a point-to-point layer 2/3 transport that many other types of protocols can ride on. It is used mostly for IP-based services and connections, such as TCP or UDP.

## XREMOTE AND LBX

Two protocols that speed up data transfer over serial lines are Xremote and LBX. Xremote compresses the X Window System protocol so that it is more efficient over slower serial lines. LBX (low-bandwidth X) is based on the Xremote technology and is part of X Window System release X11R6 and higher.

## HOST ADDRESS

Each computer interface is identified by a unique address, or host number, on its network. A system attached to more than one network has multiple interfaces—one for each network, each with a unique address.

Each packet of information that is broadcast over the network has a destination address. All hosts on the network must process each broadcast packet to see whether it is addressed to that host.<sup>6</sup> If the packet is addressed to a given host, that host continues to process it. If not, the host ignores the packet.

The network address of a machine is an IP address, which, under IPv4, is represented as one number broken into four segments separated by periods (for example, 192.168.184.5). Domain names and IP addresses are assigned through a highly distributed system coordinated by ICANN (Internet Corporation for Assigned Names and Numbers—[www.icann.org](http://www.icann.org)) via many registrars (see [www.internic.net](http://www.internic.net)). ICANN is funded by the various domain name registries and registrars and by IP address registries, which supply globally unique identifiers for hosts and services on the Internet. Although you may not deal with any of these agencies directly, your Internet service provider most assuredly does.

How a company uses IP addresses is determined by the system or network administrator. For example, the leftmost two sets of numbers in an IP address might represent

5. SLIP was one of the first serial line implementations of IP and has slightly less overhead than PPP. PPP supports multiple protocols (such as AppleTalk and IPX), whereas SLIP supports only IP.

6. Contrast broadcast packets with unicast packets: Ethernet hardware on a computer filters out unicast packets that are not addressed to that machine; the operating system on that machine never sees these packets.

a large network (campuswide or companywide); the third set, a subnetwork (perhaps a department or a single floor in a building); and the rightmost number, an individual computer. The operating system uses the address in a different, lower-level form, converting it to its binary equivalent, a series of 1s and 0s. See the following optional section for more information. Refer to “Private address space” on page 598 for information about addresses you can use on a LAN without registering them.

## STATIC VERSUS DYNAMIC IP ADDRESSES

A static IP address is one that always remains the same. A dynamic IP address is one that can change each time you connect to the network. A dynamic address remains the same during a single login session. Any server (mail, Web, and so on) must have a static address so clients can find the machine that is acting as the server. End-user systems usually work well with dynamic addresses. During a given login session, they can function as a client (your Web browser, for example) because they maintain a constant IP address. When you log out and log in again, it does not matter that you have a different IP address because your computer, acting as a client, establishes a new connection with a server. The advantage of dynamic addressing is that it allows inactive addresses to be reused, reducing the total number of IP addresses needed.

### optional IP CLASSES

To facilitate routing on the Internet, IP addresses are divided into *classes*. These classes, which are labeled class A through class E, allow the Internet address space to be broken into blocks of small, medium, and large networks that are designed to be assigned based on the number of hosts within a network.

When you need to send a message to an address outside the local network, your system looks up the address block/class in its routing table and sends the message to the next router on the way to the final destination. Every router along the way does a similar lookup and forwards the message accordingly. At the destination, local routers direct the message to the specific address. Without classes and blocks, your host would have to know every network and subnetwork address on the Internet before it could send a message. This setup would be impractical because of the huge number of addresses on the Internet.

Each of the four numbers in the IP address is in the range 0–255 because each segment of the IP address is represented by 8 bits (an *octet*), with each bit being capable of taking on two values; the total number of values is therefore  $2^8 = 256$ . When you start counting at 0, the range 1–256 becomes 0–255.<sup>7</sup> Each IP address is divided into a net address (*netid*) portion, which is part of the class, and a host address (*hostid*) portion. See Table 10-2.

7. Internally, the IP address is represented as a set of four unsigned 8-bit fields or a 32-bit unsigned number, depending on how programs are using it. The most common format in C is to represent it as a union of an unsigned 32-bit long integer, four unsigned chars, and two unsigned short integers.

**Table 10-2** IP classes

| Class               | Start bits | Address range                   | All bits (including start bits) |                  |       |       |
|---------------------|------------|---------------------------------|---------------------------------|------------------|-------|-------|
|                     |            |                                 | 0–7                             | 8–15             | 16–23 | 24–31 |
| Class A             | 0          | 001.000.000.000–126.000.000.000 | 0-netid                         | =====hostid===== |       |       |
| Class B             | 10         | 129.000.000.000–191.255.000.000 | 10----netid----                 | =====hostid===== |       |       |
| Class C             | 110        | 192.000.000.000–223.255.255.000 | 110-----netid-----              | =hostid=         |       |       |
| Class D (multicast) | 1110       | 224.000.000.000–239.255.255.000 | 1110                            |                  |       |       |
| Class E (reserved)  | 11110      | 240.000.000.000–255.255.255.000 | 11110                           |                  |       |       |

The first set of addresses, defining class A networks, is reserved for extremely large corporations, such as General Electric (3.0.0.0) and Hewlett-Packard (15.0.0.0), and for ISPs. One start bit (0) in the first position designates a class A network, 7 bits holds the network portion of the address (netid), and 24 bits holds the host portion of the address (hostid; see Table 10-2). This setup means that GE can have  $2^{24}$ , or approximately 16 million, hosts on its network. Unused address space and *subnets* (page 1109) lower this number quite a bit. The 127.0.0.0 subnet (page 373) is reserved, as are several others (see *private address space* on page 1100).

Two start bits (10) in the first two positions designates a class B network, 14 bits holds the network portion of the address (netid), and 16 bits holds the host portion of the address, for a potential total of 65,534 hosts.<sup>8</sup> A class C network uses 3 start bits (100), 21 netid bits (2 million networks), and 8 hostid bits (254 hosts). Today a new large customer will not receive a class A or B network but is likely to receive a class C or several (usually contiguous) class C networks, if merited.

Several other classes of networks exist. Class D networks are reserved for *multicast* (page 1095) networks. When you run **netstat -nr** on a Linux system, you can see whether the machine is a member of a multicast network. A 224.0.0.0 in the Destination column that **netstat** displays indicates a class D, multicast address (Table 10-2). A multicast is like a broadcast, but only hosts that subscribe to the

8. A 16-bit (class B) address can address  $2^{16} = 65,536$  hosts, yet the potential number of hosts is two fewer than that because the first and last addresses on any network are reserved. In a similar manner, an 8-bit (class C) address can address only 254 hosts ( $2^8 - 2 = 254$ ). The 0 host address (for example, 194.16.100.0 for a class C network or 131.204.0.0 for a class B network) is reserved as a designator for the network itself. Several older operating systems use this as a broadcast address. The 255 host address (for example, 194.16.100.255 for a class C network or 131.204.255.255 for a class B network) is reserved as the IP broadcast address. An IP packet (datagram) that is sent to this address is broadcast to all hosts on the network.

The netid portion of a subnet does not have the same limitations. Often you are given the choice of reserving the first and last networks in a range as you would a hostid, but this is rarely done in practice. More often the first and last networks in the netid range provide more usable address space. Refer to “Subnets” on page 371.

multicast group receive the message. To use Web terminology, a broadcast is like a “push.” A host pushes a broadcast on the network, and every host on the network must check each packet to see whether it contains relevant data. A multicast is like a “pull.” A host will see a multicast only if it registers itself as subscribed to a multicast group or service and pulls the appropriate packets from the network.

Table 10-3 shows some of the computations for the IP address 131.204.027.027. Each address is shown in decimal, hexadecimal, and binary form. Binary is the easiest to work with for bitwise (binary) computations. The first three lines show the IP address. The next three lines show the *subnet mask* (page 1109) in three bases. Next the IP address and the subnet mask are ANDed together bitwise to yield the *subnet number* (page 1109), which is shown in three bases. The last three lines show the *broadcast address* (page 1072), which is computed by taking the subnet number and turning the hostid bits to 1s. The subnet number identifies the local network. The subnet number and the subnet mask determine what range the IP address of the machine must be in. They are also used by routers to segment traffic; see *network segment* (page 1096). A broadcast on this network goes to all hosts in the range 131.204.27.1 through 131.204.27.254 but will be acted on only by hosts that have a use for it.

**Table 10-3**    Computations for IP address 131.204.027.027

|                                           | -----Class B----- |           | netid     | hostid    |             |
|-------------------------------------------|-------------------|-----------|-----------|-----------|-------------|
| IP address                                | 131               | .204      | .027      | .027      | decimal     |
|                                           | 83                | CC        | 1B        | 1B        | hexadecimal |
|                                           | 1000 0011         | 1100 1100 | 0001 1011 | 0001 1011 | binary      |
| Subnet mask                               | 255               | .255      | .255      | .000      | decimal     |
|                                           | FF                | FF        | FF        | 00        | hexadecimal |
|                                           | 1111 1111         | 1111 1111 | 1111 1111 | 0000 0000 | binary      |
| IP address bitwise AND                    | 1000 0011         | 1100 1100 | 0001 1011 | 0001 1011 |             |
| Subnet mask                               | 1111 1111         | 1111 1111 | 1111 1111 | 0000 0000 | binary      |
| = Subnet number                           | 1000 0011         | 1100 1100 | 0001 1011 | 0000 0000 |             |
| Subnet number                             | 131               | .204      | .027      | .000      | decimal     |
|                                           | 83                | CC        | 1B        | 00        | hexadecimal |
|                                           | 1000 0011         | 1100 1100 | 0001 1011 | 0000 0000 | binary      |
| Broadcast address<br>(set host bits to 1) | 131               | .204      | .27       | .255      | decimal     |
|                                           | 83                | CC        | 1B        | FF        | hexadecimal |
|                                           | 1000 0011         | 1100 1100 | 0001 1011 | 1111 1111 | binary      |

## SUBNETS

Each host on a network must process each broadcast packet to determine whether the information in the packet is useful to that host. If the network includes numerous hosts, each host must process many packets. To maintain efficiency—most networks, and particularly shared media networks such as Ethernet—need to be split into subnetworks, or *subnets*.<sup>9</sup> The more hosts on a network, the more dramatically network performance is affected. Organizations use router and switch technology called VLANs (virtual local area networks) to group similar hosts into broadcast domains (subnets) based on function. For example, it is not uncommon to see a switch with different ports being part of different subnets. See page 443 for information on how to specify a subnet.

A *subnet mask* (or *address mask*) is a bit mask that identifies which parts of an IP address correspond to the network address and the subnet portion of the address. This mask has 1s in positions corresponding to the network and subnet numbers and 0s in the host number positions. When you perform a bitwise AND on an IP address and a subnet mask (Table 10-3), the resulting address contains everything except the host address (hostid) portion.

There are several ways to represent a subnet mask: A network could have a subnet mask of 255.255.255.0 (decimal), FFFFFFF0 (hexadecimal), or /24 (the number of bits used for the subnet mask). If it were a class B network (of which 16 bits are already fixed), this yields  $2^8$  (24 total bits – 16 fixed bits = 8 bits,  $2^8 = 256$ ) networks<sup>10</sup> with  $2^8 - 2$  ( $256 - 2 = 254$ ) hosts<sup>11</sup> on each network.

For example, when you divide the class C address 192.25.4.0 into eight subnets, you get a subnet mask of 255.255.255.224, FFFFFFFE0, or /27 (27 1s). The eight resultant networks are 192.25.4.0, 192.25.4.32, 192.25.4.64, 192.25.4.96, 192.25.4.128, 192.25.4.160, 192.25.4.192, and 192.25.4.224. You can use a Web-based subnet mask calculator to calculate subnet masks (refer to “Network Calculators” on page 1039). To use this calculator to determine the preceding subnet mask, start with an IP host address of 192.25.4.0.

## CIDR: CLASSLESS INTER-DOMAIN ROUTING

CIDR (pronounced “cider”) allows groups of addresses that are smaller than a class C block to be assigned to an organization or ISP and then further subdivided and parceled out. In addition, it helps to alleviate the potential problem of routing tables on major Internet backbone and peering devices becoming too large to manage.

9. Splitting a network is also an issue with other protocols, particularly AppleTalk.

10. The first and last networks are reserved in a manner similar to the first and last hosts, although the standard is flexible. You can configure routers to reclaim the first and last networks in a subnet. Different routers have different techniques for reclaiming these networks.

11. Subtract 2 because the first and last host addresses on every network are reserved.

The pool of available IPv4 addresses has been depleted to the point that no one gets a class A address anymore. The trend is to reclaim these huge address blocks, if possible, and recycle them into groups of smaller addresses. Also, as more class C addresses are assigned, routing tables on the Internet are filling up and causing memory overflows. The solution is to aggregate<sup>12</sup> groups of addresses into blocks and allocate them to ISPs, which in turn subdivide these blocks and allocate them to their customers. The address class designations (A, B, and C) described in the previous section are used less often today, although you may still encounter subnets. When you request an address block, your ISP usually gives you as many addresses as you need—and no more. The ISP aggregates several contiguous smaller blocks and routes them to your location. This aggregation is CIDR. Without CIDR, the Internet as we know it would not function.

For example, you might be allocated the 192.168.5.0/22 IP address block, which could support  $2^{10}$  hosts ( $32 - 22 = 10$ ). Your ISP would set its routers so that any packets going to an address in that block would be sent to your network. Internally, your own routers might further subdivide this block of 1,024 potential hosts into subnets, perhaps into four networks. Four networks require an additional two bits of addressing ( $2^2 = 4$ ). You could therefore set up your router to support four networks with this allocation: 192.168.5.0/24, 192.168.6.0/24, 192.168.7.0/24, and 192.168.8.0/24. Each of these networks could then have 254 hosts. CIDR lets you arbitrarily divide networks and subnetworks into increasingly smaller blocks along the way. Each router has enough memory to keep track of the addresses it needs to direct and aggregates the rest.

This scheme uses memory and address space efficiently. For example, you could take 192.168.8.0/24 and further divide it into 16 networks with 14 hosts each. The 16 networks require four more bits ( $2^4 = 16$ ), so you would have 192.168.8.0/28, 192.168.8.16/28, 192.168.8.32/28, and so on, up through the last subnet of 192.168.8.240/28, which would have the hosts 192.168.8.241 through 192.168.8.254.

## HOSTNAMES

People generally find it easier to work with names than with numbers, so Linux provides several ways to associate hostnames with IP addresses. The oldest method is to consult a list of names and addresses that are stored in the `/etc/hosts` file:

```
$ cat /etc/hosts
127.0.0.1    localhost
130.128.52.1 gw-example.example.com gw-example
130.128.52.2 bravo.example.com  bravo
130.128.52.3 hurrah.example.com  hurrah
130.128.52.4 kudos.example.com   kudos
```

---

12. *Aggregate* means to join. In CIDR, the aggregate of 208.178.99.124 and 208.178.99.125 is 208.178.99.124/23 (the aggregation of two class C blocks).



**localhost = 127.0.0.1** The address 127.0.0.1 is reserved for the special hostname **localhost**, which serves as a hook for the system's networking software to operate on the local machine without going onto a physical network. The names of the other systems are shown in two forms: in a *fully qualified domain name* (FQDN) format that is unique on the Internet and as a nickname that is locally unique.

**NIS** As more hosts joined networks, storing these name-to-address mappings in a text file proved to be inefficient and inconvenient. The **hosts** file grew increasingly larger and became impossible to keep up-to-date. To solve this problem Linux supports NIS (Network Information Service, page 387), which was developed for use on Sun computers. NIS stores information in a database, making it easier to find a specific address, but it is useful only for host information within a single administrative domain. Hosts outside the domain cannot access the information.

**DNS** The solution to this dilemma is DNS (Domain Name Service, page 385). DNS effectively addresses the efficiency and update issues by arranging the entire network *namespace* (page 1095) as a hierarchy. Each domain in the DNS manages its own namespace (addressing and name resolution), and each domain can easily query for any host or IP address by following the tree up or down the namespace until it finds the appropriate domain. By providing a hierarchical naming structure, DNS distributes name administration across the entire Internet.

## IPv6

The explosive growth of the Internet has uncovered deficiencies in the design of the current address plan—most notably the shortage of addresses. Over the next few years, a revised protocol, named IPng (IP Next Generation), also known as IPv6 (IP version 6),<sup>13</sup> will be phased in. (It may take longer—the phase-in is going quite slowly.) This new scheme is designed to overcome the major limitations of the current approach and can be implemented gradually because it is compatible with the existing address usage. IPv6 makes it possible to assign many more unique Internet addresses ( $2^{128}$ , or 340 *undecillion* [ $10^{36}$ ]). It also supports more advanced security and performance control features:

- IPv6 enables autoconfiguration. With IPv4, autoconfiguration is available using optional DHCP (page 451). With IPv6, autoconfiguration is mandatory, making it easy for hosts to configure their IP addresses automatically.
- IPv6 reserves 24 bits in the header for advanced services, such as resource reservation protocols, better backbone routing, and improved traffic engineering.
- IPv6 makes multicast protocols mandatory and uses them extensively. In IPv4, multicast, which improves scalability, is optional.

---

13. IPv5 referred to an experimental real-time stream protocol named ST—thus the jump from IPv4 to IPv6.

- IPv6 aggregates address blocks more efficiently because of the huge address space. This aggregation makes obsolete NAT (page 1095), which decreased scalability and introduced protocol issues.
- IPv6 provides a simplified packet header that allows hardware accelerators to work better.

A sample IPv6 address is `fe80::a00:20ff:feff:5be2/10`. Each group of four hexadecimal digits is equivalent to a number between 0 and 65,536 ( $16^4$ ). A pair of adjacent colons indicates a hex value of `0x0000`; leading 0s need not be shown. With eight sets of hexadecimal groupings,  $65,536^8 = 2^{128}$  addresses are possible. In an IPv6 address on a host with the default autoconfiguration, the first characters in the address are always `fe80`. The last 64 bits hold an interface ID designation, which is often the *MAC address* (page 1092) of the system's Ethernet controller.

---

## COMMUNICATE OVER A NETWORK

Many commands that you can use to communicate with other users on a single computer system have been extended to work over a network. Examples of extended utilities include electronic mail programs, information-gathering utilities (such as `finger`, page 169), and communications utilities (such as `talk`). These utilities are examples of the UNIX philosophy: Instead of creating a new, special-purpose tool, modify an existing one.

Many utilities understand a convention for the format of network addresses: **user@host** (spoken as “user at host”). When you use an `@` sign in an argument to one of these utilities, the utility interprets the text that follows as the name of a remote host. When you omit the `@` sign, a utility assumes that you are requesting information from or corresponding with someone on the local system.

The prompts shown in the examples in this chapter include the hostname of the system you are using. If you frequently use more than one system over a network, you may find it difficult to keep track of which system you are interacting with at any particular moment. If you set your prompt to include the hostname of the current system, it will always be clear which system you are using. To identify the computer you are using, run `hostname` or `uname -n`:

```
$ hostname
kudos
```

See page 307 for information on how you can change the prompt.

## finger: DISPLAYS INFORMATION ABOUT REMOTE USERS

The `finger` utility displays information about one or more users on a system. This utility was designed for local use, but when networks became popular, it was obvious that `finger` should be enhanced to reach out and collect information remotely. In the following examples, `finger` displays information about all users logged in on the system named **bravo**:

```
[kudos]$ finger @bravo
[bravo.example.com]
Login      Name                Tty  Idle  Login Time   Office   Office Phone
root       root                *1   1:35  Oct 22  5:00
alex       Alex Watson         4           Oct 22 12:23 (kudos)
alex       Alex Watson         5      19  Oct 22 12:33 (:0)
jenny      Jenny Chen          7     2:24  Oct 22  8:45 (:0)
hls        Helen Simpson       11     2d  Oct 20 12:23 (:0)
```

A user's username in front of the @ sign causes `finger` to display information from the remote system for the specified user only. If the remote system has multiple matches for that name, `finger` displays the results for all of them:

```
[kudos]$ finger alex@bravo
[bravo.example.com]
Login      Name                Tty  Idle  Login Time   Office   Office Phone
alex       Alex Watson         4           Oct 22 12:23 (kudos)
alex       Alex Watson         5      19  Oct 22 12:33 (:0)
```

The `finger` utility works by querying a standard network service, the **in.fingerd** daemon, that runs on the system being queried. Although this service is supplied with Fedora/RHEL, some sites choose not to run it to minimize the load on their systems, reduce security risks, or maintain privacy. When you use `finger` to obtain information about someone at such a site, you will see an error message or nothing at all. The remote **in.fingerd** daemon determines how much information to share and in what format. As a result, the report displayed for any given system may differ from that shown in the preceding examples.

### The in.fingerd daemon

**security** The `finger` daemon (**in.fingerd**; part of the **finger-server** package), which is not installed by default, gives away system account information that can aid a malicious user. Some sites disable or remove `finger` or randomize user account IDs to make a malicious user's job more difficult. Disable `finger` by removing the **finger-server** package.

The information for remote `finger` looks much the same as it does when `finger` runs on the local system, with one difference: Before displaying the results, `finger` reports the name of the remote system that answered the query (**bravo**, as shown in brackets in the preceding example). The name of the host that answers may be different from the system name you specified on the command line, depending on how the `finger` daemon service is configured on the remote system. In some cases, several hostnames may be listed if one `finger` daemon contacts another to retrieve the information.

## SENDING MAIL TO A REMOTE USER

Given a user's username on a remote system and the name of the remote system or its domain, you can use an email program to send a message over the network or the Internet, using the @ form of an address:

```
jenny@bravo
```

or

```
jenny@example.com
```

Although many Linux utilities recognize the @ form of a network address, you may find that you can reach more remote computers with email than with the other networking utilities described in this chapter. This disparity arises because the email system can deliver a message to a host that does not run IP, even though it appears to have an Internet address. The message may be routed over the network, for example, until it reaches a remote system that has a point-to-point, dial-up connection to the destination system. Other utilities, such as `talk`, rely on IP and operate only between networked hosts.

## MAILING LIST SERVERS

A mailing list server (`listserv`<sup>14</sup>) allows you to create and manage an email list. An electronic mailing list provides a means for people interested in a particular topic to participate in an electronic discussion and for a person to disseminate information periodically to a potentially large mailing list. One of the most powerful features of most list servers is their ability to archive email postings to the list, create an archive index, and allow users to retrieve postings from the archive based on keywords or discussion threads. Typically you can subscribe and unsubscribe from the list with or without human intervention. The owner of the list can restrict who can subscribe, unsubscribe, and post messages to the list. Popular list servers include `LISTSERV` ([www.lsoft.com](http://www.lsoft.com)), `ListProc` ([sourceforge.net/projects/listproc](http://sourceforge.net/projects/listproc)), `Lyris` ([www.lyris.com](http://www.lyris.com)), `Majordomo` ([www.greatcircle.com/majordomo](http://www.greatcircle.com/majordomo)), and `Mailman` ([www.list.org](http://www.list.org), page 688). Red Hat maintains quite a few mailing lists and list archives for those mailing lists at [www.redhat.com/mailman/listinfo](http://www.redhat.com/mailman/listinfo). Use Google to search on **linux mailing list** to find other lists.

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## NETWORK UTILITIES

To realize the full benefits of a networked environment, it made sense to extend certain tools, some of which have already been described. The advent of networks also created a need for new utilities to control and monitor them, spurring the development of new tools that took advantage of network speed and connectivity. This section describes concepts and utilities for systems attached to a network.

## TRUSTED HOSTS

Some commands, such as `rcp` and `rsh`, work only if the remote system trusts your local computer (that is, if the remote system knows your local computer and believes that it is not pretending to be another system). The `/etc/hosts.equiv` file lists trusted systems. For reasons of security, the Superuser account does not rely on this file to identify trusted Superusers from other systems.

---

14. Although the term *listserv* is sometimes used generically to include many different list server programs, it is a specific product and a registered trademark of L-soft International, Inc.: `LISTSERV` (for more information go to [www.lsoft.com](http://www.lsoft.com)).

Host-based trust is largely obsolete. Because there are many ways to circumvent trusted host security, including subverting DNS systems and *IP spoofing* (page 1089), authentication based on IP address is widely regarded as insecure and obsolete. In a small homogeneous network of machines with local DNS control, it can be “good enough.” Its greater ease of use in these situations may outweigh the security concerns.

### Do not share your login account

**security** You can use a **.rhosts** file to allow another user to log in as you from a remote system without knowing your password. *This setup is not recommended.* Do not compromise the security of your files or the entire system by sharing your login account. Use **ssh** and **scp** instead of **rsh** and **rcp** whenever possible.

## OPENSASH TOOLS

The OpenSSH project provides a set of tools that replace **rcp**, **rsh**, and others with secure equivalents. These tools are installed by default in Fedora/RHEL and can be used as drop-in replacements for their insecure counterparts. The OpenSSH tool suite is covered in detail in Chapter 18.

## telnet: LOGS IN ON A REMOTE SYSTEM

You can use the TELNET protocol to interact with a remote computer. The **telnet** utility, a user interface to this protocol, is older than **ssh** and is not secure. Nevertheless, it may work where **ssh** (page 627) is not available (there is more non-UNIX support for TELNET access than for **ssh** access). In addition, many legacy devices, such as terminal servers and network devices, do not support **ssh**.

```
[bravo]$ telnet kudos
Trying 172.19.52.2...
Connected to kudos.example.com
Escape character is '^['.

Welcome to SuSE Linux 7.3 (i386) - Kernel 2.4.10-4GB (2).
kudos login: watson
Password:
You have old mail in /var/mail/watson.
Last login: Mon Feb 27 14:46:55 from bravo.example.com
watson@kudos:~>
...
watson@kudos:~> logout
Connection closed by foreign host.
[bravo]$
```

**telnet versus ssh** When you connect to a remote UNIX or Linux system using **telnet**, you are presented with a regular, textual **login:** prompt. Unless you specify differently, the **ssh** utility assumes that your username on the remote system matches that on the local system. Because **telnet** is designed to work with non-UNIX and non-Linux systems, it makes no such assumptions.

## telnet is not secure

**security** Whenever you enter sensitive information, such as your password, while you are using `telnet`, it is transmitted in cleartext and can be read by someone who is listening in on the session.

---

Another difference between these two utilities is that `telnet` allows you to configure many special parameters, such as how `RETURNS` or interrupts are processed. When using `telnet` between UNIX and/or Linux systems, you rarely need to change any parameters.

When you do not specify the name of a remote host on the command line, `telnet` runs in an interactive mode. The following example is equivalent to the previous `telnet` example:

```
[bravo]$ telnet
telnet> open kudos
Trying 172.19.52.2...
Connected to kudos.example.com
Escape character is '^]'.
...
```

Before connecting you to a remote system, `telnet` tells you what the *escape character* is; in most cases, it is `^]` (where `^` represents the `CONTROL` key). When you press `CONTROL-]`, you escape to `telnet`'s interactive mode. Continuing the preceding example:

```
[kudos]$ CONTROL-]
telnet> ?
```

*(displays help information)*

```
telnet> close
Connection closed.
[bravo]$
```

When you enter a question mark in response to the `telnet>` prompt, `telnet` lists its commands. The `close` command ends the current `telnet` session, returning you to the local system. To get out of `telnet`'s interactive mode and resume communication with the remote system, press `RETURN` in response to a prompt.

You can use `telnet` to access special remote services at sites that have chosen to make such services available. However, many of these services, such as the U.S. Library of Congress Information System (LOCIS), have moved to the Web. As a consequence, you can now obtain the same information using a Web browser.

## USING telnet TO CONNECT TO OTHER PORTS

By default `telnet` connects to port 23, which is used for remote logins. However, you can use `telnet` to connect to other services by specifying a port number. In addition to standard services, many of the special remote services available on the Internet use unallocated port numbers. For example, you can access some multi-player text games, called MUDs (Multi-User Dungeons, or Dimensions), using `telnet` to connect to a specified port, such as 4000 or 8888. Unlike the port numbers

for standard protocols, these port numbers can be picked arbitrarily by the administrator of the game.

While `telnet` is no longer commonly employed to log in on remote systems, it is still used extensively as a debugging tool. This utility allows you to communicate directly with a TCP server. Some standard protocols are simple enough that an experienced user can debug problems by connecting to a remote service directly using `telnet`. If you are having a problem with a network server, a good first step is to try to connect to it using `telnet`.

In the following example, a system administrator who is debugging a problem with email delivery uses `telnet` to connect to the SMTP port (port 25) on a the server at **example.com** to see why it is bouncing mail from the **spammer.com** domain. The first line of output indicates which IP address `telnet` is trying to connect to. After `telnet` displays the **Connected to smtpsrv.example.com** message, the user emulates an SMTP dialog, following the standard SMTP protocol. The first line, which starts with **helo**, begins the session and identifies the local system. After the SMTP server responds, the user enters a line that identifies the mail sender as **user@spammer.com**. The SMTP server's response explains why the message is bouncing, so the user ends the session with **quit**.

```
$ telnet smtpsrv 25
Trying 192.168.1.1...
Connected to smtpsrv.example.com.
Escape character is '^]'.
helo example.com
220 smtpsrv.example.com ESMTP Sendmail 8.13.1/8.13.1; Sun, 4 May 2008 00:13:43 -0500 (CDT)
250 smtpsrv.example.com Hello desktop.example.com [192.168.1.97], pleased to meet you
mail from:user@spammer.com
571 5.0.0 Domain banned for spamming
quit
221 2.0.0 smtpsrv.example.com closing connection
```

The `telnet` utility allows you to use any protocol you want, as long as you know it well enough to type commands manually.

## ftp: TRANSFERS FILES OVER A NETWORK

The File Transfer Protocol (FTP) is a method of downloading files from and uploading files to another system using TCP/IP over a network. FTP is not a secure protocol; use it only for downloading public information from a public server. Most Web browsers can download files from FTP servers. Chapter 19 covers FTP clients and servers.

## ping: TESTS A NETWORK CONNECTION

The `ping`<sup>15</sup> utility (<http://ftp.arl.mil/~mike/ping.html>) sends an ECHO\_REQUEST packet to a remote computer. This packet causes the remote system to send back a

---

15. The name `ping` mimics the sound of a sonar burst used by submarines to identify and communicate with each other. The word `ping` also expands to packet internet groper.

reply. This exchange is a quick way to verify that a remote system is available and to check how well the network is operating, such as how fast it is or whether it is dropping data packets. The `ping` utility uses the ICMP (Internet Control Message Protocol) protocol. Without any options, `ping` tests the connection once per second until you abort execution with `CONTROL-C`.

```
$ ping tsx-11.mit.edu
PING tsx-11.mit.edu (18.7.14.121) 56(84) bytes of data.
64 bytes from TSX-11.MIT.EDU (18.7.14.121): icmp_seq=0 ttl=45 time=97.2 ms
64 bytes from TSX-11.MIT.EDU (18.7.14.121): icmp_seq=1 ttl=45 time=96.1 ms
64 bytes from TSX-11.MIT.EDU (18.7.14.121): icmp_seq=2 ttl=45 time=95.7 ms
64 bytes from TSX-11.MIT.EDU (18.7.14.121): icmp_seq=3 ttl=45 time=96.3 ms
CONTROL-C

--- tsx-11.mit.edu ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3001ms
rtt min/avg/max/mdev = 95.755/96.361/97.202/0.653 ms
```

This example shows that the remote system named **tsx-11.mit.edu** is up and available over the network.

By default `ping` sends packets containing 64 bytes (56 data bytes and 8 bytes of protocol header information). In the preceding example, four packets were sent to the system **tsx-11.mit.edu** before the user interrupted `ping` by pressing `CONTROL-C`. The four-part number in parentheses on each line is the remote system's IP address. A packet sequence number (called `icmp_seq`) is also given. If a packet is dropped, a gap occurs in the sequence numbers. The round-trip time is listed last; it represents the time (in milliseconds) that elapsed from when the packet was sent from the local system to the remote system until the reply from the remote system was received by the local system. This time is affected by the distance between the two systems, network traffic, and the load on both computers. Before it terminates, `ping` summarizes the results, indicating how many packets were sent and received as well as the minimum, average, maximum, and mean deviation round-trip times it measured. Use `ping6` to test IPv6 networks.

### When ping cannot connect

**tip** If it is unable to contact the remote system, `ping` continues trying until you interrupt it with `CONTROL-C`. A system may not answer for any of several reasons: The remote computer may be down, the network interface or some part of the network between the systems may be broken, a software failure may have occurred, or the remote machine may be set up, for reasons of security, not to return pings (try pinging [www.microsoft.com](http://www.microsoft.com) or [www.ibm.com](http://www.ibm.com)).

---

## traceroute: TRACES A ROUTE OVER THE INTERNET

The `traceroute` utility traces the route that an IP packet follows, including all intermediary points traversed (called *network hops*), to its destination (the argument to `traceroute`—an Internet host). It displays a numbered list of hostnames, if available, and IP addresses, together with the round-trip time it took for a packet to reach each



router along the way and an acknowledgment to get back. You can put this information to good use when you are trying to identify the location of a network bottleneck.

The `traceroute` utility has no concept of the path from one host to the next; instead, it simply sends out packets with increasing *TTL* (time to live) values. *TTL* is an IP header field that indicates how many more hops the packet should be allowed to make before being discarded or returned. In the case of a `traceroute` packet, the packet is returned by the host that has the packet when the *TTL* value is zero. The result is a list of hosts that the packet traveled through to get to its destination.

The `traceroute` utility can help you solve routing configuration problems and locate routing path failures. When you cannot reach a host, use `traceroute` to discover what path the packet follows, how far it gets, and what the delay is.

The next example shows the output of `traceroute` when it follows a route from a local computer to **www.linux.org**. The first line indicates the IP address of the target, the maximum number of hops that will be traced, and the size of the packets that will be used. Each numbered line contains the name and IP address of the intermediate destination, followed by the time it takes a packet to make a trip to that destination and back again. The `traceroute` utility sends three packets to each destination; thus three times appear on each line. Line 1 shows the statistics when a packet is sent to the local gateway (less than 3 milliseconds). Lines 4–6 show the packet bouncing around Mountain View (California) before it goes to San Jose. Between hops 13 and 14 the packet travels across the United States (San Francisco to somewhere in the East). By hop 18 the packet has found **www.linux.org**. The `traceroute` utility displays asterisks when it does not receive a response. Each asterisk indicates that `traceroute` has waited three seconds. Use `traceroute6` to test IPv6 networks.

```
$ /usr/sbin/traceroute www.linux.org
traceroute to www.linux.org (198.182.196.56), 30 hops max, 38 byte packets
 1 gw.localco.com. (204.94.139.65)  2.904 ms  2.425 ms  2.783 ms
 2 covad-gw2.meer.net (209.157.140.1) 19.727 ms 23.287 ms 24.783 ms
 3 gw-mv1.meer.net (140.174.164.1) 18.795 ms 24.973 ms 19.207 ms
 4 d1-4-2.a02.mtvwca01.us.ra.verio.net (206.184.210.241) 59.091 ms d1-10-0-0-200.a03.
   mtvwca01.us.ra.verio.net (206.86.28.5) 54.948 ms 39.485 ms
 5 fa-11-0-0.a01.mtvwca01.us.ra.verio.net (206.184.188.1) 40.182 ms 44.405 ms 49.362 ms
 6 pl-1-0-0.a09.mtvwca01.us.ra.verio.net (205.149.170.66) 78.688 ms 66.266 ms 28.003 ms
 7 pl-12-0-0.a01.snjsca01.us.ra.verio.net (209.157.181.166) 32.424 ms 94.337 ms 54.946 ms
 8 f4-1-0.sjc0.verio.net (129.250.31.81) 38.952 ms 63.111 ms 49.083 ms
 9 sjc0.nuq0.verio.net (129.250.3.98) 45.031 ms 43.496 ms 44.925 ms
10 mae-west1.US.CRL.NET (198.32.136.10) 48.525 ms 66.296 ms 38.996 ms
11 t3-ames.3.sfo.us.crl.net (165.113.0.249) 138.808 ms 78.579 ms 68.699 ms
12 E0-CRL-SFO-02-E0X0.US.CRL.NET (165.113.55.2) 43.023 ms 51.910 ms 42.967 ms
13 sfo2-vva1.ATM.us.crl.net (165.113.0.254) 135.551 ms 154.606 ms 178.632 ms
14 mae-east-02.ix.ai.net (192.41.177.202) 158.351 ms 201.811 ms 204.560 ms
15 oc12-3-0-0.mae-east.ix.ai.net (205.134.161.2) 202.851 ms 155.667 ms 219.116 ms
16 border-ai.invlogic.com (205.134.175.254) 214.622 ms * 190.423 ms
17 router.invlogic.com (198.182.196.1) 224.378 ms 235.427 ms 228.856 ms
18 www.linux.org (198.182.196.56) 207.964 ms 178.683 ms 179.483 ms
```

## host AND dig: QUERY INTERNET NAMESERVERS

The `host` utility looks up an IP address given a name, or vice versa. The following example shows how to use `host` to look up the domain name of a machine, given an IP address:

```
$ host 64.13.141.6
6.141.13.64.in-addr.arpa domain name pointer ns.meer.net.
```

You can also use `host` to determine the IP address of a domain name:

```
$ host ns.meer.net
ns.meer.net. has address 64.13.141.6
```

The `dig` (domain information groper) utility queries DNS servers and individual machines for information about a domain. A powerful utility, `dig` has many features that you may never use. It is more complex than `host`.

Chapter 24 on DNS has many examples of the use of `host` and `dig`.

## jwhois: LOOKS UP INFORMATION ABOUT AN INTERNET SITE

The `jwhois` utility replaces `whois` and queries a `whois` server for information about an Internet site. This utility returns site contact and InterNIC or other registry information that can help you track down the person who is responsible for a site: Perhaps that person is sending you or your company *spam* (page 1107). Many sites on the Internet are easier to use and faster than `jwhois`. Use a browser and search engine to search on `whois` or go to [www.networksolutions.com/whois](http://www.networksolutions.com/whois) or [www.ripe.net/perl/whois](http://www.ripe.net/perl/whois) to get started.

When you do not specify a `whois` server, `jwhois` defaults to `whois.internic.net`. Use the `-h` option to `jwhois` to specify a different `whois` server. See the `jwhois` info page for more options and setup information.

To obtain information on a domain name, specify the complete domain name, as in the following example:

```
$ jwhois sobell.com
[Querying whois.internic.net]
[Redirected to whois.godaddy.com]
[Querying whois.godaddy.com]
[whois.godaddy.com]
The data contained in Go Daddy Software, Inc.'s WhoIs database,
...
Registrant:
  Sobell Associates Inc
  POBox 460068
  San Francisco, California 94146-0068
  United States
```

Registered through: GoDaddy.com  
 Domain Name: SOBELL.COM  
 Created on: 07-Apr-95  
 Expires on: 08-Apr-13  
 Last Updated on: 16-Jan-04

Administrative Contact:  
 Sobell, Mark sobell@meer.net  
 Sobell Associates Inc  
 PO BOX 460068  
 SAN FRANCISCO, California 94146-0068  
 United States  
 9999999999 Fax -- 9999999999

Technical Contact:  
 , hostmaster@meer.net  
 meer.net  
 po box 390804  
 Mountain View, California 94039  
 United States  
 18888446337 Fax -- 18888446337

Domain servers in listed order:  
 NS.MEER.NET  
 NS2.MEER.NET

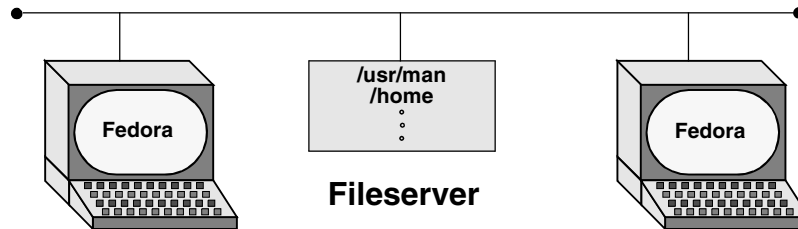
Several top-level registries serve various regions of the world. You are most likely to use the following ones:

|                         |                       |
|-------------------------|-----------------------|
| North American registry | <b>whois.arin.net</b> |
| European registry       | <b>www.ripe.net</b>   |
| Asia-Pacific registry   | <b>www.apnic.net</b>  |
| U.S. military           | <b>whois.nic.mil</b>  |
| U.S. government         | <b>www.nic.gov</b>    |

---

## DISTRIBUTED COMPUTING

When many similar systems are found on the same network, it is often desirable to share common files and utilities among them. For example, a system administrator might choose to keep a copy of the system documentation on one computer's disk and to make those files available to remote systems. In this case, the system administrator configures the files so users who need to access the online documentation are not aware that the files are stored on a remote system. This type of setup, which is an example of *distributed computing*, not only conserves disk space but also allows you to update one central copy of the documentation rather than tracking down and updating copies scattered throughout the network on many different systems.



**Figure 10-2** A fileserver

Figure 10-2 illustrates a *fileserver* that stores the system manual pages and users' home directories. With this arrangement, a user's files are always available to that user—no matter which system the user logs in on. Each system's disk might contain a directory to hold temporary files as well as a copy of the operating system. Chapter 22 contains instructions for setting up NFS clients and servers in networked configurations.

## THE CLIENT/SERVER MODEL

- Mainframe model    The client/server model was not the first computational model. First came the mainframe, which follows a one-machine-does-it-all model. That is, all the intelligence resides in one system, including the data and the program that manipulates and reports on the data. Users connect to a mainframe using terminals.
- File-sharing model    With the introduction of PCs, file-sharing networks became available. In this scheme data is downloaded from a shared location to a user's PC, where a program then manipulates the data. The file-sharing model ran into problems as networks expanded and more users needed access to the data.
- Client/server model    In the client/server model, a client uses a protocol, such as FTP, to request services, and a server provides the services that the client requests. Rather than providing data files as the file-sharing model does, the server in a client/server relationship is a database that provides only those pieces of information that the client needs or requests.

The client/server model dominates UNIX and Linux system networking and underlies most of the network services described in this book. FTP, NFS, DNS, email, and HTTP (the Web browsing protocol) all rely on the client/server model. Some servers, such as Web servers and browser clients, are designed to interact with specific utilities. Other servers, such as those supporting DNS, communicate with one another, in addition to answering queries from a variety of clients. Clients and servers can reside on the same or different systems running the same or different operating systems. The systems can be proximate or thousands of miles apart. A system that is a server to one system can turn around and act as a client to another. A server can reside on a single system or, as is the case with DNS, be distributed among thousands of geographically separated systems running many different operating systems.

- Peer-to-peer model    The peer-to-peer (PTP) model, in which either program can initiate a transaction, stands in contrast to the client/server model. PTP protocols are common on small

networks. For example, Microsoft's Network Neighborhood and Apple's AppleTalk both rely on broadcast-based PTP protocols for browsing and automatic configuration. The Zeroconf multicast DNS protocol is a PTP alternative DNS for small networks. The highest-profile PTP networks are those used for file sharing, such as Kazaa and Gnutella. Many of these networks are not pure PTP topologies. Pure PTP networks do not scale well, so networks such as Napster and Kazaa employ a hybrid approach.

## DNS: DOMAIN NAME SERVICE

DNS is a distributed service: Nameservers on thousands of machines around the world cooperate to keep the database up-to-date. The database itself, which maps hundreds of thousands of alphanumeric hostnames to numeric IP addresses, does not exist in one place. That is, no system has a complete copy of the database. Instead, each system that runs DNS knows which hosts are local to that site and understands how to contact other nameservers to learn about other, nonlocal hosts.

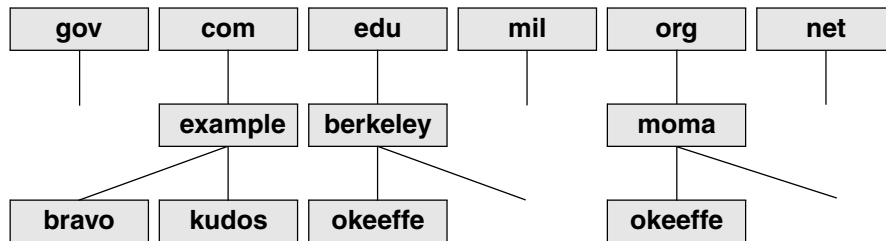
Like the Linux filesystem, DNS is organized hierarchically. Each country has an ISO (International Organization for Standardization) country code designation as its domain name. (For example, **AU** represents Australia, **IL** is Israel, and **JP** is Japan; see [www.iana.org/domains/root/ctld](http://www.iana.org/domains/root/ctld) for a complete list.) Although the United States is represented in the same way (**US**) and uses the standard two-letter Postal Service abbreviations to identify the next level of the domain, only governments and a few organizations use these codes. Schools in the **US** domain are represented by a third- (and sometimes second-) level domain: **k12**. For example, the domain name for Myschool in New York state could be `www.myschool.k12.ny.us`.

Following is a list of the six original top-level domains. These domains are used extensively within the United States and, to a lesser degree, by users in other countries:

|            |                                       |
|------------|---------------------------------------|
| <b>COM</b> | Commercial enterprises                |
| <b>EDU</b> | Educational institutions              |
| <b>GOV</b> | Nonmilitary government agencies       |
| <b>MIL</b> | Military government agencies          |
| <b>NET</b> | Networking organizations              |
| <b>ORG</b> | Other (often nonprofit) organizations |

As this book was being written, the following additional top-level domains had been approved for use:

|               |                        |
|---------------|------------------------|
| <b>AERO</b>   | Air-transport industry |
| <b>BIZ</b>    | Business               |
| <b>COOP</b>   | Cooperatives           |
| <b>INFO</b>   | Unrestricted use       |
| <b>MUSEUM</b> | Museums                |
| <b>NAME</b>   | Name registries        |



**Figure 10-3** U.S. top-level domains

Like Internet addresses, domain names were once assigned by the Network Information Center (NIC); now they are assigned by several companies. A system's full name, referred to as its *fully qualified domain name* (FQDN), is unambiguous in the way that a simple hostname cannot be. The system **okeeffe.berkeley.edu** at the University of California at Berkeley (Figure 10-3) is not the same as one named **okeeffe.moma.org**, which might represent a host at the Museum of Modern Art. The domain name not only tells you something about where the system is located but also adds enough diversity to the namespace to avoid confusion when different sites choose similar names for their systems.

Unlike the filesystem hierarchy, the top-level domain name appears last (reading from left to right). Also, domain names are not case sensitive, so the names **okeeffe.berkeley.edu**, **okeeffe.Berkeley.edu**, and **okeeffe.Berkeley.EDU** refer to the same computer. Once a domain has been assigned, the local site is free to extend the hierarchy to meet local needs.

With DNS, email addressed to **user@example.com** can be delivered to the computer named **example.com** that handles the corporate mail and knows how to forward messages to user mailboxes on individual machines. As the company grows, its site administrator might decide to create organizational or geographical subdomains. The name **delta.ca.example.com** might refer to a system that supports California offices, for example, while **alpha.co.example.com** is dedicated to Colorado. Functional subdomains might be another choice, with **delta.sales.example.com** and **alpha.dev.example.com** representing the sales and development divisions, respectively.

- BIND** On Linux systems, the most common interface to the DNS is BIND (Berkeley Internet Name Domain). BIND follows the client/server model. On any given local network, one or more systems may be running a nameserver, supporting all the local hosts as clients. When it wants to send a message to another host, a system queries the nearest nameserver to learn the remote host's IP address. The client, called a *resolver*, may be a process running on the same computer as the nameserver, or it may pass the request over the network to reach a server. To reduce network traffic and facilitate name lookups, the local nameserver maintains some knowledge of distant hosts. If the local server must contact a remote server to pick up an address, when the answer comes back, the local server adds that address to its internal table

and reuses it for a while. The nameserver deletes the nonlocal information before it can become outdated. Refer to “TTL” on page 1112.

The system’s translation of symbolic hostnames into addresses is transparent to most users; only the system administrator of a networked system needs to be concerned with the details of name resolution. Systems that use DNS for name resolution are generally capable of communicating with the greatest number of hosts—more than would be practical to maintain in a `/etc/hosts` file or private NIS database. Chapter 24 covers setting up and running a DNS server.

Three common sources are referenced for hostname resolution: NIS, DNS, and system files (such as `/etc/hosts`). Linux does not ask you to choose among these sources; rather, the `nsswitch.conf` file (page 455) allows you to choose any of these sources, in any combination, and in any order.

## PORTS

Ports are logical channels on a network interface and are numbered from 1 to 65,535. Each network connection is uniquely identified by the IP address and port number of each endpoint.

In a system that has many network connections open simultaneously, the use of ports keeps *packets* (page 1098) flowing to and from the appropriate programs. A program that needs to receive data *binds* to a port and then uses that port for communication.

**Privileged ports** Services are associated with specific ports, generally with numbers less than 1024. These ports are called *privileged* (or *reserved*) *ports*. For security reasons, only `root` can bind to privileged ports. A service run on a privileged port provides assurance that the service is being provided by someone with authority over the system, with the exception that any user on Windows 98 and earlier Windows systems can bind to any port. Commonly used ports include 22 (SSH), 23 (TELNET), 80 (HTTP), 111 (Sun RPC), and 201–208 (AppleTalk).

## NIS: NETWORK INFORMATION SERVICE

NIS (Network Information Service) simplifies the maintenance of frequently used administrative files by keeping them in a central database and having clients contact the database server to retrieve information from the database. Just as DNS addresses the problem of keeping multiple copies of `hosts` files up-to-date, NIS deals with the issue of keeping system-independent configuration files (such as `/etc/passwd`) current. Refer to Chapter 21 for coverage of NIS.

## NFS: NETWORK FILESYSTEM

The NFS (Network Filesystem) protocol allows a server to share selected local directory hierarchies with client systems on a heterogeneous network. Files on the remote fileserver appear as if they are present on the local system. NFS is covered in Chapter 22.

optional

## INTERNET SERVICES

Linux Internet services are provided by daemons that run continuously or by a daemon that is started automatically by the **xinetd** daemon (page 390) when a service request comes in. The **/etc/services** file lists network services (for example, **telnet**, **ftp**, and **ssh**) and their associated numbers. Any service that uses TCP/IP or UDP/IP has an entry in this file. IANA (Internet Assigned Numbers Authority) maintains a database of all permanent, registered services. The **/etc/services** file usually lists a small, commonly used subset of services. Visit [www.rfc.net/rfc1700.html](http://www.rfc.net/rfc1700.html) for more information and a complete list of registered services.

Most of the daemons (the executable files) are stored in **/usr/sbin**. By convention the names of many daemons end with the letter **d** to distinguish them from utilities (one common daemon whose name does not end in **d** is **sendmail**). The prefix **in.** or **rpc.** is often used for daemon names. Look at **/usr/sbin/\*d** to see a list of many of the daemon programs on the local system. Refer to “Init Scripts: Start and Stop System Services” on page 426 and “service: Configures Services I” on page 427 for information about starting and stopping these daemons.

To see how a daemon works, consider what happens when you run **ssh**. The local system contacts the **ssh** daemon (**sshd**) on the remote system to establish a connection. The two systems negotiate the connection according to a fixed protocol. Each system identifies itself to the other, and then they take turns asking each other specific questions and waiting for valid replies. Each network service follows its own protocol.

In addition to the daemons that support the utilities described up to this point, many other daemons support system-level network services that you will not typically interact with. Table 10-4 lists some of these daemons.

**Table 10-4** Common daemons

| Daemon           | Used for or by                             | Function                                                                                                                                                                                  |
|------------------|--------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>acpid</b>     | Advanced configuration and power interface | Flexible daemon for delivering ACPI events. Replaces <b>apmd</b> .                                                                                                                        |
| <b>apmd</b>      | Advanced power management                  | Reports and takes action on specified changes in system power, including shutdowns. Useful with machines, such as laptops, that run on batteries.                                         |
| <b>atd</b>       | <b>at</b>                                  | Executes a command once at a specific time and date. See <b>crond</b> for periodic execution of a command.                                                                                |
| <b>automount</b> | Automatic mounting                         | Automatically mounts filesystems when they are accessed. Automatic mounting is a way of demand-mounting remote directories without having to hard-configure them into <b>/etc/fstab</b> . |



**Table 10-4** Common daemons (continued)

| Daemon                                     | Used for or by                             | Function                                                                                                                                                                                                                                                                                                                                                                                                              |
|--------------------------------------------|--------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>crond</b>                               | cron                                       | Used for periodic execution of tasks. This daemon looks in the <b>/var/spool/cron</b> directory for files with filenames that correspond to users' usernames. It also looks at the <b>/etc/crontab</b> file and at files in the <b>/etc/cron.d</b> directory. When a task comes up for execution, <b>crond</b> executes it as the user who owns the file that describes the task.                                     |
| <b>dhcpcd</b>                              | DHCP                                       | DHCP client daemon (page 452).                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>dhcpcd</b>                              | DHCP                                       | Assigns Internet address, subnet mask, default gateway, DNS, and other information to hosts. This protocol answers DHCP requests and, optionally, BOOTP requests. Refer to "DHCP: Configures Hosts" on page 451.                                                                                                                                                                                                      |
| <b>ftpd</b>                                | FTP                                        | Handles FTP requests. Refer to "ftp: Transfers Files over a Network" on page 379. See also <b>vsftpd</b> (page 643). Can be launched by <b>xinetd</b> .                                                                                                                                                                                                                                                               |
| <b>gpm</b>                                 | General-purpose mouse or GNU paste manager | Allows you to use a mouse to cut and paste text on console applications.                                                                                                                                                                                                                                                                                                                                              |
| <b>httpd</b>                               | HTTP                                       | The Web server daemon (Apache, page 841).                                                                                                                                                                                                                                                                                                                                                                             |
| <b>in.fingerd</b>                          | finger                                     | Handles requests for user information from the <b>finger</b> utility. Launched by <b>xinetd</b> .                                                                                                                                                                                                                                                                                                                     |
| <b>inetd</b>                               |                                            | Deprecated in favor of <b>xinetd</b> .                                                                                                                                                                                                                                                                                                                                                                                |
| <b>lpd</b>                                 | Line printer spooler daemon                | Launched by <b>xinetd</b> when printing requests come to the system. Not used with CUPS.                                                                                                                                                                                                                                                                                                                              |
| <b>named</b>                               | DNS                                        | Supports DNS (page 773).                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>nfsd, statd, lockd, mountd, rquotad</b> | NFS                                        | These five daemons operate together to handle NFS (page 727) operations. The <b>nfsd</b> daemon handles file and directory requests. The <b>statd</b> and <b>lockd</b> daemons implement network file and record locking. The <b>mountd</b> daemon converts filesystem name requests from the mount utility into NFS handles and checks access permissions. If disk quotas are enabled, <b>rquotad</b> handles those. |
| <b>ntpd</b>                                | NTP                                        | Synchronizes time on network computers. Requires a <b>/etc/ntp.conf</b> file. For more information go to <a href="http://www.ntp.org">www.ntp.org</a> .                                                                                                                                                                                                                                                               |
| <b>portmap</b>                             | RPC                                        | Maps incoming requests for RPC service numbers to TCP or UDP port numbers on the local system. Refer to "RPC Network Services" on page 391. ( <i>RHEL</i> )                                                                                                                                                                                                                                                           |
| <b>pppd</b>                                | PPP                                        | For a modem, this protocol controls the pseudointerface represented by the IP connection between the local computer and a remote computer. Refer to "PPP: Point-to-Point Protocol" on page 367.                                                                                                                                                                                                                       |

**Table 10-4** Common daemons (continued)

| Daemon            | Used for or by       | Function                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-------------------|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>rexecd</b>     | rexec                | Allows a remote user with a valid username and password to run programs on a system. Its use is generally deprecated for security reasons; certain programs, such as PC-based X servers, may still have it as an option. Launched by <b>xinetd</b> .                                                                                                                                                                                                                                               |
| <b>routed</b>     | Routing tables       | Manages the routing tables so your system knows where to send messages that are destined for remote networks. If your system does not have a <b>/etc/defaultrouter</b> file, <b>routed</b> is started automatically to listen to incoming routing messages and to advertise outgoing routes to other systems on the local network. A newer daemon, the gateway daemon ( <b>gated</b> ), offers enhanced configurability and support for more routing protocols and is proportionally more complex. |
| <b>rsyslogd</b>   | System log           | Transcribes important system events and stores them in files and/or forwards them to users or another host running the <b>rsyslogd</b> daemon. This daemon is configured with <b>/etc/rsyslog.conf</b> and used with the rsyslog utility. See page 582.                                                                                                                                                                                                                                            |
| <b>sendmail</b>   | Mail programs        | The <b>sendmail</b> daemon came from Berkeley UNIX and has been available for a long time. The de facto mail transfer program on the Internet, the <b>sendmail</b> daemon always listens on port 25 for incoming mail connections and then calls a local delivery agent, such as <b>/bin/mail</b> . Mail user agents, such as KMail and Thunderbird, typically use <b>sendmail</b> to deliver mail messages.                                                                                       |
| <b>smbd, nmbd</b> | Samba                | Allow Windows PCs to share files and printers with UNIX and Linux computers (page 749).                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>sshd</b>       | ssh, scp             | Enables secure logins between remote systems (page 633).                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>talkd</b>      | talk                 | Allows you to have a conversation with another user on the same or a remote machine. The <b>talkd</b> daemon handles the connections between the machines. The <b>talk</b> utility on each system contacts the <b>talkd</b> daemon on the other system for a bidirectional conversation. Launched by <b>xinetd</b> .                                                                                                                                                                               |
| <b>telnetd</b>    | TELNET               | One of the original Internet remote access protocols (page 377). Launched by <b>xinetd</b> .                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>tftpd</b>      | TFTP                 | Used to boot a system or get information from a network. Examples include network computers, routers, and some printers. Launched by <b>xinetd</b> .                                                                                                                                                                                                                                                                                                                                               |
| <b>timed</b>      | Time server          | On a LAN synchronizes time with other computers that are also running <b>timed</b> .                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>xinetd</b>     | Internet superserver | Listens for service requests on network connections and starts up the appropriate daemon to respond to any particular request. Because of <b>xinetd</b> , a system does not need the daemons running continually to handle various network requests. For more information refer to “The xinetd Superserver” on page 445.                                                                                                                                                                           |

## PROXY SERVERS

A *proxy* is a network service that is authorized to act for a system while not being part of that system. A proxy server or proxy gateway provides proxy services; it is a transparent intermediary, relaying communications back and forth between an application, such as a browser and a server, usually outside of a LAN and frequently on the Internet. When more than one process uses the proxy gateway/server, the proxy must keep track of which processes are connecting to which hosts/servers so that it can route the return messages to the proper process. The most commonly encountered proxies are email and Web proxies.

A proxy server/gateway insulates the local computer from all other computers or from specified domains by using at least two IP addresses: one to communicate with the local computer and one to communicate with a server. The proxy server/gateway examines and changes the header information on all packets it handles so that it can encode, route, and decode them properly. The difference between a proxy gateway and a proxy server is that the proxy server usually includes *cache* (page 1073) to store frequently used Web pages so that the next request for that page is available locally and quickly; a proxy gateway typically does not use cache. The terms “proxy server” and “proxy gateway” are frequently used interchangeably.

Proxy servers/gateways are available for such common Internet services as HTTP, HTTPS, FTP, SMTP, and SNMP. When an HTTP proxy sends queries from local systems, it presents a single organizationwide IP address (the external IP address of the proxy server/gateway) to all servers. It funnels all user requests to the appropriate servers and keeps track of them. When the responses come back, the HTTP proxy fans them out to the appropriate applications using each machine’s unique IP address, thereby protecting local addresses from remote/specified servers.

Proxy servers/gateways are generally just one part of an overall firewall strategy to prevent intruders from stealing information or damaging an internal network. Other functions, which can be either combined with or kept separate from the proxy server/gateway, include packet filtering, which blocks traffic based on origin and type, and user activity reporting, which helps management learn how the Internet is being used.

## RPC NETWORK SERVICES

Much of the client/server interaction over a network is implemented using the RPC (Remote Procedure Call) protocol, which is implemented as a set of library calls that make network access transparent to the client and server. RPC specifies and interprets messages but does not concern itself with transport protocols; it runs on top of TCP/IP and UDP/IP. Services that use RPC include NFS and NIS. RPC was developed by Sun as ONC RPC (Open Network Computing Remote Procedure Calls) and differs from Microsoft RPC.

In the client/server model, a client contacts a server on a specific port (page 387) to avoid any mixup between services, clients, and servers. To avoid maintaining a long list of port numbers and to enable new clients/servers to start up without registering a port number with a central registry, when a server that uses RPC starts, it specifies

the port it expects to be contacted on. RPC servers typically use port numbers that have been defined by Sun. If a server does not use a predefined port number, it picks an arbitrary number.

The server then registers this port with the RPC portmapper (the **rpcbind** [FEDORA] or **portmap** [RHEL] daemon) on the local system. The server tells the daemon which port number it is listening on and which RPC program numbers it serves. Through these exchanges, the portmapper learns the location of every registered port on the host and the programs that are available on each port. The **rpcbind/portmap** daemon, which always listens on port 111 for both TCP and UDP, must be running to make RPC calls.

**Files** The **/etc/rpc** file (page 477) maps RPC services to RPC numbers. The **/etc/services** file (page 477) lists system services.

**RPC client/server communication** The sequence of events for communication between an RPC client and server occurs as follows:

1. The client program on the client system makes an RPC call to obtain data from a (remote) server system. (The client issues a “read record from a file” request.)
2. If RPC has not yet established a connection with the server system for the client program, it contacts **rpcbind/portmap** on port 111 of the server and asks which port the desired RPC server is listening on (for example, **rpc.nfsd**).
3. The **rpcbind/portmap** daemon on the remote server looks in its tables and returns a UDP/TCP port number to the local system, the client (typically 2049 for **nfs**).
4. The RPC libraries on the server system receive the call from the client and pass the request to the appropriate server program. The origin of the request is transparent to the server program. (The filesystem receives the “read record from file” request.)
5. The server responds to the request. (The filesystem reads the record.)
6. The RPC libraries on the remote server return the result over the network to the client program. (The read record is returned to the calling program.)

**RHEL** Because standard RPC servers are normally started by the **xinetd** daemon (page 445), the **portmap** daemon must be started before the **xinetd** daemon is invoked. The init scripts (page 426) make sure **portmap** starts before **xinetd**. You can confirm this sequence by looking at the numbers associated with **/etc/rc.d/\*/\*S\*portmap** and **/etc/rc.d/\*/\*S\*/xinetd**. If the **portmap** daemon stops, you must restart all RPC servers on the local system.

## USENET

One of the earliest information services available on the Internet, Usenet is an electronic bulletin board that allows users with common interests to exchange information. Usenet comprises an informal, loosely connected network of systems that exchange email and news items (commonly referred to as *netnews*). It was formed

in 1979 when a few sites decided to share some software and information on topics of common interest. They agreed to contact one another and to pass the information along over dial-up telephone lines (at that time running at 1,200 baud at best), using UNIX's `uucp` utility (UNIX-to-UNIX copy program).

The popularity of Usenet led to major changes in `uucp` to handle the escalating volume of messages and sites. Today much of the news flows over network links using a sophisticated protocol designed especially for this purpose: NNTP (Network News Transfer Protocol). The news messages are stored in a standard format, and the many public domain programs available let you read them. An old, simple interface is named `readnews`. Other interfaces, such as `rn`, its X Window System cousin `xrn`, `tin`, `nn`, and `xvnews`, have many features that help you browse through and reply to the articles that are available or create articles of your own. In addition, Netscape and Mozilla include an interface that you can use to read news (Netscape/Mozilla News) as part of their Web browsers. One of the easiest ways to read netnews is to go to `groups.google.com`. The program you select to read netnews is largely a matter of personal taste.

As programs to read netnews articles have been ported to non-UNIX and non-Linux systems, the community of netnews users has become highly diversified. In the UNIX tradition, categories of netnews groups are structured hierarchically. The top level includes such designations as **comp** (computer-related), **misc** (miscellaneous), **rec** (recreation), **sci** (science), **soc** (social issues), and **talk** (ongoing discussions). Usually at least one regional category is at the top level, such as **ba** (San Francisco Bay Area), and includes information about local events. New categories are continually being added to the more than 30,000 newsgroups. The names of newsgroups resemble domain names but are read from left to right (like Linux filenames): **comp.os.unix.misc**, **comp.lang.c**, **misc.jobs.offered**, **rec.skiing**, **sci.med**, **soc.singles**, and **talk.politics** are but a few examples. The following article appeared in **linux.redhat.install**:

```
> I have just installed Fedora 12 and when i try to start X I get the
> following error message:
>
> Fatal Server Error.
> no screens found
>
> XI0: Fatal IO err 104 (connection reset by peer) on X server ",0.0" after
> 0 requests (0 known processed) with 0 events remaining.
>
> How can I solve this problem?
>
> Thanks,
> Fred
```

Fred,

It would appear that your X configuration is incorrect or missing. You should run `system-config-display` and set up the configuration for your video card and monitor.

Carl

A great deal of useful information is available on Usenet, but you need patience and perseverance to find what you are looking for. You can ask a question, as the user did in the previous example, and someone from halfway around the world might answer it. Before posing such a simple question and causing it to appear on thousands of systems around the world, however, first ask yourself whether you can get help in a less invasive way. Try the following:

- Refer to the man pages and info.
- Look through the files in `/usr/share/doc`.
- Ask the system administrator or another user for help.
- All of the popular newsgroups have FAQs (lists of frequently asked questions). Consult these lists and see whether your question has been answered. FAQs are periodically posted to the newsgroups; in addition, all the FAQs are archived at sites around the Internet, including Google groups ([groups.google.com](http://groups.google.com)).
- Because someone has probably asked the same question earlier, search the netnews archives for an answer. Try looking at [groups.google.com](http://groups.google.com), which has a complete netnews archive.
- Use a search engine to find an answer. One good way to get help is to search on an error message.
- Review support documents at [www.redhat.com](http://www.redhat.com).
- Contact a Fedora/RHEL users' group.

Post a query to the worldwide Usenet community as a last resort. If you are stuck on a Linux question and cannot find any other help, try submitting it to one of these newsgroups:

- `linux.redhat.install`
- `linux.redhat.misc`

For more generic questions, try these lists:

- `comp.os.linux.misc`
- `comp.os.linux.networking`
- `comp.os.linux.security`
- `comp.os.linux.setup`
- `linux.redhat.rpm`

One way to find out about new tools and services is to read Usenet news. The `comp.os.linux` hierarchy is of particular interest to Linux users; for example, news about newly released software for Linux is posted to `comp.os.linux.announce`. People often announce the availability of free software there, along with instructions on how to get a copy for your own use using anonymous FTP (page 649). Other tools to help you find resources, both old and new, exist on the network; see Appendix B.

---

## WWW: WORLD WIDE WEB

The World Wide Web (WWW, W3, or the Web) provides a unified, interconnected interface to the vast amount of information stored on computers around the world. The idea that spawned the World Wide Web came from the mind of Tim Berners-Lee ([www.w3.org/People/Berners-Lee](http://www.w3.org/People/Berners-Lee)) of the European Particle Physics Laboratory (CERN) in response to a need to improve communications throughout the high-energy physics community. The first-generation solution consisted of a notebook program named Enquire, short for *Enquire Within Upon Everything* (the name of a book from Berners-Lee's childhood), which he created in 1980 on a NeXT computer and which supported links between named nodes. Not until 1989 was the concept proposed as a global hypertext project to be known as the World Wide Web. In 1990, Berners-Lee wrote a proposal for a hypertext project, which eventually produced HTML (Hypertext Markup Language), the common language of the Web. The World Wide Web program became available on the Internet in the summer of 1991. By designing the tools to work with existing protocols, such as FTP and gopher, the researchers who created the Web produced a system that is generally useful for many types of information and across many types of hardware and operating systems.

The WWW is another example of the client/server paradigm. You use a WWW client application, or *browser*, to retrieve and display information stored on a server that may be located anywhere on your local network or the Internet. WWW clients can interact with many types of servers. For example, you can use a WWW client to contact a remote FTP server and display the list of files it offers for anonymous FTP. Most commonly you use a WWW client to contact a WWW server, which offers support for the special features of the World Wide Web that are described in the remainder of this chapter.

The power of the Web derives from its use of *hypertext*, a way to navigate through information by following cross-references (called *links*) from one piece of information to another. To use the Web effectively, you need to run interactive network applications. The first GUI for browsing the Web was a tool named Mosaic, which was released in February 1993. Designed at the National Center for Supercomputer Applications at the University of Illinois, its introduction sparked a dramatic increase in the number of users of the World Wide Web. Marc Andreessen, who participated in the Mosaic project at the University of Illinois, later cofounded Netscape Communications with the founder of Silicon Graphics, Jim Clark. The pair created Netscape Navigator, a Web client program that was designed to perform better and support more features than the Mosaic browser. Netscape Navigator enjoyed immense success and was a popular choice for exploring the World Wide Web. Important for Linux users is the fact that from its inception Netscape provided versions of its tools that ran on Linux. Also, Netscape created Mozilla ([mozilla.org](http://mozilla.org)) as an open-source browser project, and from Mozilla came Firefox.

These browsers provide GUIs that allow you to listen to sounds, watch Web events or live news reports, and display pictures as well as text, giving you access to

*hypermedia*. A picture on your screen may be a link to more detailed, nonverbal information, such as a copy of the same picture at a higher resolution or a short animation. If your system can produce audio output, you can listen to audio clips that have been linked to a document.

## URL: UNIFORM RESOURCE LOCATOR

Consider the URL `http://www.w3.org/Consortium/siteindex`. The first component in the URL indicates the type of resource, in this case **http** (HTTP—Hypertext Transfer Protocol). Other valid resource names, such as **https** (HTTPS—secure HTTP) and **ftp** (FTP—File Transfer Protocol), represent information available on the Web using other protocols. Next come a colon and double slash (`://`). Frequently the **http://** string is omitted from a URL in print, as you seldom need to enter it to reach the URL. The next element is the full name of the host that acts as the server for the information (**www.w3.org**). The rest of the URL consists of a relative pathname to the file that contains the information (**Consortium/siteindex**). If you enter a URL in the location bar of a Web browser, the Web server returns the page, frequently an *HTML* (page 1086) file, pointed to by this URL.

By convention many sites identify their WWW servers by prefixing a host or domain name with **www**. For example, you can reach the Web server at the New Jersey Institute of Technology at `www.njit.edu`. When you use a browser to explore the World Wide Web, you may never need to enter a URL. However, as more information is published in hypertext form, you cannot help but find URLs everywhere—not just online in email messages and Usenet articles, but also in newspapers, in advertisements, and on product labels.

## BROWSERS

Mozilla (`www.mozilla.org`) is the open-source counterpart to Netscape. Mozilla, which was first released in March 1998, was based on Netscape 4 code. Since then, Mozilla has been under continuous development by employees of Netscape (now a division of AOL), Red Hat, and other companies and by contributors from the community. Firefox is the Web browser component of Mozilla. KDE offers Konqueror, an all-purpose file manager and Web browser. Other popular browsers include Opera (`www.opera.com`) and Epiphany (`www.gnome.org/projects/epiphany`). Although each Web browser is unique, all of them allow you to move about the Internet, viewing HTML documents, listening to sounds, and retrieving files. If you do not use the X Window System, try a text browser, such as `lynx` or `links`. The `lynx` browser works well with Braille terminals.

## SEARCH ENGINES

*Search engine* is a name that applies to a group of hardware and software tools that help you search for World Wide Web sites that contain specific information. A search engine relies on a database of information collected by a *Web crawler*, a program that regularly looks through the millions of pages that make up the World Wide Web. A search engine must also have a way of collating the information the



Web crawler collects so that you can access it quickly, easily, and in a manner that makes it most useful to you. This part of the search engine, called an *index*, allows you to search for a word, a group of words, or a concept; it returns the URLs of Web pages that pertain to what you are searching for. Many different types of search engines are available on the Internet, each with its own set of strengths and weaknesses.

---

## CHAPTER SUMMARY

A Linux system attached to a network is probably communicating on an Ethernet, which may in turn be linked to other local area networks (LANs) and wide area networks (WANs). Communication between LANs and WANs requires the use of gateways and routers. Gateways translate the local data into a format suitable for the WAN, and routers make decisions about the optimal routing of the data along the way. The most widely used network, by far, is the Internet.

Basic networking tools allow Linux users to log in and run commands on remote systems (`ssh`, `telnet`) and copy files quickly from one system to another (`scp`, `ftp/sftp`). Many tools that were originally designed to support communication on a single-host computer (for example, `finger` and `talk`) have since been extended to recognize network addresses, thus allowing users on different systems to interact with one another. Other features, such as the Network Filesystem (NFS), were created to extend the basic UNIX model and to simplify information sharing.

Concern is growing about our ability to protect the security and privacy of machines connected to networks and of data transmitted over networks. Toward this end, many new tools and protocols have been created: `ssh`, `scp`, HTTPS, IPv6, firewall hardware and software, VPN, and so on. Many of these tools take advantage of newer, more impenetrable encryption techniques. In addition, some weaker concepts (such as that of trusted hosts) and some tools (such as `finger` and `rwho`) are being discarded in the name of security.

Computer networks offer two major advantages of over other ways of connecting computers: They enable systems to communicate at high speeds and they require few physical interconnections (typically one per system, often on a shared cable). The Internet Protocol (IP), the universal language of the Internet, has made it possible for dissimilar computer systems around the world to readily communicate with one another. Technological advances continue to improve the performance of computer systems and the networks that link them.

One way to gather information on the Internet is via Usenet. Many Linux users routinely peruse Usenet news (`netnews`) to learn about the latest resources available for their systems. Usenet news is organized into newsgroups that cover a wide range of topics, computer-related and otherwise. To read Usenet news, you need to have

access to a news server and the appropriate client software. Many modern email programs, such as Mozilla and Netscape, can display netnews.

The rapid increase of network communication speeds in recent years has encouraged the development of many new applications and services. The World Wide Web provides access to vast information stores on the Internet and makes extensive use of hypertext links to promote efficient searching through related documents. It adheres to the client/server model that is so pervasive in networking. Typically the WWW client is local to a site or is made available through an Internet service provider. WWW servers are responsible for providing the information requested by their many clients.

Mozilla/Firefox is a WWW client program that has enormous popular appeal. Firefox and other browsers use a GUI to give you access to text, picture, and audio information: Making extensive use of these hypermedia simplifies access to and enhances the presentation of information.

---

## EXERCISES

1. Describe the similarities and differences between these utilities:
  - a. scp and ftp
  - b. ssh and telnet
  - c. rsh and ssh
2. Assuming `rwho` is disabled on the systems on your LAN, describe two ways to find out who is logged in on some of the other machines attached to your network.
3. Explain the client/server model. Give three examples of services on Linux systems that take advantage of this model.
4. A software implementation of chess was developed by GNU and is available for free. How can you use the Internet to find a copy and download it?
5. What is the difference between the World Wide Web and the Internet?
6. If you have access to the World Wide Web, answer the following questions.
  - a. Which browser do you use?
  - b. What is the URL of the author of this book's home page? How many links does it have?
  - c. Does your browser allow you to create bookmarks? If so, how do you create a bookmark? How can you delete one?
7. Give one advantage and two disadvantages of using a wireless network.

## ADVANCED EXERCISES

8. Suppose the link between routers 1 and 2 is down in the Internet shown in Figure 10-1 on page 364. What happens if someone at site C sends a message to a user on a workstation attached to the Ethernet cable at site A? What happens if the router at site A is down? What does this tell you about designing network configurations?
9. If you have a class B network and want to divide it into subnets, each with 126 hosts, which subnet mask should you use? How many networks will be available? What are the four addresses (broadcast and network number) for the network starting at 131.204.18?
10. Suppose you have 300 hosts and want to have no more than 50 hosts per subnet. What size of address block should you request from your ISP? How many class C-equivalent addresses would you need? How many subnets would you have left over from your allocation?
11.
  - a. On your system, find two daemons running that are not listed in this chapter and explain what purpose they serve.
  - b. Review which services/daemons are automatically started on your system, and consider which you might turn off. Are there any services/daemons in the list in Table 10-4 on page 388 that you would consider adding?

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# PART IV

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## SYSTEM ADMINISTRATION

- CHAPTER 11  
SYSTEM ADMINISTRATION: CORE CONCEPTS 403
- CHAPTER 12  
FILES, DIRECTORIES, AND FILESYSTEMS 467
- CHAPTER 13  
DOWNLOADING AND INSTALLING SOFTWARE 497
- CHAPTER 14  
PRINTING WITH CUPS 519
- CHAPTER 15  
REBUILDING THE LINUX KERNEL 543
- CHAPTER 16  
ADMINISTRATION TASKS 555
- CHAPTER 17  
CONFIGURING AND MONITORING A LAN 595

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# 11

## SYSTEM ADMINISTRATION: CORE CONCEPTS

### IN THIS CHAPTER

|                                                                         |     |
|-------------------------------------------------------------------------|-----|
| System Administrator and Superuser. ....                                | 405 |
| Rescue Mode. ....                                                       | 411 |
| SELinux. ....                                                           | 414 |
| The Upstart Event-Based init Daemon ( <i>FEDORA</i> ). ....             | 417 |
| rpcinfo: Displays Information About rpcbind. ....                       | 443 |
| The xinetd Superserver. ....                                            | 445 |
| TCP Wrappers: Client/Server Security (hosts.allow and hosts.deny). .... | 447 |
| Setting Up a chroot Jail. ....                                          | 448 |
| DHCP: Configures Hosts. ....                                            | 451 |
| nsswitch.conf: Which Service to Look at First. ....                     | 455 |
| PAM. ....                                                               | 458 |

The job of a system administrator is to keep one or more systems in a useful and convenient state for users. On a Linux system, the administrator and user may both be you, with you and the computer being separated by only a few feet. Or the system administrator may be halfway around the world, supporting a network of systems, with you being simply one of thousands of users. A system administrator can be one person who works part-time taking care of a system and perhaps is also a user of the system. Or the administrator can be several people, all working full-time to keep many systems running.

A well-maintained system

- Runs quickly enough so users do not get too frustrated waiting for the system to respond or complete a task.
- Has enough storage to accommodate users' reasonable needs.
- Provides a working environment appropriate to each user's abilities and requirements.
- Is secure from malicious and accidental acts altering its performance or compromising the security of the data it holds and exchanges with other systems.
- Is backed up regularly, with recently backed-up files readily available to users.
- Has recent copies of the software that users need to get their jobs done.
- Is easier to administer than a poorly maintained system.

In addition, a system administrator should be available to help users with all types of system-related problems—from logging in to obtaining and installing software updates to tracking down and fixing obscure network issues.

Part V of this book breaks system administration into seven chapters:

- Chapter 11 covers the core concepts of system administration, including working with root privileges (Superuser), system operation, the Fedora/RHEL configuration tools and other useful utilities, general information about setting up and securing a server (including a section on DHCP), and PAM.
- Chapter 12 covers files, directories, and filesystems from an administrator's point of view.
- Chapter 13 covers installing software on the system, including the use of yum, pirut, Red Hat Network (RHN), BitTorrent, and wget.
- Chapter 14 discusses how to set up local and remote printers that use the CUPS printing system.
- Chapter 15 explains how to rebuild the Linux kernel.
- Chapter 16 covers additional system administrator tasks and tools, including setting up users and groups, backing up files, scheduling tasks, printing system reports, and general problem solving.
- Chapter 17 goes into detail about how to set up a LAN, including setting up and configuring the network hardware and configuring the software.

Because Linux is configurable and runs on a variety of platforms (Sun SPARC, DEC/Compaq Alpha, Intel x86, AMD, PowerPC, and more), this chapter cannot discuss every system configuration or every action you will have to take as a system



administrator. Instead, this chapter seeks to familiarize you with the concepts you need to understand and the tools you need to use to maintain a Red Hat Enterprise Linux or Fedora system. Where it is not possible to go into depth about a subject, the chapter provides references to other sources.

This chapter assumes you are familiar with the following terms:

|                                    |                                |                                    |
|------------------------------------|--------------------------------|------------------------------------|
| <i>block device</i> (page 1071)    | <i>filesystem</i> (page 1082)  | <i>root filesystem</i> (page 1104) |
| <i>daemon</i> (page 1078)          | <i>fork</i> (page 1083)        | <i>runlevel</i> (page 1104)        |
| <i>device</i> (page 1079)          | <i>kernel</i> (page 1090)      | <i>signal</i> (page 1106)          |
| <i>device filename</i> (page 1079) | <i>login shell</i> (page 1092) | <i>spawn</i> (page 1107)           |
| <i>disk partition</i> (page 1079)  | <i>mount</i> (page 1094)       | <i>system console</i> (page 1110)  |
| <i>environment</i> (page 1081)     | <i>process</i> (page 1100)     | <i>X server</i> (page 1116)        |

### If something does not work, see if the problem is caused by SELinux

**tip** If a server or other system software does not work properly, and especially if it displays a permissions-related error message, the problem may lie with SELinux. To see if SELinux is the cause of the problem, put SELinux in permissive mode and run the software again. If the problem goes away, you need to modify the SELinux policy. Remember to turn SELinux back on. For more information refer to “Setting the Targeted Policy with system-config-selinux” on page 416.

## SYSTEM ADMINISTRATOR AND SUPERUSER

Much of what a system administrator does is work that ordinary users do not have permission to do. When performing one of these tasks, the system administrator logs in as **root** (or uses another method; see the list starting on page 406) to have systemwide powers that are beyond those of ordinary users: A user with **root** privileges is referred to as *Superuser*. The username is **root** by default. Superuser has the following powers and more:

- Some commands, such as those that add new users, partition hard drives, and change system configuration, can be executed only by **root**. Superuser can use certain tools, such as **sudo**, to give specific users permission to perform tasks that are normally reserved for Superuser.
- Read, write, and execute file access and directory access permissions do not affect **root**: Superuser can read from, write to, and execute all files, as well as examine and work in all directories.
- Some restrictions and safeguards that are built into some commands do not apply to **root**. For example, **root** can change any user’s password without knowing the old password.

When you are running with **root** (Superuser) privileges, the shell by convention displays a special prompt to remind you of your status. By default, this prompt is or ends with a pound sign (#).

## Least privilege

**caution** When you are working on the computer, especially when you are working as the system administrator, perform any task while using the least privilege possible. When you can perform a task logged in as an ordinary user, do so. When you must be logged in as Superuser, do as much as you can as an ordinary user, log in or use `su` so you have **root** privileges, complete the part of the task that has to be done as Superuser, and revert to being an ordinary user as soon as you can. Because you are more likely to make a mistake when you are rushing, this concept becomes more important when you have less time to apply it.

---

You can gain or grant Superuser privileges in a number of ways:

1. When you bring the system up in single-user mode (page 430), you are Superuser.
2. Once the system is up and running in multiuser mode (page 431), you can log in as **root**. When you supply the proper password, you will be Superuser.
3. You can give an `su` (substitute user) command while you are logged in as yourself and, with the proper password, you will have Superuser privileges. For more information refer to “`su`: Gives You Another User’s Privileges” on page 408.
4. You can use `sudo` selectively to give users Superuser privileges for a limited amount of time on a per-user and per-command basis. The `sudo` utility is controlled by the `/etc/sudoers` file, which must be set up by **root**. Refer to the `sudo` man page for more information.
5. Any user can create a *setuid* (set user ID) file (page 205). Setuid programs run on behalf of the owner of the file and have all the access privileges that the owner has. While you are running as Superuser, you can change the permissions of a file owned by **root** to setuid. When an ordinary user executes a file that is owned by **root** and has setuid permissions, the program has *full root privileges*. In other words, the program can do anything **root** can do and that the program does or allows the user to do. The user’s privileges do not change. When the program finishes running, all user privileges revert to the way they were before the program started. Setuid programs that are owned by **root** are both extremely powerful and extremely dangerous to system security, which is why a system contains very few of them. Examples of setuid programs that are owned by **root** include `passwd`, `at`, and `crontab`. The following example shows two ways for Superuser to give a program setuid privileges:

```
# ls -l my*
-rwxr-xr-x  1 root    other      24152 Apr 29 16:30 myprog
-rwxr-xr-x  1 root    other      24152 Apr 29 16:31 myprog2
# chmod 4755 myprog
# chmod u+s myprog2
```

```
# ls -l my*
-rwsr-xr-x 1 root other 24152 Apr 29 16:30 myprog
-rwsr-xr-x 1 root other 24152 Apr 29 16:31 myprog2
```

The **s** in the owner execute position of the **ls -l** output (page 203) indicates that the file has **setuid** permission.

### root-owned setuid programs are extremely dangerous

**security** Because **root**-owned **setuid** programs allow someone who does not know the **root** password to exercise the powers of Superuser, they are tempting targets for a malicious user. A system should have as few of these programs as possible. You can disable **setuid** programs at the filesystem level by mounting a filesystem with the **nosuid** option (page 488). You can also use SELinux (page 414) to disable **setuid** programs. See page 413 for a **find** command that lists **setuid** files on the local system.

6. Some programs ask you for a password (either your password or the **root** password, depending on the particular command and the configuration of the system) when they start. When you provide the **root** password, the program runs with **root** privileges.

When a program requests the **root** password when it starts, you stop running as the privileged user when you quit using the program. This setup keeps you from remaining logged in as Superuser when you do not need or intend to do so. Refer to “consolehelper: Runs Programs as **root**” on page 409.

Some techniques limit the number of ways to become Superuser. For example, PAM (page 458) controls the who, when, and how of logging in. The **/etc/securetty** file controls which terminals (ttys) a user can log in on as **root**. The **/etc/security/access.conf** file adds another dimension to login control (see the file for details).

### Do not allow root access over the Internet

**security** Prohibiting **root** logins using login over a network is the default policy of Fedora/RHEL and is implemented by the PAM **securetty** module. The **/etc/security/access.conf** file must contain the names of all users and terminals/workstations that you want a user to be able to log in on as **root**. Initially every line in **access.conf** is commented out.

You can, however, log in as **root** over a network using **ssh** (page 621). As shipped by Fedora/RHEL, **ssh** does not follow the instructions in **securetty** or **access.conf**. Also, in **/etc/ssh/sshd\_config**, Fedora/RHEL sets **PermitRootLogin** to **YES** (it is set by default) to permit **root** to log in using **ssh** (page 637).

## SYSTEM ADMINISTRATION TOOLS

Many tools can help you be an efficient and thorough system administrator. A few of these tools/utilities are described in this section, another group of administration utilities is described starting on page 436, and others are scattered throughout Part IV.

## SU: GIVES YOU ANOTHER USER'S PRIVILEGES

The `su` (substitute user) utility can create a shell or execute a program with the identity and permissions of a specified user. Follow `su` on the command line with the name of a user; if you are working with `root` privileges or if you know the user's password, you take on the identity of that user. When you give an `su` command without an argument, `su` defaults to Superuser so that you take on the identity of `root` (you have to know the `root` password).

To ensure that you are using the system's official version of `su` (and not one planted on your system by a malicious user), specify `su`'s absolute pathname (`/bin/su`) when you use it. (Of course, if someone has compromised your system enough that you are running a fake `su` command, you are in serious trouble anyway—but using an absolute pathname for `su` is still a good idea.)

When you give an `su` command to become Superuser, you spawn a new shell, which displays the `#` prompt. You return to your normal status (and your former shell and prompt) by terminating this shell: Press `CONTROL-D` or give an `exit` command. Giving an `su` command by itself changes your user and group IDs but makes minimal changes to your environment. You still have the same `PATH` you did when you logged in as yourself. When you run a utility that is normally run by `root` (the utilities in `/sbin` and `/usr/sbin`), you may need to specify an absolute pathname for the utility (such as `/sbin/service`). When you give the command `su -` (you can use `-l` or `--login` in place of the hyphen), you get a `root` login shell: It is as though you logged in as `root`. Not only are your user and group IDs the same as those of `root`, but your entire environment is that of `root`. The login shell executes the appropriate startup scripts before displaying a prompt, and your `PATH` is set to what it would be if you had logged in as `root`, typically including `/sbin` and `/usr/sbin`.

Use the `id` utility to display the changes in your user and group IDs and in the groups you are associated with. In the following example, the information that starts with `context` pertains to SELinux:

```
$ id
uid=500(alex) gid=500(alex) groups=500(alex) context=user_u:system_r:unconfined_t
$ su
Password:
# id
uid=0(root) gid=0(root) groups=0(root),1(bin),2(daemon),3(sys), ...
```

You can use `su` with the `-c` option to run a single command with `root` privileges, returning to your original shell when the command finishes executing. The following example first shows that a user is not permitted to kill a process. With the use of `su -c` and the `root` password, the user is permitted to kill (page 409) the process. The quotation marks are necessary because `su -c` takes its command in the form of a single argument.

```
$ kill -15 4982
-bash: kill: (4982) - Operation not permitted
$ su -c "kill -15 4982"
Password:
$
```

## Superuser, PATH, and security

### security

The fewer directories you keep in your **PATH** when you are working with **root** privileges, the less likely you will be to execute an untrusted program as **root**. If possible, keep only the default directories, along with **/sbin** and **/usr/sbin**, in **root**'s **PATH**. *Never include the working directory (as **.** or **::** anywhere in **PATH**, or **:** as the last element of **PATH**).* For more information refer to “PATH: Where the Shell Looks for Programs” on page 306.

## consolehelper: RUNS PROGRAMS AS root

The **consolehelper** utility can make it easier for someone who is logged in on the system console but not logged in as **root** to run system programs that normally can be run only by **root**. PAM (page 458), which authenticates users, can be set to trust all console users, to require user passwords (not the **root** password), or to require the **root** password before granting trust. The concept underlying **consolehelper** is that you may want to consider as trustworthy anyone who has access to the console. For example, Alex can log in on the console as himself and run **halt** without knowing the **root** password. For more information refer to the discussion of **consolehelper** on page 434 and to the **consolehelper** man page.

## kill: SENDS A SIGNAL TO A PROCESS

The **kill** builtin sends a signal to a process. This signal may or may not terminate (kill) the process, depending on which signal is sent and how the process is designed. Refer to “trap: Catches a Signal” on page 943 for a discussion of the various signals and their interaction with a process. Running **kill** is not the first method a user or system administrator should try when a process needs to be aborted.

### kill: Use the kill signal (**-KILL** or **-9**) as a method of last resort

### caution

When you do need to use **kill**, send the termination signal (**kill -TERM** or **kill -15**) first. Only if that tactic does not work should you attempt to use the kill signal (**kill -KILL** or **kill -9**).

Because of its inherent dangers, using a kill signal is a method of last resort, especially when you are running with **root** privileges. One **kill** command issued by **root** can bring the system down without warning.

Usually a user can kill a process by working in another window or by logging in on another terminal. Sometimes you may have to log in as **root** (or use **su**) to kill a process for a user. To kill a process, you need to know its PID. The **ps** utility can provide this information once you determine the name of the program the user is running and/or the username of the user. The **top** utility (page 567) can also be helpful in finding and killing (see **top**'s **k** command) a runaway process.

In the following example, Zach complains that **gnome-calculator** is stuck and that he cannot do anything from the **gnome-calculator** window—not even close it. A more experienced user could open another window and kill the process, but in this case you kill it for Zach. First use **ps** with the **-u** option, followed by the name of the user and the **-f** (full/wide) option to view all processes associated with that user.

```
$ ps -u zach -f
UID      PID    PPID   C  STIME TTY          TIME CMD
zach     1312      1    0 12:29 ?        00:00:00 /usr/bin/gnome-keyring-daemon --
zach     1319    1261    0 12:29 ?        00:00:01 gnome-session
zach     1327      1    0 12:29 ?        00:00:00 dbus-launch --sh-syntax --exit-w
zach     1328      1    0 12:29 ?        00:00:01 /bin/dbus-daemon --fork --print-
zach     1394      1    0 12:29 ?        00:00:01 /usr/libexec/gconfd-2
zach     1401      1    0 12:29 ?        00:00:02 /usr/libexec/gnome-settings-daem
zach     1407      1    0 12:29 ?        00:00:00 /usr/libexec/gvfsd
zach     1411    1319    0 12:29 ?        00:00:01 metacity
...
zach     1618      1    0 12:29 ?        00:00:00 /usr/libexec/gvfsd-trash --spawn
zach     1620      1    0 12:29 ?        00:00:00 /usr/libexec/notification-daemon
zach     1623      1    0 12:29 ?        00:00:00 gnome-screensaver
zach     1637      1    0 12:29 ?        00:00:00 /usr/libexec/gvfsd-burn --spawne
zach     1657      1    0 12:30 ?        00:00:02 gnome-terminal
zach     1658    1657    0 12:30 ?        00:00:00 gnome-pty-helper
zach     1659    1657    0 12:30 pts/0    00:00:00 bash
zach     1800    1659    4 13:00 pts/0    00:00:01 gnome-calculator
```

This list is fairly short, and the process running `gnome-calculator` is easy to find. Another way to search for a process is to use `ps` to produce a long list of all processes and then use `grep` to find which ones are running `gnome-calculator`.

```
$ ps -ef | grep gnome-calculator
zach     1800    1659    0 13:00 pts/0    00:00:01 gnome-calculator
zach     1800    1719    0 13:04 pts/1    00:00:00 grep gnome-calculator
```

If several people are running `gnome-calculator`, you may need to look in the left column to find the name of the user so you can kill the right process. You can combine the two commands as `ps -u zach -f | grep gnome-calculator`.

Now that you know Zach's process running `gnome-calculator` has a PID of 1800, you can use `kill` to terminate it. The safest way to do so is to log in as Zach (perhaps allow him to log in for you or `su` to zach [`su zach`] if you are logged in as `root`) and give any of the following commands (all of which send a termination signal to process 1800):

```
$ kill 1800
```

*or*

```
$ kill -15 1800
```

*or*

```
$ kill -TERM 1800
```

Only if this command fails should you send the kill signal:

```
$ kill -KILL 1800
```

The `-KILL` option instructs `kill` to send a `SIGKILL` signal, which the process cannot ignore. You can give the same command while you are logged in as `root`, but a typing mistake can have much more far-reaching consequences in this circumstance

than if you make the same mistake while you are logged in as an ordinary user. A user can kill only her own processes, whereas Superuser can kill any process, including system processes.

As a compromise between speed and safety, you can combine the `su` and `kill` utilities by using the `-c` option to `su`. The following command runs the part of the command line after the `-c` with the identity of Zach:

```
# su zach -c "kill -TERM 1800"
```

Two useful utilities related to `kill` are `killall` and `pidof`. The `killall` utility is very similar to `kill` but uses a command name instead of a PID number. To kill all your processes that are running `gnome-calculator` or `vi`, you can give the following command:

```
$ killall gnome-calculator vi
```

When a user running with **root** privileges gives this command, all processes that are running `gnome-calculator` or `vi` on the system are terminated.

The `pidof` utility displays the PID number of each process running the command you specify. Because this utility resides in `/sbin`, you may have to give the absolute path-name if you are not running as **root**:

```
$ /sbin/pidof httpd
567 566 565 564 563 562 561 560 553
```

If it is difficult to find the right process, try using `top`. Refer to the man pages for these utilities for more information, including lists of options.

## RESCUE MODE

Rescue mode is an environment you can use to fix a system that does not boot normally. To bring a system up in rescue mode, boot the system from the first installation CD, the Net Boot CD, or the install DVD. From the install DVD, select **Rescue installed system** from the Welcome menu (page 56). From the first installation CD and the Net Boot CD, enter the **rescue** (*FEDORA*) or **boot rescue** (*RHEL*) boot parameter. For more information refer to “Modifying Boot Parameters (Options)” on page 68. The boot process may take several minutes. The system then comes up in rescue mode.

In rescue mode, you can change or replace configuration files, check and repair partitions using `fsck` (page 492), rewrite boot information, and more. The rescue screen first asks if you want to set up the network interface. This interface is required if you want to copy files from other systems on the LAN or download files from the Internet. When you choose to set up the network interface, you need to decide whether to have DHCP automatically configure the network connection or to manually supply the IP address and netmask of the interface, as well as the IP addresses of the gateway and DNS server(s).

If the rescue setup finds an existing Linux installation, you can choose to mount it under `/mnt/sysimage`, optionally in readonly mode. With the existing installation mounted, once the system displays a shell prompt (similar to `sh-3.2#`), you can give the command `chroot /mnt/sysimage` to access the existing installation as it would be if you booted normally, with the existing installation's root directory available as `/` (root). (See page 448 for more information on `chroot`.) If you choose not to mount the existing installation, you are running a rescue system with standard tools mounted in standard locations (`/bin`, `/usr/bin`, and so on). Partitions from your local installation are available for fixing or mounting. When you exit from the rescue shell, the system reboots. Remove the CD or DVD if you want to boot from the hard drive.

## AVOIDING A TROJAN HORSE

A *Trojan horse* is a program that does something destructive or disruptive to a system while appearing to be benign. As an example, you could store the following script in an executable file named `mkfs`:

```
while true
do
    echo 'Good Morning Mr. Jones. How are you? Ha Ha Ha.' > /dev/console
done
```

If you are running as Superuser when you run this command, it would continuously write a message to the console. If the programmer were malicious, it could do worse. The only thing missing in this plot is access permissions.

A malicious user could implement this Trojan horse by changing Superuser's `PATH` variable to include a publicly writable directory at the start of the `PATH` string. (The catch is that you need to be able to write to `/etc/profile`—where the `PATH` variable is set for `root`—and only `root` can do that.) Then you would need to put the bogus `mkfs` program file in that directory. Because the fraudulent version appears in a directory mentioned earlier than the real one in `PATH`, the shell would run it rather than the legitimate version. The next time Superuser tries to run `mkfs`, the fraudulent version would run.

Trojan horses that lie in wait for and take advantage of the misspellings that most people make are among the most insidious types. For example, you might type `sl` instead of `ls`. Because you do not regularly execute a utility named `sl` and you may not remember typing the command `sl`, it is more difficult to track down this type of Trojan horse than one that takes the name of a more familiar utility.

A good way to help prevent the execution of a Trojan horse is to make sure that your `PATH` variable does not contain a single colon (`:`) at the beginning or end of the `PATH` string or a period (`.`) or double colon (`::`) anywhere in the `PATH` string. This precaution ensures that you will not execute a file in the working directory by accident. To check for a possible Trojan horse, examine the filesystem periodically for files with `setuid` (refer to item 5 on page 406) permission. The following command lists these files:



```
Listing setuid files # find / -perm -4000 -exec ls -lh {} \; 2> /dev/null
-rws--x--x. 1 root root 30K Oct  5 12:10 /usr/sbin/userhelper
-r--s--x---. 1 root apache 11K Aug 21 07:15 /usr/sbin/suexec
-rws--x--x. 1 root root 1.9M Oct  4 21:38 /usr/bin/Xorg
-rws--x--x. 1 root root 15K Oct  5 08:28 /usr/bin/chsh
-rwsr-xr-x. 1 root root 23K Sep 14 05:14 /usr/bin/passwd
-rws--x--x. 1 root root 16K Oct  5 08:28 /usr/bin/chfn
---s--x--x. 2 root root 169K Aug 21 04:24 /usr/bin/sudoedit
-rwsr-sr-x. 1 root root 45K Aug 21 03:26 /usr/bin/crontab
---s--x--x. 2 root root 169K Aug 21 04:24 /usr/bin/sudo
-rwsr-xr-x. 1 root root 60K Sep  7 08:04 /usr/bin/gpasswd
-rwsr-xr-x. 1 root root 51K Sep 29 11:58 /usr/bin/at
...
```

This command uses `find` to locate all files that have their setuid bit set (mode 4000). The hyphen preceding the mode causes `find` to report on any file that has this bit set, regardless of how the other bits are set. The output sent to standard error is redirected to `/dev/null` so that it does not clutter the screen.

You can also set up a program, such as AIDE (Advanced Intrusion Detection Environment; part of the `aide` package), that will take a snapshot of the system and check it periodically. See [sourceforge.net/projects/aide](http://sourceforge.net/projects/aide) for more information.

## GETTING HELP

The Fedora/RHEL distribution comes with extensive documentation (page 124). Red Hat maintains a Web page that points you toward many useful support documents: [www.redhat.com/apps/support](http://www.redhat.com/apps/support). Links to many other sources of assistance can be found at [fedoraproject.org/en/get-help](http://fedoraproject.org/en/get-help). Fedora maintains documents at [docs.fedoraproject.org](http://docs.fedoraproject.org). You can also find help on the System Administrators Guild site ([www.sage.org](http://www.sage.org)). The Internet is another rich source of information on managing a Linux system; refer to Appendix B (page 1033) and to the author's home page ([www.sobell.com](http://www.sobell.com)) for pointers to useful sites.

You do not need to act as a Fedora/RHEL system administrator in isolation; a large community of Linux/Fedora/RHEL experts is willing to assist you in getting the most out of your system, although you will get better help if you have already tried to solve a problem yourself by reading the available documentation. If you are unable to solve a problem by consulting the documentation, a well-thought-out question posed to the appropriate newsgroup, such as `comp.os.linux.misc`, or mailing list can often generate useful information. Be sure you describe the problem accurately and identify your system carefully. Include information about your version of Fedora/RHEL and any software packages and hardware that you think relate to the problem. The newsgroup `comp.os.linux.answers` contains postings of solutions to common problems and periodic postings of the most up-to-date versions of FAQs and HOWTO documents. See [www.catb.org/~esr/faqs/smart-questions.html](http://www.catb.org/~esr/faqs/smart-questions.html) for a helpful paper by Eric S. Raymond and Rick Moen titled "How to Ask Questions the Smart Way."

## SELINUX

Traditional Linux security, called *Discretionary Access Control* (DAC), is based on users and groups. Because a process run by a user has access to anything the user has access to, fine-grained access control is difficult to achieve. Fine-grained access control is particularly important on servers, which often hold programs that require **root** privileges to run.

SELinux (Security Enhanced Linux), which was developed by the U.S. National Security Agency (NSA), implements *Mandatory Access Control* (MAC) in the Linux kernel. MAC enforces security policies that limit what a user or program can do. It defines a security policy that controls some or all objects, such as files, devices, sockets, and ports, and some or all subjects, such as processes. Using SELinux, you can grant a process only those permissions it needs to be functional, following the principle of least privilege (page 406). MAC is an important tool for limiting security threats that come from user errors, software flaws, and malicious users. The kernel checks MAC rules after it checks DAC rules.

SELinux can be in one of three states (modes):

- **Enforcing**—The default state, wherein SELinux security policy is enforced. No user or program will be able to do anything not permitted by the security policy.
- **Permissive**—The diagnostic state, wherein SELinux sends warning messages to a log but does not enforce the security policy. You can use the log to build a security policy that matches your requirements.
- **Disabled**—SELinux does not enforce a security policy because no policy is loaded.

Running SELinux in permissive or enforcing state degrades system performance somewhat. Although SELinux usually does not provide benefit on a single-user system, you may want to consider using SELinux on a server that connects to the Internet. If you are unsure whether to use SELinux, selecting permissive state allows you to easily change to disabled or enforcing state at a later date.

SELinux implements one of the following policies:

- **Targeted**—Applies SELinux MAC controls only to certain (targeted) processes (default).
- **MLS**—Multilevel Security protection.
- **Strict**—Applies SELinux MAC controls to all processes (*RHEL*).

This section discusses the targeted policy. With such a policy, daemons and system processes that do not have a specified policy are controlled by traditional Linux DACs. With the strict policy, all processes are controlled by SELinux (MACs). Setting up a system that runs under strict policy is beyond the scope of this book.

There is always a tradeoff between security and usability. The targeted policy is less secure than the strict policy, but it is much easier to maintain. When you run the strict policy, you will likely have to customize the policy so that users can do their work and the system can function appropriately.

You can switch from one policy to the other (as explained shortly). Despite this flexibility, it is not a good idea to switch from a targeted to a strict policy on a production system. If you do so, some users may not be able to do their work. You would need to customize the policy in such a case. Changing from a strict to a targeted policy should not create any problems.

## MORE INFORMATION

Web NSA: [www.nsa.gov/research/selinux](http://www.nsa.gov/research/selinux)  
 Fedora SELinux wiki: [fedoraproject.org/wiki/SELinux](http://fedoraproject.org/wiki/SELinux)  
 SELinux News: [selinuxnews.org](http://selinuxnews.org)  
 SELinux for distributions (Sourceforge): [selinux.sourceforge.net](http://selinux.sourceforge.net)  
 Fedora SELinux mailing list: [www.redhat.com/mailman/listinfo/fedora-selinux-list](http://www.redhat.com/mailman/listinfo/fedora-selinux-list)  
 Fedora security: [fedoraproject.org/wiki/Security](http://fedoraproject.org/wiki/Security)  
 SELinux reference policy: [oss.tresys.com/projects/refpolicy](http://oss.tresys.com/projects/refpolicy)

### Turning off SELinux

**tip** There are two ways to disable SELinux: You can modify the `/etc/selinux/config` file so that it includes the line **SELINUX=disabled** and reboot the system, or you can use **system-config-selinux** (as explained on the next page).

If there is a chance you will want to enable SELinux in the future, putting SELinux in permissive mode is a better choice than disabling it. This strategy allows you to turn on SELinux more quickly when you decide to do so.

## config: THE SELINUX CONFIGURATION FILE

The `/etc/selinux/config` file, which has a link at `/etc/sysconfig/selinux`, controls the state of SELinux on the local system. Although you can modify this file, it may be more straightforward to work with `system-config-selinux` (as explained in the next section). In the following example, the policy is set to targeted, but that setting is of no consequence because SELinux is disabled:

```
$ cat /etc/selinux/config
# This file controls the state of SELinux on the system.
# SELINUX= can take one of these three values:
#     enforcing - SELinux security policy is enforced.
#     permissive - SELinux prints warnings instead of enforcing.
#     disabled - SELinux is fully disabled.
SELINUX=disabled
# SELINUXTYPE= type of policy in use. Possible values are:
#     targeted - Only targeted network daemons are protected.
#     strict - Full SELinux protection.
SELINUXTYPE=targeted
```

To put SELinux in enforcing mode, change the line containing the **SELINUX** assignment to **SELINUX=enforcing**. Similarly, you can change the policy by setting **SELINUXTYPE**.

### If you will use SELinux in the future

**tip** If you will use SELinux in the future but not now, turn it on when you install Linux, and run it in permissive state with the policy set to the policy you will eventually use. Permissive state writes the required extended information to inodes, but it does not stop you from doing anything on the system.

If you turn on SELinux after it has been disabled, when you reboot the system SELinux has to add extended attributes to the files in the filesystem. This process can take a long time on a large filesystem. If you are never going to use SELinux, disable it.

---

## getenforce, setenforce, AND sestatus: WORK WITH SELINUX

The **getenforce** and **setenforce** utilities report on and temporarily set the SELinux mode. The **sestatus** utility displays a summary of the state of SELinux:

```
# getenforce
Enforcing

# setenforce permissive

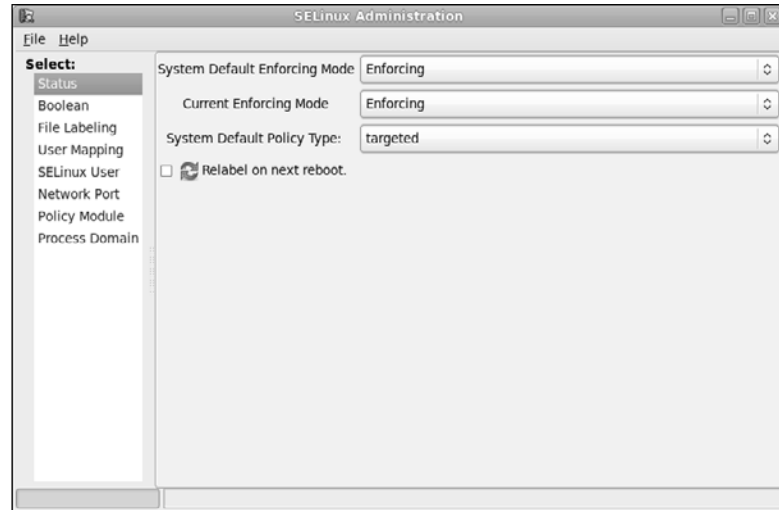
# sestatus
SELinux status:           enabled
SELinuxfs mount:         /selinux
Current mode:             permissive
Mode from config file:    enforcing
Policy version:           24
Policy from config file:   targeted
```

## SETTING THE TARGETED POLICY WITH system-config-selinux

The **system-config-selinux** utility displays the SELinux Administration window (Figure 11-1), which controls SELinux. To run this utility, enter **system-config-selinux** from a command line in a graphical environment or select **Main menu: System⇒Administration⇒SELinux Management**.

With **Status** highlighted on the left side of the SELinux Administration window, choose Enforcing (default), Permissive, or Disabled from the drop-down list labeled **System Default Enforcing Mode**. The mode you choose becomes effective next time you reboot the system. You can use the drop-down list labeled **Current Enforcing Mode** to change between Enforcing and Permissive modes immediately. When you change the mode using this list, the system resumes the default mode when you reboot it.

To modify the SELinux policy, highlight **Boolean** on the left side of the SELinux Administration window and scroll through the list of modules. For example, the SpamAssassin (page 682) module has two policies. The first, **Allow user spamassassin**



**Figure 11-1** The SELinux Administration window (system-config-selinux)

clients to use the network, does not have a tick in the check box in the column labeled **Active** (the left column) so SELinux does *not* allow user SpamAssassin clients to use the network. The second policy, **Allow spamd to read/write user home directories**, has a tick in the check box in the column labeled **Active**, which means that the SpamAssassin daemon (**spamd**) is allowed to read from and write to the home directories of users.

To find modules that pertain to NFS, type **nfs** in the text box labeled **Filter** and then press RETURN. The SELinux Administration window displays all modules with the string **nfs** in their descriptions. The modules with tick marks in the Active column are in use.

## THE UPSTART EVENT-BASED init DAEMON (FEDORA)

Because the traditional System V **init** daemon (SysVinit) does not deal well with modern hardware, including hotplug devices, USB hard and flash drives, and network-mounted filesystems, Fedora replaced it with the Upstart **init** daemon ([fedora-project.org/wiki/Features/Upstart](http://fedora-project.org/wiki/Features/Upstart)). RHEL still uses **xinetd** (page 445), a successor to the **init** daemon.

Several other replacements for SysVinit are also available. One of the most prominent, **initng** ([www.initng.org](http://www.initng.org)), is available for Debian and runs on Ubuntu. In addition, Solaris uses SMF (Service Management Facility) and MacOS uses **launchd**. Over time, Upstart will likely incorporate features of each of these systems.

The runlevel-based SysVinit daemon (**sysvinit** package) uses runlevels (single-user, multiuser, and more) and links from the `/etc/rc?.d` directories to the init scripts in `/etc/init.d` to start and stop system services. The event-based Upstart **init** daemon uses events to start and stop system services. With version 9, Fedora switched to the Upstart **init** daemon and began the transition from the SysVinit setup to the Upstart setup. This section discusses Upstart and the parts of SysVinit that remain: the `/etc/rc?.d` and `/etc/init.d` directories and the concept of runlevels.

The Upstart **init** daemon is event based and runs specified programs when something on the system changes. These programs, which are frequently scripts, start and stop services. This setup is similar in concept to the links to init scripts that SysVinit calls as a system enters runlevels, except Upstart is more flexible. Instead of starting and stopping services only when the runlevel changes, Upstart can start and stop services upon receiving information that something on the system has changed. Such a change is called an *event*. For example, Upstart can take action when it learns from `udev` (page 482) that a filesystem, printer, or other device has been added or removed from the running system. It can also start and stop services when the system boots, when the system is shut down, or when a job changes state.

**Future of Upstart** Changing from SysVinit to Upstart involves many parts of the Linux system. To make the switch smoothly and to introduce as few errors as possible, the Upstart team elected to make this transition over several releases.

Over time, Fedora will move away from the SysVinit setup and toward the cleaner, more flexible Upstart setup. As more system services are put under the control of Upstart, entries in the `/etc/event.d` directory will replace the contents of the `/etc/init.d` and `/etc/rc?.d` directories. Runlevels will no longer be a formal feature of Fedora, although they will be maintained for compatibility with third-party software. Eventually Upstart will also replace **crond**.

**Software package** The Upstart system uses the **upstart** package, which is installed by default. Some of the files Upstart uses are found in the **initscripts** package, which is also installed by default.

## DEFINITIONS

**Events** An *event* is a change in state that **init** can be informed of. Almost any change in state—either internal or external to the system—can trigger an event. For example, the boot loader triggers the **startup** event, the system entering runlevel 2 triggers the **runlevel 2** event, and a filesystem being mounted triggers the **path-mounted** event. Removing and installing a hotplug or USB device (such as a printer) can trigger an event. You can also trigger an event manually by giving the `initctl emit` command (page 421).

**Jobs** A *job* is a series of instructions that **init** reads. These instructions typically include a program (binary file or shell script) and the name of an event. The Upstart **init** daemon runs the program when the event is triggered. You can run and stop a job manually giving the `initctl start` and `stop` commands, respectively (page 421). Jobs are divided into tasks and services.

- Tasks** A *task* is a job that performs its work and returns to a waiting state when it is done.
- Services** A *service* is a job that does not normally terminate by itself. For example, the **logd** daemon and **getty** processes (page 423) are implemented as services. The **init** daemon monitors each service, restarting the service if it fails and killing the service if it is stopped manually or by an event.
- Job definition files** The **/etc/event.d** directory holds *job definition files* (files defining the jobs that the Upstart **init** daemon runs). Initially this directory is populated by the Upstart software packages (page 418). Installing some services will add files to this directory to control the service, replacing the files that were previously placed in the **/etc/rc?.d** and **/etc/init.d** directories when the service was installed.
- init is a state machine** At its core, the Upstart **init** daemon is a state machine. It keeps track of the state of jobs and, as events are triggered, tracks jobs as they change states. When **init** tracks a job from one state to another, it may execute the job's commands or terminate the job.
- Runlevel emulation** The System V **init** daemon used changes in runlevels (page 424) to determine when to start and stop processes. Fedora systems, which rely on the Upstart **init** daemon, have no concept of runlevels. To ease migration from a runlevel-based system to an event-based system, and to provide compatibility with software intended for other distributions, Fedora emulates runlevels using Upstart.
- The **rc?** jobs, which are defined by the **/etc/event.d/rc?** files, run the **/etc/init.d/rc** script. This script runs the **init** scripts in **/etc/init.d** from the links in the **/etc/rc?.d** directories, emulating the functionality of these links under SysVinit. The **rc?** jobs run these scripts as the system enters a runlevel; they take no action when the system leaves a runlevel. See page 422 for a discussion of the **rc2** job and page 426 for information on **init** scripts. Upstart implements the **runlevel** (page 424) and **telinit** (page 424) utilities to provide compatibility with SysVinit systems.
- initctl** The **initctl** (**init** control) utility allows a system administrator working with **root** privileges to communicate with the Upstart **init** daemon. This utility can start, stop, and report on jobs. For example, the **initctl list** command lists jobs and their states:

```
$ sudo initctl list
ck-log-system-restart (stop) waiting
ck-log-system-start (stop) waiting
ck-log-system-stop (stop) waiting
control-alt-delete (stop) waiting
logd (stop) waiting
...
tty5 (start) running, process 1271
tty6 (start) running, process 1274
vpnc-cleanup (stop) waiting
```

See the **initctl** man page and the examples in this section for more information. You can give the command **initctl help** (no hyphens before **help**) to display a list of **initctl** commands. Alternatively, you can give the following command to display more information about the **list** command:

```
$ initctl list --help
Usage: initctl list [OPTION]...
List known jobs.

Options:
  --show-ids          show job ids, as well as names
  -p, --pid=PID       destination process
  -q, --quiet          reduce output to errors only
  -v, --verbose        increase output ...
  --help              display this help and exit
  --version            output version information and exit
```

Report bugs to <fedora-devel-list@redhat.com>

Replace **list** with the **initctl** command for which you want to obtain more information. The **start**, **stop**, and **status** utilities are links to **initctl** that run the **initctl** commands they are named for.

## JOBS

Each file in the **/etc/event.d** directory defines a job and usually contains at least an event and a command. When the event is triggered, **init** executes the command. This section describes examples of both administrator-defined jobs and jobs installed with the Upstart packages.

### ADMINISTRATOR-DEFINED JOBS

**mudat** example The following administrator-defined job uses the **exec** keyword to execute a shell command. You can also use this keyword to execute a shell script stored in a file or a binary executable file.

```
$ cat /etc/event.d/mudat
start on runlevel 5
exec echo "Entering runlevel 5 on " $(date) > /tmp/mudat.out
```

This file defines a task: It runs the **echo** shell command when the system enters runlevel 5. This command writes a message that includes the time and date to **/tmp/mudat.out**. The shell uses command substitution (page 348) to execute the **date** utility. After this job runs to completion, the **mudat** task stops and enters a wait state. In the next example, the **cat** utility shows the contents of the **/tmp/mudat.out** file and the **initctl list** command reports on this task (the **status** utility displays the same information):

```
# cat /tmp/mudat.out
Entering runlevel 5 on  Sat Oct 17 12:27:14 PDT 2009

# initctl list mudat
mudat (stop) waiting
```

If the **exec** command line contains shell special characters (page 148), **init** executes **/bin/sh** (a link to **bash**) and passes the command line to the shell. Otherwise, **exec**



executes the command line directly. To run multiple shell commands, either use **exec** to run a shell script stored in a file or use **script...end script** (discussed next).

The Upstart **init** daemon can monitor only jobs (services) whose programs are executed using **exec**. It cannot monitor jobs run using **script...end script**. Put another way, *services* require the use of **exec** while *tasks* can use either method to run a program.

**myjob example** You can also define an event and set up a job that is triggered by that event. The **myjob** job definition file defines a job that is triggered by the **hithere** event:

```
$ cat /etc/event.d/myjob
start on hithere
script
    echo "Hi there, here I am!" > /tmp/myjob.out
    date >> /tmp/myjob.out
end script
```

The **myjob** file shows another way of executing commands: It includes two command lines between the **script** and **end script** keywords. These keywords always cause **init** to execute **/bin/sh**. The commands write a message and the date to the **/tmp/myjob.out** file. You can use the **initctl emit** command to trigger the job. In the next example, **init** displays the stages **myjob** goes through when you trigger it:

```
initctl emit      # initctl emit hithere
                  hithere
                  myjob (start) waiting
                  myjob (start) starting
                  myjob (start) pre-start
                  myjob (start) spawned, process 1772
                  myjob (start) post-start, (main) process 1772
                  myjob (start) running, process 1772
                  myjob (stop) running
                  myjob (stop) stopping
                  myjob (stop) killed
                  myjob (stop) post-stop
                  myjob (stop) waiting

                  # cat /tmp/myjob.out
                  Hi there, here I am!
                  Sat Oct 17 12:33:39 PDT 2009

                  # initctl list myjob
                  myjob (stop) waiting
```

**initctl start and stop** In this example, **cat** shows the output that **myjob** generates and **initctl** displays the status of the job. You can run the same job by giving the command **initctl start myjob** (or just **start myjob**). The **initctl start** command is useful when you want to run a job without triggering an event. For example, you can use the command **initctl start mudat** to run the **mudat** job from the previous example without triggering the **runlevel 2** event.

## JOB DEFINITION FILES IN `/etc/event.d`

As Fedora transitions from SysVinit to Upstart `init`, more jobs will be defined in the `/etc/event.d` directory. This section describes some of the jobs that the Upstart packages (page 418) put in this directory.

### optional SPECIFYING EVENTS WITH ARGUMENTS

The `telinit` and `shutdown` utilities emit `runlevel` events that include arguments. For example, `shutdown` emits `runlevel 0`, and `telinit 2` emits `runlevel 2`. You can match these events within a job definition using the following syntax:

```
start|stop on event [arg]
```

where *event* is an event such as `runlevel` and *arg* is an optional argument. To stop a job when the system enters runlevel 2, specify `stop on runlevel 2`. You can also specify `runlevel [235]` to match runlevels 2, 3, and 5 or `runlevel [!2]` to match any runlevel except 2.

**Event arguments** Although Upstart ignores additional arguments in an event, additional arguments in an event name within a job definition file must exist in the event. For example, `runlevel` (no argument) in a job definition file matches all `runlevel` events (regardless of arguments), whereas `runlevel S arg2` does not match any `runlevel` event because the `runlevel` event takes only one argument.

**rc2 task** The `/etc/event.d/rc2` job definition file defines the `rc2` task, which is similar to the other `rcn` tasks. The `rc2` task is started when the system enters multiuser mode without NFS (the event is named `runlevel 2`); it is stopped when the system enters any runlevel other than runlevel 2 (`runlevel [!2]`). The first part of the script calls the `runlevel` utility (page 424), which makes the system appear to be in runlevel 2 (there are no real runlevels) and assigns values to two variables. The real work is done by the `exec` command, which runs the `/etc/init.d/rc` script with an argument of `2`. This script calls the links in the `/etc/rcn.d` directory that correspond to its argument. Thus the `rc2` task runs the init scripts that the links in the `/etc/rc2.d` directory point to.

```
$ cat /etc/event.d/rc2
# rc2 - runlevel 2 compatibility
#
# This task runs the old sysv-rc runlevel 2 ("multi-user") scripts. It
# is usually started by the telinit compatibility wrapper.

start on runlevel 2

stop on runlevel [!2]

console output
script
    set $(runlevel --set 2 || true)
    if [ "$1" != "unknown" ]; then
        PREVLEVEL=$1
```

```

        RUNLEVEL=$2
        export PREVLEVEL RUNLEVEL
    fi

```

```

    exec /etc/init.d/rc 2
end script

```

tty services Following is the job definition file for the service that starts and monitors the **getty** process on **tty1**:

```

$ cat /etc/event.d/tty1
# tty1 - getty
#
# This service maintains a getty on tty1 from the point the system is
# started until it is shut down again.

start on stopped rc2
start on stopped rc3
start on stopped rc4

stop on runlevel 0
stop on runlevel 1
stop on runlevel 6

respawn
exec /sbin/mingetty tty1

```

This service starts the **getty** process when any of the events **runlevel 2** through **runlevel 4** are triggered and stops the **getty** process when either the **runlevel 0**, **runlevel 1**, or **runlevel 6** event is triggered (i.e., when the system is shut down, enters single-user mode, or is rebooted). The **respawn** keyword tells **init** to restart the job if it terminates, and **exec** runs a **mingetty** process on **tty1**. The **initctl** utility reports that the **tty1** service is stopped and waiting:

```

# initctl list tty1
tty1 (stop) waiting

```

**control-alt-delete** task See page 434 for a discussion of the **control-alt-delete** task, which you can use to bring the system down.

**rc-default** task and **inittab** Under SysVinit, the **initdefault** entry in the **/etc/inittab** file tells **init** which runlevel (page 424) to bring the system to when it comes up. Fedora includes an **inittab** file for compatibility with the old **init** daemon. If this file is not present, the Upstart **init** daemon (using the **rcS** task) boots the system to runlevel 3 (multiuser mode without X11). If you want the system to boot to a different runlevel, edit the **inittab** file. The following file causes the system to boot to runlevel 2:

```

$ cat /etc/inittab
...
:id:2:initdefault:

```

When the system comes up in single-user (recovery) mode, **init** requests the **root** password before displaying the **root** prompt.

Never set the system to boot to runlevel 0 or 6, as it will not come up properly. To boot to multiuser mode (runlevel 5), edit the **inittab** file shown in the example, replacing the 2 with a 5.

# SYSTEM OPERATION

This section covers the basics of how the system functions and how you can make intelligent decisions as a system administrator. It does not examine every aspect of system administration in the depth necessary to enable you to set up or modify all system functions. Instead, it provides a guide to bringing a system up and keeping it running from day to day.

## RUNLEVELS

With the introduction of Upstart, true runlevels disappeared from the system. As a transitional tool, runlevels were replaced with a structure that runs under Upstart and emulates runlevels (page 419). Table 11-1 lists these pseudorunlevels as they exist under Upstart.

**Table 11-1**    Pseudorunlevels

| Number         | Name                  | Login     | Network        | Filesystems |
|----------------|-----------------------|-----------|----------------|-------------|
| 0              | Halt                  |           |                |             |
| 1 (not S or s) | Single user           | Textual   | Down           | Mounted     |
| 2              | Multiuser without NFS | Textual   | Up (partially) | Mounted     |
| 3              | Multiuser             | Textual   | Up             | Mounted     |
| 4              | User defined          |           |                |             |
| 5              | Multiuser with X      | Graphical | Up             | Mounted     |
| 6              | Reboot                |           |                |             |

Default runlevel    By default, Fedora systems boot to graphical multiuser mode (runlevel 5). See “**rc-default task** and **inittab**” on page 423 for instructions explaining how to change this default.

runlevel    The **runlevel** utility displays the previous and current runlevels. This utility is a transitional tool; it provides compatibility with SysVinit. In the following example, the **N** indicates that the system does not know what the previous runlevel was and the **5** indicates that the system is in multiuser mode.

```
$ runlevel
N 5
```

telinit    The **telinit** utility allows a user with **root** privileges to bring the system down, reboot the system, or change between recovery (single-user) and multiuser modes. The

`telinit` utility is a transitional tool; it provides compatibility with SysVinit. On a system running Upstart, this utility emits a runlevel event based on its argument. The format of a `telinit` command is

*`telinit runlevel`*

where *`runlevel`* is one of the pseudorunlevels described in Table 11-1.

Recovery mode and  
the **root** password

When the system enters recovery (single-user) mode, **init** requests the **root** password before displaying the **root** prompt. When the system enters graphical multiuser mode, it displays a graphical login screen.

### Do not change runlevels directly into runlevel S

#### caution

Using `telinit` to request that the system change to runlevel 1 brings the system first to runlevel 1, where appropriate system processes (running system services) are killed, and then automatically to runlevel S. Changing directly to runlevel S puts the system into runlevel S but does not kill any processes first; it is usually a poor idea.

The Upstart **init** daemon consults `/etc/inittab` (page 423) only when the system is booting. At that time there are no processes left running from a previous runlevel, so going directly to runlevel S does not present a problem.

## BOOTING THE SYSTEM

*Booting* a system is the process of reading the Linux *kernel* (page 1090) into system memory and starting it running. Refer to “Boot Loader” on page 551 for more information on the initial steps of bringing a system up.

As the last step of the boot procedure, Linux runs the **init** program as PID number 1. The **init** program is the first genuine process to run after booting and is the parent of all system processes. (That is why when you run as **root** and kill process 1, the system dies.)

**initdefault**

The **initdefault** entry in the `/etc/inittab` file (page 473) tells **init** which runlevel to bring the system to (see Table 11-1 on page 424). Set **initdefault** to 3 to cause the system to present a text login message when it boots; set it to 5 to present a graphical login screen (default). For more information refer to “**rc-default** task and **inittab**” on page 423.

**init daemon**

As the last step of the boot procedure, Linux starts the **init** daemon (page 417) as PID number 1. The **init** daemon is the first genuine process to run after booting and is the parent of all system processes. (That is why when you kill process 1 while you are working with **root** privileges, the system dies.)

Once **init** is running, the **startup** event triggers the **rcS** task, which stops when the system enters any runlevel. The **rc-default** task starts when **rcS** stops. Based on the contents of `/etc/inittab` (page 423) or the absence of this file, **rc-default** either

- Executes `telinit` with an argument of S, which triggers **rcS-sulogin** and brings the system to recovery (single-user) mode, or
- Executes `telinit` with an argument of 2, which triggers **rc2** (page 422) and brings the system to multiuser mode.

Reinstalling the MBR If the Master Boot Record (MBR) is overwritten, the system will not boot into Linux and you need to rewrite the MBR.

## INIT SCRIPTS: START AND STOP SYSTEM SERVICES

The first script that runs is `/etc/rc.d/rc.sysinit`, which performs basic system configuration, including setting the system clock, hostname, and keyboard mapping; setting up swap partitions; checking the filesystems for errors; and turning on quota management (page 582). This script is run by the `rcS` task (as specified by the `/etc/event.d/rcS` job definition file; see page 422 for more information).

### List the kernel boot messages

**tip** To save a list of kernel boot messages, run `dmesg` immediately after booting the system and logging in:

```
$ dmesg > dmesg.boot
```

This command saves the kernel messages in a file named `dmesg.boot`. This list can be educational; it can also be useful when you are having a problem with the boot process. For more information see page 553.

**rc scripts** Next the `rcn` tasks (see “`rc2` task” on page 422 for an example) run the `/etc/rc.d/rc` init script, which runs the scripts for the services that need to be started when you first bring the system up and that need to be started or stopped when the system goes from single-user to multiuser mode and back down again. The init (initialization) scripts, also called rc (run command) scripts, are shell scripts located in the `/etc/rc.d/init.d` directory. They run via symbolic links in the `/etc/rc.d/rcn.d` directories, where `n` is the runlevel the system is entering.

The `/etc/rc.d/rcn.d` directories contain scripts whose names begin with the letter **K** (e.g., `K15httpd`, `K60nfs`, `K83bluetooth`) and scripts whose names begin with the letter **S** (e.g., `S25cups`, `S27NetworkManager`, `S55sshd`). When entering a new runlevel, each **K** (kill) script is executed with an argument of `stop`, and then each **S** (start) script is executed with an argument of `start`. Each of the **K** files is run in numerical order. The **S** files are run in similar fashion. This arrangement allows the person who sets up these files to control which services are stopped and which are started, and in what order, whenever the system enters a given runlevel. Using scripts with `start` and `stop` arguments promotes flexibility because it allows one script to both start and kill a process, depending on the argument it is called with.

To customize system initialization, you can add shell scripts to the `/etc/rc.d/init.d` directory and place links to these files in the `/etc/rc.d/rcn.d` directories. The following example shows several links to the `cups` script. These links are called to run the `cups` init script to start or stop the `cupsd` daemon at various runlevels:

```
$ pwd
/etc/rc.d
$ ls -l */*cups
-rwxr-xr-x. 1 root root 2947 Oct  8 04:45 init.d/cups
lrwxrwxrwx. 1 root root  14 Oct 14 20:38 rc0.d/K10cups -> ../init.d/cups
```

```

lrwxrwxrwx. 1 root root 14 Oct 14 20:38 rc1.d/K10 cups -> ../init.d/cups
lrwxrwxrwx. 1 root root 14 Oct 14 20:38 rc2.d/S25 cups -> ../init.d/cups
lrwxrwxrwx. 1 root root 14 Oct 14 20:38 rc3.d/S25 cups -> ../init.d/cups
lrwxrwxrwx. 1 root root 14 Oct 14 20:38 rc4.d/S25 cups -> ../init.d/cups
lrwxrwxrwx. 1 root root 14 Oct 14 20:38 rc5.d/S25 cups -> ../init.d/cups
lrwxrwxrwx. 1 root root 14 Oct 14 20:38 rc6.d/K10 cups -> ../init.d/cups

```

Each link in `/etc/rc.d/rcn.d` should point to a file in `/etc/rc.d/init.d`. For example, the file `/etc/rc.d/rc1.d/K10 cups` is a link to the file named `cups` in `/etc/rc.d/init.d`. (The numbers that are part of the filenames of the links in the `/etc/rc.d/rcn.d` directories may change from one release of the operating system to the next, but the scripts in `/etc/rc.d/init.d` always have the same names.) The names of files in the `/etc/rc.d/init.d` directory are functional. Thus, when you want to turn NFS services on or off, use the `nfs` script. Similarly when you want to turn basic network services on or off, run the `NetworkManager` script. The `cups` script controls the printer daemon. Each script takes an argument of `stop` or `start`, depending on what you want to do. Some scripts also take other arguments, such as `restart`, `reload`, and `status`. Run a script without an argument to display a usage message indicating which arguments it accepts.

Following are three examples of calls to init scripts. You may find it easier to use `service` (discussed next) in place of the pathnames in these commands:

```

# /etc/rc.d/init.d/nfs stop
# /etc/rc.d/init.d/NetworkManager start
# /etc/rc.d/init.d/NetworkManager restart

```

The first example stops all NFS processes (processes related to serving filesystems over the network). The second example starts all processes related to basic network services. The third example stops and then restarts these same processes.

### Maintain the links in the `/etc/rc*.d` hierarchy

**tip** Refer to page 429 for information about using `chkconfig` to maintain the symbolic links in the `/etc/rc*.d` hierarchy.

The `/etc/rc.d/rc.local` file is executed after the other init scripts. Put commands that customize the system in `rc.local`. Although you can add any commands you like to `rc.local`, it is best to run them in the background so that if they hang, they do not stop the boot process.

## service: CONFIGURES SERVICES I

Fedora/RHEL provides `service`, a handy utility that can report on or change the status of any of the system services in `/etc/rc.d/init.d`. In place of the commands described at the end of the previous section, you can give the following commands from any directory:

```

# /sbin/service nfs stop
# /sbin/service NetworkManager start
# /sbin/service NetworkManager restart

```

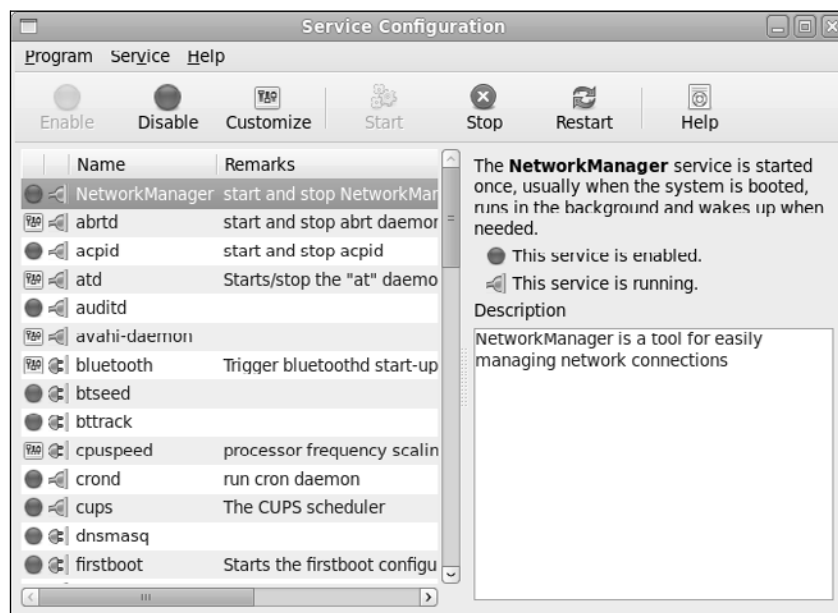
The command `/sbin/service --status-all` displays the status of all system services. The next section explores yet another way to configure system services.

## system-config-services: CONFIGURES SERVICES II

The `system-config-services` utility displays the Service Configuration window (Figure 11-2). This utility has two functions: It turns system services on and off immediately, and it controls which services are stopped and started when the system enters and leaves runlevels 2–5. The `system-config-services` utility works with many of the services listed in `/etc/rc.d/init.d` as well as with those controlled by `xinetd` (page 445) and listed in `/etc/xinetd.d` (or specified in `/etc/xinetd.conf`). To run `system-config-services`, enter `system-config-services` from a command line in a graphical environment or select **Main menu: System**⇒**Administration**⇒**Services**.

The left side of the Service Configuration window displays a scrollable list of services. At the left end of each line is a red or green circle or a small bank of three switches. A green circle indicates the service is enabled; a red circle indicates it is disabled. The same information is repeated on the right side of the window. If a bank of switches appears in place of the circle, the right side of the window contains information about which runlevels the service is enabled in.

To the right of the circle or switches is a plug that is either plugged in or unplugged to indicate the service highlighted on the left is running or not running, respectively. Additionally, the right side of the window displays a description of the service.



**Figure 11-2** The Service Configuration window



Scroll to and highlight the service you want to work with. Click the buttons on the tool bar to enable, disable, customize, start, stop, or restart (stop and then start) the highlighted service.

The start, stop, and restart buttons turn the service on or off immediately; the change does not affect whether the service will run the next time you boot the system, enter another runlevel, or reenter the current runlevel. These changes are equivalent to those you would make with the `service` utility (page 427).

When you click **Customize**, `system-config-services` displays the Customize Runlevels window. Put ticks in the check boxes labeled with the runlevels you want the service enabled in and then click **OK**. Now when the system enters one of the runlevels marked with a tick, it will turn the service on. The current state of the service is not changed.

### SERVICES THAT DEPEND ON `xinetd`

Some services, such as `rsync`, depend on the `xinetd` daemon (page 445) being installed and running. As with other services, highlight the service to read a description of it. Click the Enable or Disable button on the toolbar to turn the service on or off. This action changes the **yes/no** parameter of the **disable** line discussed on page 447. Restart `xinetd` by scrolling to the `xinetd` service and clicking **Restart**. These changes affect all runlevels and will remain in effect through changes in runlevels and reboots unless you change them again. They are equivalent to the changes you would make with the `chkconfig` utility (see the next section).

## chkconfig: CONFIGURES SERVICES III

The `chkconfig` character-based utility duplicates much of what the `system-config-services` utility does: It makes it easier for a system administrator to maintain the `/etc/rc.d` directory hierarchy. This utility can add, remove, list startup information, and check the state of system services. It changes the configuration only—it does not change the current state of any service. To see a list of all services, give the following command (you can omit the `--l` option):

```
$ /sbin/chkconfig --list
NetworkManager 0:off 1:off 2:on 3:on 4:on 5:on 6:off
abrttd          0:off 1:off 2:off 3:on 4:off 5:on 6:off
atd             0:off 1:off 2:off 3:on 4:on 5:on 6:off
auditd          0:off 1:off 2:on 3:on 4:on 5:on 6:off
avahi-daemon    0:off 1:off 2:off 3:on 4:on 5:on 6:off
bluetooth       0:off 1:off 2:off 3:on 4:on 5:on 6:off
cpuspeed        0:off 1:on 2:on 3:on 4:on 5:on 6:off
crond           0:off 1:off 2:on 3:on 4:on 5:on 6:off
cups            0:off 1:off 2:on 3:on 4:on 5:on 6:off
...
```

All services that run their own daemons are listed, one to a line, followed by their configured state for each runlevel. You can check how a specific daemon is configured by adding its name to the previous command:

```
$ /sbin/chkconfig --list sshd
sshd          0:off  1:off  2:on   3:on   4:on   5:on   6:off
```

To make changes using `chkconfig`, you must work with **root** privileges. In the next example, `chkconfig` configures the `/etc/rc.d` directory hierarchy so that `sshd` will be off in runlevels 2, 3, 4, and 5 and then confirms this change:

```
# /sbin/chkconfig --level 2345 sshd off
# /sbin/chkconfig --list sshd
sshd          0:off  1:off  2:off  3:off  4:off  5:off  6:off
```

For convenience, you can omit the `--level 2345` option. When you specify an init script and **on** or **off**, `chkconfig` defaults to runlevels 2, 3, 4, and 5. The following command is equivalent to the first of the preceding commands:

```
# chkconfig sshd off
```

Both `ps` and `service` confirm that even though `chkconfig` set things up so that `sshd` would be off in all runlevels, this daemon is still running. The `chkconfig` utility did not shut down `sshd`. In the following example, the second command line shows that when you give a `service` command followed by the name of an init script, you get the usage message from the script:

```
# ps -ef | grep sshd
root      6735    1  0 13:55 ?          00:00:00 /usr/sbin/sshd
root      6790  6667  0 13:57 pts/0    00:00:00 grep sshd
# /sbin/service sshd
Usage: /etc/init.d/sshd {start|stop|restart|reload|force-reload|condrestart|try-restart|status}
# /sbin/service sshd status
openssh-daemon (pid 6735) is running...
```

With the preceding changes, when you reboot the system, `sshd` will not start. You can stop it more easily using the `service` utility, however:

```
# /sbin/service sshd stop
Stopping sshd: [ OK ]
# ps -ef | grep sshd
root      6834  6667  0 13:57 pts/0    00:00:00 grep sshd
# /sbin/service sshd status
openssh-daemon is stopped
```

## SINGLE-USER MODE

When the system is in single-user mode, only the system console is enabled. You can run programs from the console in single-user mode just as you would from any terminal in multiuser mode. The only difference is that few of the system daemons will be running. The scripts in `/etc/rc.d/rc1.d` are run as part of single-user initialization. See page 435 for instructions on bringing the system to single-user mode.

With the system in single-user mode, you can perform system maintenance that requires filesystems to be unmounted or that requires just a quiet system—no one except you using it, so that no user programs interfere with disk maintenance and backup programs. The classical UNIX term for this state is *quiescent*. See “Backing Up Files” on page 558 for a discussion of one of the most important and often neglected areas of system administration.

## GOING TO MULTIUSER MODE

After you have determined that all is well with the filesystems, you can bring the operating system up to multiuser mode. When you exit from the single-user shell, `init` brings the system to the default runlevel—usually `5` (page 425). Alternatively, you can give the following command in response to the Superuser prompt to bring the system to textual multiuser mode (use `5` to go to graphical multiuser mode):

```
# /sbin/telinit 3
```

The `telinit` utility tells `init` which runlevel to enter. Under RHEL, the `telinit` executable is a symbolic link to the `init` executable, but by convention, running `telinit` is preferred to running `init` directly. Under Fedora it is a separate utility.

When it goes from single-user to textual multiuser mode, the system executes the **K** (kill or stop) scripts and then the **S** (start) scripts in `/etc/rc.d/rc3.d`. For more information refer to “Init Scripts: Start and Stop System Services” on page 426. Use `chkconfig` (page 429) to stop one of these scripts from running when the system enters the new runlevel.

Runlevel `2` is referred to as multiuser mode, and runlevel `3` is called extended multiuser mode. But because runlevel `2` is rarely used, this chapter uses the term *multiuser* to refer to runlevel `3`. Runlevel `4` is not used, and runlevel `5` is graphics or X11 mode.

## GRAPHICAL MULTIUSER MODE

Graphical multiuser mode is the default state for a Fedora/RHEL system. In this mode all appropriate filesystems are mounted, and users can log in from all connected terminals, dial-up lines, and network connections. All support services and daemons are enabled and running. Once the system is in graphical multiuser mode, a login screen appears on the console. Most systems are set up to boot directly to graphical multiuser mode without stopping at single-user mode.

## LOGGING IN

**Textual login** With a textual login, the system uses `init`, `mingetty`, and `login` to allow a user to log in; `login` uses PAM modules (page 458) to authenticate users. Once the system is in multiuser mode, the Upstart `init` daemon is responsible for spawning a `mingetty` process on each of the lines that a user can use to log in. For more information refer to “tty services” on page 423.

When you enter your username, `mingetty` establishes the characteristics of your terminal. It then overlays itself with a login process and passes to the login process whatever you entered in response to the **login:** prompt. Using PAM, the login process examines the `/etc/passwd` file to see whether a username matches the username you entered. PAM then examines the `/etc/shadow` file to see whether a password is associated with the username. If it is, login prompts you for a password; if not, it continues without requiring a password. When your username requires a password, login verifies the password you enter by checking the `/etc/shadow` file again. If either

your username or your password is not correct, login displays **Login incorrect**, pauses, and prompts you to log in again.

All passwords in the `/etc/shadow` file are encrypted or hashed using MD5 (page 1093). It is not feasible to recover an encrypted password. When you log in, the login process encrypts/hashes the password you type at the prompt and compares it to the encrypted/hashed password in `/etc/shadow`. If the two passwords match, you are authenticated.

**Graphical login** With a graphical login, the Upstart `init` daemon starts `gdm` (the GNOME display manager) by default on the first free virtual terminal, providing features similar to those offered by `mingetty` and `login`. The `gdm` utility starts an X server and presents a login window. The `gdm` display manager then uses PAM to authenticate the user and runs the scripts in the `/etc/gdm/PreSession` directory. These scripts inspect the user's `~/.dmrc` file, which stores the user's default session and language, and launch the user's session. GNOME stores the state of the last saved session and attempts to restore it when the user logs back in.

With NIS, login compares the username and password with the information in the appropriate naming service instead of (or in addition to) the `passwd` and `shadow` files. If the system is configured to use both methods (`/etc/passwd` and NIS), it checks the `/etc/nsswitch.conf` file (page 455) to see in which order it should consult them.

PAM (page 458)—the Pluggable Authentication Module facility—allows you greater control over user logins than the `/etc/passwd` and `/etc/shadow` files do. Using PAM, you can specify multiple levels of authentication, mutually exclusive authentication methods, or parallel methods, each of which is by itself sufficient to grant access to the system. For example, you can have different authentication methods for console logins and for `ssh` logins. Likewise, you can require that modem users authenticate themselves via two or more methods (such as a smart-card or badge reader and a password). PAM modules also provide security technology vendors with a convenient way to interface their hardware or software products with a system.

When the username and password are correct, login or the scripts in `PreSession` consult the appropriate services to initialize your user and group IDs, establish your home directory, and determine which shell or desktop manager you will be working with.

The login utility/`PreSession` scripts assign values to the `HOME`, `PATH`, `LOGNAME`, `SHELL`, `TERM`, and `MAIL` variables. They look in the `/etc/group` file (page 472) to identify the groups the user belongs to. When login has finished its work, it overlays itself with the login shell, which inherits the variables set by login. In a graphical environment, the `PreSession` scripts start the desktop manager.

During a textual login, the login shell assigns values to additional shell variables and executes the commands in the system startup shell scripts `/etc/profile` and `/etc/bashrc`. Some systems have additional system startup shell scripts. Although the actions performed by these scripts are system dependent, they typically display the contents of the `/etc/motd` (message of the day) and `/etc/issue` files, let you know that you have mail, and set `umask` (page 440), the file-creation mask.

After executing the system startup commands, the shell executes the commands from the personal startup shell scripts in your home directory. For a list of these scripts, refer to page 281. Because the shell executes the personal startup scripts *after* the system scripts, a sophisticated user can override any variables or conventions that were established by the system, whereas a new user can remain uninvolved in these matters.

## LOGGING OUT

When the system displays a shell prompt, you can either execute a program or exit from the shell. If you exit from the shell, the process running the shell dies and the parent process wakes up. When the shell is a child of another shell, the parent shell wakes up and displays a prompt. Exiting from a login shell causes the operating system to send Upstart a signal that one of its children has died. Upon receiving this signal, Upstart takes action based on the contents of the appropriate `tty` job definition file (page 423). In the case of a process controlling a line for a terminal, Upstart informs `mingetty` that the line is free for another user.

When you are at runlevel 5 and exit from a GUI, the GNOME display manager, `gdm`, initiates a new login display.

## BRINGING THE SYSTEM DOWN

The shutdown and halt utilities perform the tasks needed to bring the system down safely. These utilities can restart the system, prepare the system to be turned off, put the system in single-user mode, and, on some hardware, power down the system. The `poweroff` and `reboot` utilities are linked to `halt`. If you call `halt` when the system is not shutting down (runlevel 0) or rebooting (runlevel 6), `halt` calls `shutdown`. (When you are running as a user other than Superuser, the link goes through `consolehelper` [page 409].)

You must tell `shutdown` when you would like to bring the system down. This time can be expressed as an absolute time of day, as in 19:15, which causes the shutdown to occur at 7:15 P.M. Alternatively, you can give the number of minutes from the present time, as in +15, which means 15 minutes from now. To bring the system down immediately (recommended for emergency shutdowns only or when you are the only user logged in), you can give the argument +0, or its synonym, **now**. When the shutdown time exceeds 5 minutes, all `nonroot` logins are disabled for the last 5 minutes before shutdown.

Calling `shutdown` with the `-r` option causes the system to reboot (same as the `reboot` command except that `reboot` implies **now**). Adding the `-f` option forces a fast reboot, in which filesystem checking is disabled (see the `shutdown` man page for details). Using `-h` instead of `-r` forces the system to halt (same as the `halt` command except that `halt` implies **now**). A message appears once the system has been safely halted: **System halted**. Because most ATX systems turn off automatically after shutdown, you are unlikely to see this message.

Because Linux is a multiuser system, `shutdown` warns all users before taking action. This warning gives users a chance to prepare for the shutdown, perhaps by writing out editor files or exiting from networking applications. You can replace the default shutdown message with one of your own by following the time specification on the command line with a message:

```
# /sbin/shutdown -h 09:30 Going down 9:30 to install disk, up by 10am.
```

### Do not turn the power off before bringing the system down

---

**caution** Do not turn the power off on a Linux system without first bringing it down as described here. Like UNIX, Linux speeds disk access by keeping an in-memory collection of disk buffers that are written to the disk periodically or when system use is momentarily low. When you turn off or reset the computer without writing the contents of these disk buffers to the disk, you lose any information in the buffers. Running the `shutdown` utility forces these buffers to be written. You can force the buffers to be written at any time by issuing a `sync` command. However, `sync` does not unmount filesystems, nor does it bring the system down.

---

### CONTROL-ALT-DEL: REBOOTS THE SYSTEM

In a textual environment, pressing the key sequence CONTROL-ALT-DEL (also referred to as the *three-finger salute* or the *Vulcan death grip*) on the console causes the kernel to trigger a `control-alt-delete` event that causes `init` to run the commands in `/etc/event.d/control-alt-delete`. See page 418 for more information on Upstart events. These commands safely reboot the system by issuing a `shutdown` command. You can disable the CONTROL-ALT-DEL sequence by removing the `/etc/event.d/control-alt-delete` file (or by moving it to another directory for safekeeping).

In a graphical environment, the X Window System traps this key sequence but the window manager does not pass it to the kernel. As a result, CONTROL-ALT-DEL does not work in a graphical environment.

### consolehelper: ALLOWS AN ORDINARY USER TO RUN A PRIVILEGED COMMAND

Two executable `reboot` files exist:

```
$ file /sbin/reboot /usr/bin/reboot
/sbin/reboot:      ELF 32-bit LSB executable, Intel 80386, version 1 ...
/usr/bin/reboot:   symbolic link to 'consolehelper'
```

The file in `/sbin` runs the `reboot` utility, whereas the file in `/usr/bin` is a link to `consolehelper`. In `root`'s `PATH` variable, `/sbin` normally precedes `/usr/bin`. Thus, when someone running in a `root` environment gives a `reboot` command, the shell executes `/sbin/reboot` (the `reboot` utility). Normally `/usr/bin` appears before `/sbin` in an ordinary user's `PATH`; when an ordinary user gives a `reboot` command, the shell follows the link from `/usr/bin/reboot` and executes `/usr/bin/consolehelper`.

What `consolehelper` does depends on how PAM is set up. See `/etc/pam.d/reboot` to determine which modules it calls, `/usr/share/doc/pam-*/txts` to read descriptions of the modules, the `pam_console` man page to obtain general information on this facility, and “PAM” on page 458 for more information. As shipped by Fedora/RHEL, `consolehelper` does not require the `root` password; any user can give a `reboot` command from the system console to shut the system down.

## GOING TO SINGLE-USER MODE

Because going from multiuser to single-user mode can affect other users, you must be working as Superuser to make this change. Make sure that you give other users enough warning before switching to single-user mode; otherwise, they may lose whatever they were working on.

The following steps describe a method of manually bringing the system down to single-user mode—the point where it is safe to turn the power off. You must be working as Superuser to perform these tasks.

1. Use `wall` (write all) to warn everyone who is using the system to log out.
2. If you are sharing files via NFS, use `exportfs -ua` to disable network access to the shared filesystems. (Use `exportfs` without an argument to see which filesystems are being shared.)
3. Confirm that no critical processes are running in the background (some-one running an unattended compile or some other job).
4. Give the command `/sbin/telinit 1` to bring the system down to single-user mode. The system will display messages about the services it is shutting down and finally display a `bash` shell prompt similar to `sh-3.1#`. The `runlevel` utility confirms that the system is in runlevel 1 (S for single-user mode):

```
# /sbin/telinit 1
```

```
# runlevel
1 S
```

5. Use `umount -a` to unmount all mounted devices that are not in use. Use `mount` without an argument to make sure that no devices other than root (`/`) are mounted before continuing.

## TURNING THE POWER OFF

Once the system is in single-user mode, shutting it down is quite straightforward: Give the command `telinit 0` (preferred), `poweroff`, `reboot -p`, or `halt`. You can build a kernel with `apm` so it turns the machine off at the appropriate time. If your machine is not set up this way, turn the power off when the appropriate prompt appears or when the system starts rebooting.

## CRASH

A *crash* occurs when the system stops suddenly or fails unexpectedly. A crash may result from software or hardware problems or from a loss of power. As a running system loses power, it may behave in erratic or unpredictable ways. In a fraction of a second, some components are supplied with enough voltage; others are not. Buffers are not flushed, corrupt data may be written to the hard disk, and so on. IDE drives do not behave as predictably as SCSI drives under these circumstances. After a crash, you must bring the operating system up carefully to minimize possible damage to the filesystems. On many occasions, little or no damage will have occurred.

### REPAIRING A FILESYSTEM

Although the filesystems are checked automatically during the boot process if needed, you will have to check them manually if a problem cannot be repaired automatically. To check the filesystems manually after a crash, boot the system to single-user mode. *Do not* mount any devices other than root, which Linux mounts automatically. Run `fsck` (page 492) on all local filesystems that were mounted at the time of the crash, repairing them as needed. Depending on how the system is set up, when `fsck` cannot repair a filesystem automatically, the system may enter emergency mode so that you can run `fsck` manually. Make note of any ordinary files or directories that you repair (and can identify), and inform their owners that they may not be complete or correct. Look in the **lost+found** directory *in each filesystem* for missing files. After successfully running `fsck`, type `exit` to exit from the single-user shell and resume booting the system.

If files are not correct or are missing altogether, you may have to re-create them from a backup copy of the filesystem. For more information refer to “Backing Up Files” on page 558.

### WHEN THE SYSTEM DOES NOT BOOT

When you cannot boot the computer from the hard drive, you can try to boot the system into rescue mode. For more information refer to “Rescue Mode” on page 411. If the system comes up in rescue mode, run `fsck` on the root filesystem and try booting from the hard drive again.

When all else fails, go through the install procedure, and perform an “upgrade” to the current version of Linux. Fedora/RHEL systems can perform a nondestructive upgrade and can fix quite a bit of damage in the process. For more information refer to page 29.

---

## SYSTEM ADMINISTRATION UTILITIES

This section briefly describes a few of the many utilities that can help you perform system administration tasks. Some of these utilities are incorporated as part of the Main menu, and some are useful to users other than the system administrator.



## FEDORA/RHEL CONFIGURATION TOOLS

Most of the Fedora/RHEL configuration tools are named `system-config-*`. These tools bring up a graphical display when called from a GUI; some display a textual interface when called from a non-GUI command line. Some, such as `system-config-firewall-tui`, use a name with a `-tui` extension for the textual interface. In general, these tools, which are listed in Table 11-2, are simple to use and require little explanation beyond what the tool presents. Some have Help selections on their toolbar; most do not have man pages.

If the tool is not present on your system, use `yum` (page 498) to install it.

**Table 11-2** Fedora/RHEL configuration tools

| Tool                                                        | Function                                                                                                                                                                                                                                                                                                                                                                      |
|-------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>system-config-authentication</code>                   | Displays the Authentication Configuration window with three tabs. The User Information tab allows you to enable NIS, LDAP, Hesiod, and Winbind support. The Authentication tab allows you to work with Kerberos, LDAP, Smart Card, Fingerprint Reader, and Windbind. The Options tab allows you to use shadow and sha512 passwords as well as to enable other system options. |
| <code>system-config-bind</code>                             | Displays the Domain Name Service window. (page 789).                                                                                                                                                                                                                                                                                                                          |
| <code>system-config-boot</code>                             | Allows you to specify a default kernel and timeout for the <code>grub.conf</code> file (page 552).                                                                                                                                                                                                                                                                            |
| <code>system-config-date</code>                             | Displays the Date/Time Properties window with two tabs: Date & Time and Time Zone. You can set the date and time or enable NTP (Network Time Protocol) from the first tab. The Time Zone tab allows you to specify the time zone of the system clock or set the system clock to <i>UTC</i> (page 1114).                                                                       |
| <code>system-config-display</code>                          | Brings up the Display Settings window with three tabs: Settings, Hardware, and Dual Head (page 84).                                                                                                                                                                                                                                                                           |
| <code>system-config-firewall[-tui]</code> ( <i>FEDORA</i> ) | Displays the Firewall Configuration window (page 824).                                                                                                                                                                                                                                                                                                                        |
| <code>system-config-httpd</code>                            | Displays the HTTP window with four tabs: Main, Virtual Hosts, Server, and Performance Tuning (page 846).                                                                                                                                                                                                                                                                      |
| <code>system-config-keyboard</code>                         | Displays the Keyboard window, which allows you to select the type of keyboard attached to the system. You use this utility to select the keyboard when you install the system.                                                                                                                                                                                                |

**Table 11-2**    Fedora/RHEL configuration tools (continued)

| Tool                           | Function                                                                                                                                                                                                             |
|--------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| system-config-language         | Displays the Language Selection window, which allows you to specify the default system language from among those that are installed. You use this utility to select the system language when you install the system. |
| system-config-lvm              | Displays the Logical Volume Management window, which allows you to modify existing logical volumes (page 38).                                                                                                        |
| system-config-network[-tui]    | Displays the Network Configuration window (page 601).                                                                                                                                                                |
| system-config-network-cmd      | Displays the parameters that system-config-network uses.                                                                                                                                                             |
| system-config-nfs              | Displays the NFS Server Configuration window (page 737).                                                                                                                                                             |
| system-config-packages (RHEL)  | Runs pirut (page 505).                                                                                                                                                                                               |
| system-config-printer          | Displays the Printer Configuration window, which allows you to set up printers and edit printer configurations (page 521).                                                                                           |
| system-config-rootpassword     | Displays the Root Password window, which allows you to change the <b>root</b> password. While logged in as <b>root</b> , you can also use <b>passwd</b> from a command line to change the <b>root</b> password.      |
| system-config-samba            | Displays the Samba Server Configuration window, which can help you configure Samba (page 753).                                                                                                                       |
| system-config-selinux (FEDORA) | Displays the SELinux Administration window, which controls SELinux (page 416).                                                                                                                                       |
| system-config-services         | Displays the Service Configuration window, which allows you to specify which daemons (services) run at each runlevel (page 428).                                                                                     |
| system-config-soundcard (RHEL) | Displays the Audio Devices window, which tells you which audio device the system detected and gives you the option of playing a sound to test the device.                                                            |
| system-config-users            | Displays the User Manager window, which allows you to work with users and groups (page 556).                                                                                                                         |

## COMMAND-LINE UTILITIES

This section describes a few command-line system administration tools you may find useful. To learn more about most of these utilities, read the *man* pages. For information about *umask* and *uname*, see the *info* pages.

**chsh** Changes the login shell for a user. When you call **chsh** without an argument, you change your own login shell. Superuser can change the shell for any user by calling **chsh** with that user's username as an argument. When changing a login shell with **chsh**, you must specify an installed shell that is listed in the file `/etc/shells`; other entries are rejected. Also, you must give the pathname to the shell exactly as it appears in `/etc/shells`. The **chsh --list-shells** command displays the list of available shells. In the following example, Superuser changes Sam's shell to **tcsh**:

```
# chsh sam
Changing shell for sam.
New shell [/bin/bash]: /bin/tcsh
Shell changed.
```

**clear** Clears the screen. You can also use **CONTROL-L** from the **bash** shell to clear the screen. The value of the environment variable **TERM** (page 1040) is used to determine how to clear the screen.

**dmesg** Displays the kernel ring buffer (page 553).

**e2label** Displays or creates a volume label on an **ext2**, **ext3**, or **ext4** filesystem. An **e2label** command has the following format:

```
e2label device [newlabel]
```

where *device* is the name of the device (e.g., `/dev/hda2`, `/dev/sdb1`, `/dev/fd0`) you want to work with. When you include the optional *newlabel* parameter, **e2label** changes the label on *device* to *newlabel*. Without this parameter, **e2label** displays the label. You can also create a volume label with the **-L** option of **tune2fs** (page 492).

**mkfs** Creates a new filesystem on a device. This utility is a front end for many utilities, each of which builds a different type of filesystem. By default, **mkfs** builds an **ext2** filesystem and works on either a hard disk partition or a floppy diskette. Although it can take many options and arguments, you can use **mkfs** simply as

```
# mkfs device
```

where *device* is the name of the device (e.g., `/dev/hda2`, `/dev/sdb1`, `/dev/fd0`) you want to make a filesystem on. Use the **-t** option to specify a type of filesystem. The following command creates an **ext4** filesystem on `/dev/sda1`:

```
# mkfs -t ext4 /dev/sda1
```

**ping** Sends packets to a remote system. This utility determines whether you can reach a remote system through the network and tells you how much time it takes to exchange messages with the remote system. Refer to “ping: Tests a Network Connection” on page 379.

**reset** (link to **tset**) Resets terminal characteristics. The value of the environment variable **TERM** (page 1040) determines how to reset the screen. The screen is cleared, the kill and interrupt characters are set to their default values, and character echo is turned on. When given from a graphical terminal emulator, this command also changes the size of the window to its default. The **reset** utility is useful to restore your screen to a sane state after it has been corrupted. It is similar to an **stty sane** command.

**setserial** Gets and sets serial port information. Superuser can use this utility to configure a serial port. The following command sets the input address of `/dev/ttys0` to 0x100, the interrupt (IRQ) to 5, and the baud rate to 115,000 baud:

```
# setserial /dev/ttys0 port 0x100 irq 5 spd_vhi
```

You can also check the configuration of a serial port with **setserial**:

```
# setserial /dev/ttys0
/dev/ttyS0, UART: 16550A, Port: 0x0100, IRQ: 5, Flags: spd_vhi
```

Normally, **setserial** is called when the system is booting if a serial port needs custom configuration.

**stat** Displays information about a file or filesystem. Giving the `-f` (filesystem) option followed by the device name or mount point of a filesystem displays information about the filesystem including the maximum length of filenames (**Namelen** in the following example). See the **stat** man page for more information.

```
$ stat -f /dev/sda
File: "/dev/sda"
ID: 0          Namelen: 255      Type: tmpfs
Block size: 4096      Fundamental block size: 4096
Blocks: Total: 121237   Free: 121206    Available: 121206
Inodes: Total: 121237   Free: 120932
```

**umask** A shell builtin that specifies a mask the system uses to set up access permissions when you create a file. A **umask** command has the following format:

```
umask [mask]
```

where *mask* is a three-digit octal number or a symbolic value such as you would use with **chmod** (page 204). The *mask* specifies the permissions that are *not* allowed. When *mask* is an octal number, the digits correspond to the permissions for the owner of the file, members of the group the file is associated with, and everyone else. Because *mask* specifies the permissions that are *not* allowed, the system subtracts each of the three digits from 7 when you create a file. The result is three octal numbers that specify the access permissions for the file (the numbers you would use with **chmod**). A *mask* that you specify using symbolic values indicates the permissions that *are* allowed.

Most utilities and applications do not attempt to create files with execute permissions, regardless of the value of *mask*; they assume you do not want an executable file. As a result, when a utility or application (such as **touch**) creates a file, the system subtracts each of the three digits in *mask* from 6. An exception is **mkdir**, which assumes that you want the execute (access in the case of a directory) bit set.

The following commands set the file-creation permissions mask and display the mask and its effect when you create a file and a directory. The mask of 022, when subtracted from 777, gives permissions of 644 (**rw-r--r--**) for a file and 755 (**rxwxr-xr-x**) for a directory.

```

$ umask 022
$ umask
0022
$ touch afile
$ mkdir adirectory
$ ls -ld afile adirectory
drwxr-xr-x  2 sam sam 4096 May  2 23:57 adirectory
-rw-r--r--  1 sam sam   0 May  2 23:57 afile

```

The next example sets the same mask using symbolic values. The `-S` option displays the mask symbolically:

```

$ umask u=rwx,g=rx,o=rx
$ umask
0022
$ umask -S
u=rwx,g=rx,o=rx

```

`uname` Displays information about the system. Without any arguments, this utility displays the name of the operating system (**Linux**). With a `-a` (all) option, it displays the operating system name, hostname, version number and release date of the operating system, and type of hardware you are using:

```

$ uname -a
Linux F12 2.6.31.6-145.fc12.i686.PAE #1 SMP Sat Nov 21 16:12:37 EST 2009 i686 athlon i386 GNU/Linux

```

---

## SETTING UP A SERVER

This section discusses issues you may need to address when setting up a server: how to write configuration files; how to specify hosts and subnets; how to use **rpcbind** (*FEDORA*) or **portmap** (*RHEL*), **rpcinfo**, **xinetd**, and TCP wrappers (**hosts.allow** and **hosts.deny**); and how to set up a chroot jail. Setting up specific servers is covered in Chapters 14 and 18–26. Setting up a LAN is covered in Chapter 17.

## STANDARD RULES IN CONFIGURATION FILES

Most configuration files, which are typically named `*.conf`, rely on the following conventions:

- Blank lines are ignored.
- A `#` anywhere on a line starts a comment that continues to the end of the line. Comments are ignored.
- When a name contains a `SPACE`, you must quote the `SPACE` by preceding it with a backslash (`\`) or by enclosing the entire name within single or double quotation marks.
- To make long lines easier to read and edit, you can break them into several shorter lines. Break a line by inserting a backslash (`\`) immediately followed

by a NEWLINE (press RETURN in a text editor). When you insert the NEWLINE before or after a SPACE, you can indent the following line to make it easier to read. Do not break lines in this manner while editing on a Windows machine, as the NEWLINES may not be properly escaped (Windows uses RETURN-LINEFEEDs to end lines).

Configuration files that do not follow these conventions are noted in the text.

### SPECIFYING CLIENTS

Table 11-3 shows some common ways to specify a host or a subnet. Most of the time you can specify multiple hosts or subnets by separating the host or subnet specifications with SPACES.

**Table 11-3**    Specifying a client

| Client name pattern              | Matches                                                                                                                                                                                                                                                                                                 |
|----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| n.n.n.n                          | One IP address.                                                                                                                                                                                                                                                                                         |
| <b>name</b>                      | One hostname, either local or remote.                                                                                                                                                                                                                                                                   |
| Name that starts with .          | Matches a hostname that ends with the specified string. For example, <b>.tcorp.com</b> matches the systems <b>kudos.tcorp.com</b> and <b>speedy.tcorp.com</b> , among others.                                                                                                                           |
| IP address that ends with .      | Matches a host address that starts with the specified numbers. For example, <b>192.168.0.</b> matches <b>192.168.0.0 – 192.168.0.255</b> . If you omit the trailing period, this format does not work.                                                                                                  |
| Starts with @                    | Specifies a netgroup.                                                                                                                                                                                                                                                                                   |
| n.n.n.n/m.m.m.m or<br>n.n.n.n/mm | An IP address and subnet mask specify a subnet.                                                                                                                                                                                                                                                         |
| Starts with /                    | An absolute pathname of a file containing one or more names or addresses as specified in this table.                                                                                                                                                                                                    |
| Wildcard                         | Matches                                                                                                                                                                                                                                                                                                 |
| * and ?                          | Matches one (?) or more (*) characters in a simple hostname or IP address. These wildcards do not match periods in a domain name.                                                                                                                                                                       |
| ALL                              | Always matches.                                                                                                                                                                                                                                                                                         |
| LOCAL                            | Matches any hostname that does not contain a period.                                                                                                                                                                                                                                                    |
| Operator                         |                                                                                                                                                                                                                                                                                                         |
| EXCEPT                           | Matches anything in the preceding list that is not in the following list. For example, <b>a b c d EXCEPT c</b> matches <b>a</b> , <b>b</b> , and <b>d</b> . Thus you could use <b>192.168. EXCEPT 192.168.0.1</b> to match all IP addresses that start with <b>192.168.</b> except <b>192.168.0.1</b> . |

Examples Each of the following examples specifies one or more systems:

|                    |                                                                                     |
|--------------------|-------------------------------------------------------------------------------------|
| <b>10.10.</b>      | Matches all systems with IP addresses that start with <b>10.10.</b>                 |
| <b>.redhat.com</b> | Matches all named hosts on the Red Hat network                                      |
| <b>localhost</b>   | Matches the local system                                                            |
| <b>127.0.0.1</b>   | The loopback address; always resolves to <b>localhost</b>                           |
| <b>192.168.*.1</b> | Could match all routers on a network of /24 subnets (discussed in the next section) |

## SPECIFYING A SUBNET

When you set up a server, you frequently need to specify which clients are allowed to connect to the server. Sometimes it is convenient to specify a range of IP addresses, called a subnet. The discussion on page 371 explains what a subnet is and how to use a subnet mask to specify a subnet. Usually, you can specify a subnet as

*n.n.n.n/m.m.m.m*

or

*n.n.n.n/maskbits*

where *n.n.n.n* is the base IP address and the subnet is represented by *m.m.m.m* (the subnet mask) or *maskbits* (the number of bits used for the subnet mask). For example, *192.168.0.1/255.255.255.0* represents the same subnet as *192.168.0.1/24*. In binary, decimal *255.255.255.0* is represented by 24 ones followed by 8 zeros. The */24* is shorthand for a subnet mask with 24 ones. Each line in Table 11-4 presents two notations for the same subnet followed by the range of IP addresses that the subnet includes.

**Table 11-4** Different ways to represent a subnet

| Bits           | Mask                    | Range                         |
|----------------|-------------------------|-------------------------------|
| 10.0.0.0/8     | 10.0.0.0/255.0.0.0      | 10.0.0.0 – 10.255.255.255     |
| 172.16.0.0/12  | 172.16.0.0/255.240.0.0  | 172.16.0.0 – 172.31.255.255   |
| 192.168.0.0/16 | 192.168.0.0/255.255.0.0 | 192.168.0.0 – 192.168.255.255 |

## rpcinfo: DISPLAYS INFORMATION ABOUT rpcbind

### Fedora uses rpcbind; RHEL uses portmap

**tip** Fedora uses the **rpcbind** daemon while RHEL uses **portmap** for the same purpose. This chapter describes the Fedora implementation. If you are running RHEL, replace all instances of **rpcbind** with **portmap**.

The **rpcinfo** utility displays information about programs registered with **rpcbind** and makes RPC calls to programs to see if they are alive. For more information on **rpcbind**, refer to “RPC Network Services” on page 391. The **rpcinfo** utility takes the following options and arguments:

```
rpcinfo -p [host]  
rpcinfo [-n port] -u | -t host program [version]  
rpcinfo -b | -d program version
```

- b (broadcast) Makes an RPC broadcast to *version* of *program* and lists hosts that respond.
- d (delete) Removes local RPC registration for *version* of *program*. Available to Superuser only.
- n (port number) With -t or -u, uses the port numbered *port* instead of the port number specified by **rpcbind**.
- p (probe) Lists all RPC programs registered with **rpcbind** on *host* or on the local system if *host* is not specified.
- t (TCP) Makes a TCP RPC call to *version* (if specified) of *program* on *host* and reports whether it received a response.
- u (UDP) Makes a UDP RPC call to *version* (if specified) of *program* on *host* and reports whether it received a response.

Give the following command to see which RPC programs are registered with the **rpcbind** daemon (portmapper) on the system named **peach**:

```
$ /usr/sbin/rpcinfo -p peach  
program vers proto  port  
100000    2    tcp   111  portmapper  
100000    2    udp   111  portmapper  
100024    1    udp  32768 status  
100024    1    tcp  32768 status  
100021    1    udp  32769 nlockmgr  
100021    3    udp  32769 nlockmgr  
...
```

Use the -u option to display a list of versions of a daemon, such as **ypserv**, registered on a remote system (**peach**):

```
$ /usr/sbin/rpcinfo -u peach ypserv  
program 100004 version 1 ready and waiting  
program 100004 version 2 ready and waiting
```

Specify **localhost** to display a list of versions of a daemon registered on the local system:

```
$ /usr/sbin/rpcinfo -u localhost nfs  
program 100003 version 2 ready and waiting  
program 100003 version 3 ready and waiting
```

Locking down **rpcbind** Because the **rpcbind** daemon holds information about which servers are running on the local system and which port each server is running on, only trusted systems should have access to this information. One way to ensure only selected systems have access to **rpcbind** is to lock it down in the **/etc/hosts.allow** and **/etc/hosts.deny**



files (page 447). Put the following line in **hosts.deny** to prevent all systems from using **rpcbind** on the local (server) system:

```
rpcbind: ALL
```

To test this setup from a remote system, give the following command:

```
$ /usr/sbin/rpcinfo -p hostname
No remote programs registered.
```

Replace *hostname* with the name of the remote system that you changed the **hosts.deny** file on. The change is immediate; you do not need to kill or restart a daemon.

Next add the following line to the **hosts.allow** file on the server system:

```
rpcbind: host-IP
```

where *host-IP* is the IP address of the trusted, remote system that you gave the preceding **rpcinfo** command from. Use only IP addresses with **rpcbind** in **hosts.allow**; do not use system names that **rpcbind** could get stuck trying to resolve. Give the same **rpcinfo** command, and you should now see a list of the servers that RPC knows about, including **rpcbind**. See page 701 for more examples.

### Set the clocks

**caution** The **rpcbind** daemon relies on the client's and the server's clocks being synchronized. A simple *DoS attack* (page 1080) can be initiated by setting the server's clock to the wrong time.

## THE xinetd SUPERSEVER

RHEL uses the **xinetd** daemon, a more secure replacement for the **inetd** superserver that was originally shipped with 4.3BSD. Fedora uses the Upstart **init** daemon (page 417) for runlevel control and most servers. However, some Fedora servers still require **xinetd** to be installed and running. The **xinetd** superserver listens for network connections. When one is made, it launches a specified server daemon and forwards the data from the socket (page 483) to the daemon's standard input.

The version of **xinetd** distributed with Fedora/RHEL is linked against **libwrap.so**, so it can use the **/etc/hosts.allow** and **/etc/hosts.deny** files for access control (see "TCP Wrappers" on page 447 for more information). Using TCP wrappers can simplify configuration but hides some of the more advanced features of **xinetd**.

### xinetd may not be installed

**tip** Working as **root**, give the following command to install **xinetd**:

```
# yum install xinetd
```

The base configuration for **xinetd** is stored in the **/etc/xinetd.conf** file. If this file is not present, **xinetd** is probably not installed. (See the preceding tip.) The default

**xinetd.conf** file is well commented. The following sample **xinetd.conf** file shows some of the more common defaults:

```
$ cat /etc/xinetd.conf
# Sample configuration file for xinetd

defaults
{
    instances            = 60
    log_type              = SYSLOG authpriv
    log_on_success        = HOST PID
    log_on_failure        = HOST
    cps                   = 25 30
}
includedir /etc/xinetd.d
```

The **defaults** section specifies the default configuration of **xinetd**; the files in the included directory, **/etc/xinetd.d**, specify server-specific configurations. Defaults can be overridden by server-specific configuration files.

In the preceding file, the **instances** directive specifies that no daemon may run more than 60 copies of itself at one time. The **log\_type** directive specifies that **xinetd** send messages to the system log daemon (**syslogd**; page 582) using the **authpriv** facility. The next two lines specify what to log on success and on failure. The **cps** (connections per second) directive specifies that no more than 25 connections to a specific service should be made per second and that the service should be disabled for 30 seconds if this limit is exceeded.

The following **xinetd** configuration file allows **telnet** connections from the local system and any system with an IP address that starts with **192.168.**. This configuration file does not rely on TCP wrappers, so it does not depend on the **hosts.allow** and **hosts.deny** files.

```
$ cat /etc/xinetd.d/telnet
service telnet
{
    socket_type          = stream
    wait                 = no
    user                 = root
    server                = /usr/sbin/in.telnetd
    only_from             = 192.168.0.0/16 127.0.0.1
    disable               = no
}
```

The **socket\_type** indicates whether the socket uses TCP or UDP. TCP-based protocols establish a connection between the client and the server and are identified by the type **stream**. UDP-based protocols rely on the transmission of individual datagrams and are identified by the type **dgram**.

When **wait** is set to **no**, **xinetd** handles multiple concurrent connections to this service. Setting **wait** to **yes** causes **xinetd** to wait for the server process to complete before handling the next request for that service. In general, UDP services should be

set to **yes** and TCP services to **no**. If you were to set **wait** to **yes** for a service such as **telnet**, only one person would be able to use the service at any given time.

The **user** specifies which user the server runs as. If this user is a member of multiple groups, you can also specify the group on a separate line with the keyword **group**. The **user** directive is ignored if **xinetd** is run without **root** permissions. The **server** provides the pathname of the server program that **xinetd** runs for this service.

The **only\_from** specifies which systems **xinetd** allows to use the service. It is a good idea to use IP addresses only—using hostnames can render the service unavailable if DNS fails. Zeros at the right of an IP address are treated as wildcards. For example, **192.168.0.0** allows access from any system in the **192.168** subnet.

The **disable** line disables a service without removing the configuration file. As shipped by Fedora/RHEL, a number of services include an **xinetd** configuration file with **disable** set to **yes**. To run one of these services, change **disable** to **no** in the appropriate file in **xinetd.d** and restart **xinetd**:

```
# /sbin/service xinetd restart
Stopping xinetd:          [ OK ]
Starting xinetd:          [ OK ]
```

## SECURING A SERVER

You may secure a server either by using TCP wrappers or by setting up a chroot jail.

### TCP WRAPPERS: CLIENT/SERVER SECURITY (**hosts.allow** AND **hosts.deny**)

When you open a local system to access from remote systems, you must ensure that the following criteria are met:

- Open the local system only to systems you want to allow to access it.
- Allow each remote system to access only the data you want it to access.
- Allow each remote system to access data only in the appropriate manner (readonly, read/write, write only).

As part of the client/server model, TCP wrappers, which can be used for any daemon that is linked against **libwrap.so**, rely on the **/etc/hosts.allow** and **/etc/hosts.deny** files as the basis of a simple access control language. This access control language defines rules that selectively allow clients to access server daemons on a local system based on the client's address and the daemon the client tries to access.

Each line in the **hosts.allow** and **hosts.deny** files has the following format:

```
daemon_list : client_list [: command]
```

where ***daemon\_list*** is a comma-separated list of one or more server daemons (such as **rpcbind**, **vsftpd**, or **sshd**), ***client\_list*** is a comma-separated list of one or more clients (see Table 11-3, “Specifying a client,” on page 442), and the optional ***command***

is the command that is executed when a client from *client\_list* tries to access a server daemon from *daemon\_list*.

When a client requests a connection with a local server, the **hosts.allow** and **hosts.deny** files are consulted in the following manner until a match is found:

1. If the daemon/client pair matches a line in **hosts.allow**, access is granted.
2. If the daemon/client pair matches a line in **hosts.deny**, access is denied.
3. If there is no match in either the **hosts.allow** or **hosts.deny** files, access is granted.

The first match determines whether the client is allowed to access the server. When either **hosts.allow** or **hosts.deny** does not exist, it is as though that file was empty. Although it is not recommended, you can allow access to all daemons for all clients by removing both files.

Examples For a more secure system, put the following line in **hosts.deny** to block all access:

```
$ cat /etc/hosts.deny
```

```
...  
ALL : ALL : echo '%c tried to connect to %d and was blocked' >> /var/log/tcpwrappers.log
```

This line prevents any client from connecting to any service, unless specifically permitted in **hosts.allow**. When this rule is matched, it adds a line to the file named **/var/log/tcpwrappers.log**. The **%c** expands to client information and the **%d** expands to the name of the daemon the client attempted to connect to.

With the preceding **hosts.deny** file in place, you can include lines in **hosts.allow** that explicitly allow access to certain services and systems. For example, the following **hosts.allow** file allows anyone to connect to the OpenSSH daemon (**ssh**, **scp**, **sftp**) but allows **telnet** connections only from the same network as the local system and users on the 192.168. subnet:

```
$ cat /etc/hosts.allow  
sshd : ALL  
in.telnet : LOCAL  
in.telnet : 192.168.* 127.0.0.1  
...
```

The first line allows connection from any system (**ALL**) to **sshd**. The second line allows connection from any system in the same domain as the server (**LOCAL**). The third line matches any system whose IP address starts with **192.168.** as well as the local system.

## SETTING UP A chroot JAIL

On early UNIX systems, the root directory was a fixed point in the filesystem. On modern UNIX variants, including Linux, you can define the root directory on a per-process basis. The **chroot** utility allows you to run a process with a root directory other than **/**.

The root directory appears at the top of the directory hierarchy and has no parent: A process cannot access any files above the root directory (because they do not exist). If, for example, you run a program (process) and specify its root directory as `/home/sam/jail`, the program would have no concept of any files in `/home/sam` or above: **jail** is the program's root directory and is labeled `/` (not **jail**).

By creating an artificial root directory, frequently called a (chroot) jail, you prevent a program from accessing or modifying—possibly maliciously—files outside the directory hierarchy starting at its root. You must set up a chroot jail properly to increase security: If you do not set up the chroot jail correctly, you can actually make it easier for a malicious user to gain access to a system than if there were no chroot jail.

### USING chroot

Creating a chroot jail is simple: Working as **root**, give the command `/usr/sbin/chroot directory`. The *directory* becomes the root directory and the process attempts to run the default shell. Working with **root** privileges from the `/home/sam` directory, give the following command to set up a chroot jail in the (existing) `/home/sam/jail` directory:

```
# /usr/sbin/chroot /home/sam/jail
/usr/sbin/chroot: cannot run command '/bin/bash': No such file or directory
```

This example sets up a chroot jail, but when it attempts to run the **bash** shell, the operation fails. Once the jail is set up, the directory that was named **jail** takes on the name of the root directory, `/`, so chroot cannot find the file identified by the path-name `/bin/bash`. In this situation the chroot jail is working but is not useful.

Getting a chroot jail to work the way you want is a bit more complicated. To have the preceding example run **bash** in a chroot jail, you need to create a **bin** directory in **jail** (`/home/sam/jail/bin`) and copy `/bin/bash` to this directory. Because the **bash** binary is dynamically linked to shared libraries, you need to copy these libraries into **jail** as well. The libraries go in **lib**.

The next example creates the necessary directories, copies **bash**, uses **ldd** to display the shared library dependencies of **bash**, and copies the necessary libraries into **lib**. The `linux-gate.so.1` file is a dynamically shared object (DSO) provided by the kernel to speed system calls; you do not need to copy it to the **lib** directory.

```
$ pwd
/home/sam/jail
$ mkdir bin lib
$ cp /bin/bash bin
$ ldd bin/bash
    linux-gate.so.1 => (0x0089c000)
    libtinfo.so.5 => /lib/libtinfo.so.5 (0x00cdb000)
    libdl.so.2 => /lib/libdl.so.2 (0x00b1b000)
    libc.so.6 => /lib/libc.so.6 (0x009cb000)
    /lib/ld-linux.so.2 (0x009ae000)
$ cp /lib/{libtinfo.so.5,libdl.so.2,libc.so.6,ld-linux.so.2} lib
```

Now that everything is set up, you can start the chroot jail again. Although all of the setup can be done by an ordinary user, you have to run chroot as Superuser:

```
$ su
Password:
# /usr/sbin/chroot .
bash-3.2# pwd
/
bash-3.2# ls
bash: ls: command not found
bash-3.2#
```

This time the chroot finds and starts **bash**, which displays its default prompt (**bash-3.2#**). The **pwd** command works because it is a shell builtin (page 247). However, **bash** cannot find the **ls** utility (it is not in the chroot jail). You can copy **/bin/ls** and its libraries into the jail if you want users in the jail to be able to use **ls**.

To set up a useful chroot jail, first determine which utilities the users of the chroot jail will need. Then copy the appropriate binaries and their libraries into the jail. Alternatively, you can build static copies of the binaries and put them in the jail without installing separate libraries. (The statically linked binaries are considerably larger than their dynamic counterparts. The base system with **bash** and the core utilities exceeds 50 megabytes.) You can find the source code for most of the common utilities in the **bash** and **coreutils** SRPMS (source rpm) packages.

Whichever technique you choose, you must put a copy of **su** in the jail. The **su** command is required to run programs while working as a user other than **root**. Because **root** can break out of a chroot jail, it is imperative that you run a program in the chroot jail as a user other than **root**.

The dynamic version of **su** distributed by Fedora/RHEL requires PAM and will not work within a jail. You need to build a copy of **su** from the source to use in a jail. By default, any copy of **su** you build does not require PAM. Refer to “GNU Configure and Build System” on page 513 for instructions on how to build packages such as **coreutils** (which includes **su**).

To use **su**, you must copy the relevant lines from the **/etc/passwd** and **/etc/shadow** files into files with the same names in the **etc** directory inside the jail.

### Keeping multiple chroot jails

---

**tip** If you plan to deploy multiple chroot jails, it is a good idea to keep a clean copy of the **bin** and **lib** files somewhere other than in one of the active jails.

---

### RUNNING A SERVICE IN A chroot JAIL

Running a shell inside a jail has limited usefulness. In reality, you are more likely to need to run a specific service inside the jail. To run a service inside a jail, you must make sure all files needed by that service are inside the jail. The format of a command to start a service in a chroot jail is

```
# /usr/sbin/chroot jailpath /bin/su user daemonname &
```

where *jailpath* is the pathname of the jail directory, *user* is the username that runs the daemon, and *daemonname* is the path (inside the jail) of the daemon that provides the service.

Some servers are already set up to take advantage of **chroot** jails. For example, you can set up DNS so that **named** runs in a jail (page 804), and the **vsftpd** FTP server can automatically start **chroot** jails for clients (page 658).

### SECURITY CONSIDERATIONS

Some services need to be run as **root**, but they release their **root** privileges once started (Procmail and **vsftpd** are examples). If you are running such a service, you do not need to put **su** inside the jail.

A process run as **root** could potentially escape from a **chroot** jail. For this reason, you should always **su** to another user before starting a program running inside the jail. Also, be careful about which **setuid** (page 205) binaries you allow inside a jail—a security hole in one of them could compromise the security of the jail. In addition, make sure the user cannot access executable files that he uploads.

## DHCP: CONFIGURES HOSTS

Instead of storing network configuration information in local files on each system, DHCP (Dynamic Host Configuration Protocol) enables client systems to retrieve network configuration information each time they connect to the network. A DHCP server assigns IP addresses from a pool of addresses to clients as needed. Assigned addresses are typically temporary, but need not be.

This technique has several advantages over storing network configuration information in local files:

- A new user can set up an Internet connection without having to deal with IP addresses, netmasks, DNS addresses, and other technical details. An experienced user can set up a connection more quickly.
- DHCP facilitates assignment and management of IP addresses and related network information by centralizing the process on a server. A system administrator can configure new systems, including laptops that connect to the network from different locations, to use DHCP; DHCP then assigns IP addresses only when each system connects to the network. The pool of IP addresses is managed as a group on the DHCP server.
- IP addresses can be used by more than one system, reducing the total number of IP addresses needed. This conservation of addresses is important because the Internet is quickly running out of IPv4 addresses. Although a particular IP address can be used by only one system at a time, many end-user systems require addresses only occasionally, when they connect to the Internet. By reusing IP addresses, DHCP lengthens the life of the IPv4 protocol. DHCP applies to IPv4 only, as IPv6 forces systems to configure their IP addresses automatically (called autoconfiguration) when they connect to a network (page 373).

DHCP is particularly useful for administrators who are responsible for maintaining a large number of systems because individual systems no longer need to store unique configuration information. With DHCP, the administrator can set up a master system and deploy new systems with a copy of the master's hard disk. In educational establishments and other open access facilities, the hard disk image may be stored on a shared drive, with each workstation automatically restoring itself to pristine condition at the end of each day.

## MORE INFORMATION

Web [www.dhcp.org](http://www.dhcp.org)

FAQ [www.dhcp-handbook.com/dhcp\\_faq.html](http://www.dhcp-handbook.com/dhcp_faq.html)

HOWTO *DHCP Mini HOWTO*

## How DHCP Works

The client daemon, **dhclient** (part of the **dhcp** package), contacts the server daemon, **dhcpd**, to obtain the IP address, netmask, broadcast address, nameserver address, and other networking parameters. The server provides a *lease* on the IP address to the client. The client can request the specific terms of the lease, including its duration; the server can, in turn, limit these terms. While connected to the network, a client typically requests extensions of its lease as necessary so its IP address remains the same. The lease can expire once the client is disconnected from the network, with the server giving the client a new IP address when it requests a new lease. You can also set up a DHCP server to provide static IP addresses for specific clients (refer to “Static Versus Dynamic IP Addresses” on page 368).

DHCP is broadcast based, so both client and server must be on the same subnet (page 371).

## DHCP CLIENT

A DHCP client requests network configuration parameters from the DHCP server and uses those parameters to configure its network interface.

### PREREQUISITES

Install the following package:

- **dhclient**

### dhclient: THE DHCP CLIENT

When a DHCP client system connects to the network, **dhclient** requests a lease from the DHCP server and configures the client's network interface(s). Once a DHCP client has requested and established a lease, it stores information about the lease in a file named **dhclient.leases**, which is stored in the **/var/lib/dhclient** directory. This information is used to reestablish a lease when either the server or the client needs to reboot. The DHCP client configuration file, **/etc/dhclient.conf**, is required only for custom configurations. The following **dhclient.conf** file specifies a single interface, **eth0**:



```
$ cat /etc/dhclient.conf
interface "eth0"
{
    send dhcp-client-identifier 1:xx:xx:xx:xx:xx:xx;
    send dhcp-lease-time 86400;
}
```

In the preceding file, the 1 in the **dhcp-client-identifier** specifies an Ethernet network and **xx:xx:xx:xx:xx:xx** is the *MAC address* (page 1092) of the device controlling that interface. See page 454 for instructions on how to display a MAC address. The **dhcp-lease-time** is the duration, in seconds, of the lease on the IP address. While the client is connected to the network, **dhclient** automatically renews the lease each time half of the lease is up. A lease time of 86,400 seconds (or one day) is a reasonable choice for a workstation.

## DHCP SERVER

The DHCP server maintains a list of IP addresses and other configuration parameters. When requested to do so, the DHCP server provides configuration parameters to a client.

### PREREQUISITES

Install the following package:

- **dhcp**

Run **chkconfig** to cause **dhcpd** to start when the system enters multiuser mode:

```
# /sbin/chkconfig dhcpd on
```

Start **dhcpd**:

```
# /sbin/service dhcpd start
```

### dhcpd: THE DHCP DAEMON

A simple DHCP server allows you to add clients to a network without maintaining a list of assigned IP addresses. A simple network, such as a home LAN sharing an Internet connection, can use DHCP to assign a dynamic IP address to almost all nodes. The exceptions are servers and routers, which must be at known network locations to be able to receive connections. If servers and routers are configured without DHCP, you can specify a simple DHCP server configuration in **/etc/dhcp/dhcpd.conf** (*FEDORA*) or **/etc/dhcpd.conf** (*RHEL*):

```
$ cat /etc/dhcp/dhcpd.conf
default-lease-time 600;
max-lease-time 86400;

option subnet-mask 255.255.255.0;
option broadcast-address 192.168.1.255;
option routers 192.168.1.1;
option domain-name-servers 192.168.1.1;

subnet 192.168.1.0 netmask 255.255.255.0 {
    range 192.168.1.2 192.168.1.200;
}
```

The preceding configuration file specifies a LAN where the router and DNS are both located on **192.168.1.1**. The **default-lease-time** specifies the number of seconds the dynamic IP lease will remain valid if the client does not specify a duration. The **max-lease-time** is the maximum time allowed for a lease.

The information in the **option** lines is sent to each client when it connects. The names following the word **option** specify what the following argument represents. For example, the **option broadcast-address** line specifies the broadcast address of the network. The **routers** and **domain-name-servers** options can be followed by multiple values separated by commas.

The **subnet** section includes a **range** line that specifies the range of IP addresses that the DHCP server can assign. If you define multiple subnets, you can define options, such as **subnet-mask**, inside the **subnet** section. Options defined outside all **subnet** sections are global and apply to all subnets.

The preceding configuration file assigns addresses in the range between 192.168.1.2 and 192.168.1.200. The DHCP server starts at the bottom (*FEDORA*) or top (*RHEL*) of this range and attempts to assign a new IP address to each new client. Once the DHCP server reaches the top/bottom of the range, it starts reassigning IP addresses that have been used in the past, but are not currently in use. If you have fewer systems than IP addresses, the IP address of each system should remain fairly constant. You cannot use the same IP address for more than one system at a time.

Once you have configured a DHCP server, you can start (or restart) it by using the **dhcpd** init script:

```
# /sbin/service dhcpd restart
```

Once the server is running, clients configured to obtain an IP address from the server using DHCP should be able to do so.

## STATIC IP ADDRESSES

As mentioned earlier, routers and servers typically require static IP addresses. While you can manually configure IP addresses for these systems, it may be more convenient to have the DHCP server provide them with static IP addresses.

When a system that requires a specific static IP address connects to the network and contacts the DHCP server, the server needs a way to identify the system so the server can assign the proper IP address to the system. The DHCP server uses the *MAC address* (page 1092) of the system's Ethernet card (NIC) as an identifier. When you set up the server, you must know the MAC address of each system that requires a static IP address.

Displaying a MAC address You can use **ifconfig** to display the MAC addresses of the Ethernet cards (NICs) in a system. In the following example, the MAC addresses are the colon-separated series of hexadecimal number pairs following **HWaddr**:

```
$ /sbin/ifconfig | grep -i hwaddr
eth0      Link encap:Ethernet HWaddr BA:DF:00:DF:C0:FF
eth1      Link encap:Ethernet HWaddr 00:02:B3:41:35:98
```

Run `ifconfig` on each system that requires a static IP address. Once you have determined the MAC address of each of these systems, you can add a **host** section to the `/etc/dhcp/dhcpd.conf` file for each system, instructing the DHCP server to assign a specific address to the system. The following **host** section assigns the address 192.168.1.1 to the system with the MAC address of BA:DF:00:DF:C0:FF:

```
$ cat /etc/dhcp/dhcpd.conf
...
host router {
    hardware ethernet BA:DF:00:DF:C0:FF;
    fixed-address 192.168.1.1;
    option host-name router;
}
```

The name following **host** is used internally by **dhcpd**. The name specified after **option host-name** is passed to the client and can be a hostname or an FQDN.

After making changes to `dhcpd.conf`, restart **dhcpd** using the `service` utility and the `dhcpd` init script (page 453).

## nsswitch.conf: WHICH SERVICE TO LOOK AT FIRST

With the advent of NIS and DNS, finding user and system information was no longer a simple matter of searching a local file. Where once you looked in `/etc/passwd` to get user information and in `/etc/hosts` to find system address information, you can now use several methods to find this type of information. The `/etc/nsswitch.conf` (name service switch configuration) file specifies the methods to use and the order in which to use them when looking for a certain type of information. You can also specify what action the system takes based on whether a method works or fails.

**Format** Each line in `nsswitch.conf` specifies how to search for a piece of information, such as a user's password. A line in `nsswitch.conf` has the following format:

```
info:           method [[action]] [method [[action]]...]
```

where *info* is the type of information that the line describes, *method* is the method used to find the information, and *action* is the response to the return status of the preceding *method*. The action is enclosed within square brackets.

## How nsswitch.conf WORKS

When called upon to supply information that `nsswitch.conf` describes, the system examines the line with the appropriate *info* field. It uses the methods specified on the line starting with the method on the left. By default, when it finds the desired information, the system stops searching. Without an *action* specification, when a method fails to return a result, the system tries the next method. It is possible for the search to end without finding the requested information.

## INFORMATION

The **nsswitch.conf** file commonly controls searches for users (in **passwd**), passwords (in **shadow**), host IP addresses, and group information. The following list describes most of the types of information (*info* in the format discussed earlier) that **nsswitch.conf** controls searches for.

|                   |                                                                           |
|-------------------|---------------------------------------------------------------------------|
| <b>automount</b>  | Automount ( <b>/etc/auto.master</b> and <b>/etc/auto.misc</b> ; page 744) |
| <b>bootparams</b> | Diskless and other booting options (See the <b>bootparam</b> man page.)   |
| <b>ethers</b>     | MAC address (page 1092)                                                   |
| <b>group</b>      | Groups of users ( <b>/etc/group</b> ; page 472)                           |
| <b>hosts</b>      | System information ( <b>/etc/hosts</b> ; page 472)                        |
| <b>netgroup</b>   | Netgroup information ( <b>/etc/netgroup</b> ; page 474)                   |
| <b>networks</b>   | Network information ( <b>/etc/networks</b> )                              |
| <b>passwd</b>     | User information ( <b>/etc/passwd</b> ; page 475)                         |
| <b>protocols</b>  | Protocol information ( <b>/etc/protocols</b> ; page 476)                  |
| <b>publickey</b>  | Used for NFS running in secure mode                                       |
| <b>rpc</b>        | RPC names and numbers ( <b>/etc/rpc</b> ; page 477)                       |
| <b>services</b>   | Services information ( <b>/etc/services</b> ; page 477)                   |
| <b>shadow</b>     | Shadow password information ( <b>/etc/shadow</b> ; page 477)              |

## METHODS

Following is a list of the types of information that **nsswitch.conf** controls searches for (*method* in the syntax shown on page 455). For each type of information, you can specify one or more of the following methods:<sup>1</sup>

|               |                                                                                   |
|---------------|-----------------------------------------------------------------------------------|
| <b>files</b>  | Searches local files such as <b>/etc/passwd</b> and <b>/etc/hosts</b>             |
| <b>nis</b>    | Searches the NIS database; <b>yp</b> is an alias for <b>nis</b>                   |
| <b>dns</b>    | Queries the DNS ( <b>hosts</b> queries only)                                      |
| <b>compat</b> | $\pm$ syntax in <b>passwd</b> , <b>group</b> , and <b>shadow</b> files (page 458) |

## SEARCH ORDER

The information provided by two or more methods may overlap: For example, **files** and **nis** may each provide password information for the same user. With overlapping information, you need to consider which method you want to be authoritative (take precedence) and then put that method at the left of the list of methods.

The default **nsswitch.conf** file lists methods without actions, assuming no overlap (which is normal). In this case, the order is not critical: When one method fails, the system goes to the next one; all that is lost is a little time. Order becomes critical when you use actions between methods or when overlapping entries differ.

---

1. There are other, less commonly used methods. See the default **/etc/nsswitch.conf** file and the **nsswitch.conf** man page for more information. Although NIS+ belongs in this list, it is not implemented for Linux and is not discussed in this book.

The first of the following lines from **nsswitch.conf** causes the system to search for password information in **/etc/passwd** and, if that fails, to use NIS to find the information. If the user you are looking for is listed in both places, the information in the local file would be used—it would be authoritative. The second line uses NIS; if that fails, it searches **/etc/hosts**; if that fails, it checks with DNS to find host information.

```
passwd      files nis
hosts      nis files dns
```

## ACTION ITEMS

Each method can optionally be followed by an action item that specifies what to do if the method succeeds or fails for any of a number of reasons. An action item has the following format:

```
[!]STATUS=action]
```

where the opening and closing square brackets are part of the format and do not indicate that the contents are optional; **STATUS** (by convention uppercase although it is not case sensitive) is the status being tested for; and **action** is the action to be taken if **STATUS** matches the status returned by the preceding method. The leading exclamation point (!) is optional and negates the status.

**STATUS** **STATUS** may have the following values:

**NOTFOUND**—The method worked but the value being searched for was not found. Default action is **continue**.

**SUCCESS**—The method worked and the value being searched for was found; no error was returned. Default action is **return**.

**UNAVAIL**—The method failed because it is permanently unavailable. For example, the required file may not be accessible or the required server may be down. Default action is **continue**.

**TRYAGAIN**—The method failed because it was temporarily unavailable. For example, a file may be locked or a server overloaded. Default action is **continue**.

**action** Values for **action** are as follows:

**return**—Returns to the calling routine with or without a value.

**continue**—Continues with the next method. Any returned value is overwritten by a value found by the next method.

**Example** The following line from **nsswitch.conf** causes the system first to use DNS to search for the IP address of a given host. The action item following the DNS method tests whether the status returned by the method is not (!) **UNAVAIL**.

```
hosts      dns [!UNAVAIL=return] files
```

The system takes the action associated with the **STATUS** (**return**) if the DNS method does not return **UNAVAIL** (**!UNAVAIL**)—that is, if DNS returns **SUCCESS**, **NOTFOUND**, or **TRYAGAIN**. As a consequence, the following method (**files**) is

used only when the DNS server is unavailable: If the DNS server is *not* unavailable (read the two negatives as “is available”), the search returns the domain name or reports that the domain name was not found. The search uses the **files** method (check the local **/etc/hosts** file) only if the server is not available.

### COMPAT METHOD: $\pm$ IN **passwd**, **group**, AND **shadow** FILES

You can put special codes in the **/etc/passwd**, **/etc/group**, and **/etc/shadow** files that cause the system, when you specify the **compat** method in **nsswitch.conf**, to combine and modify entries in the local files and the NIS maps. That is, a plus sign (+) at the beginning of a line in one of these files adds NIS information; a minus sign (–) removes information.

For example, to use these codes in the **passwd** file, specify **passwd: compat** in **nsswitch.conf**. The system then goes through the **passwd** file in order, adding or removing the appropriate NIS entries when it reaches each line that starts with a + or –.

Although you can put a plus sign at the end of the **passwd** file, specify **passwd: compat** in **nsswitch.conf** to search the local **passwd** file, and then go through the NIS map, it is more efficient to put **passwd: file nis** in **nsswitch.conf** and not modify the **passwd** file.

---

## PAM

PAM (actually Linux-PAM, or Linux Pluggable Authentication Modules) allows a system administrator to determine how applications use *authentication* (page 1070) to verify the identity of a user. PAM provides shared libraries of modules (located in **/lib/security**) that, when called by an application, authenticate a user. The term “Pluggable” in PAM’s name refers to the ease with which you can add and remove modules from the authentication stack. The configuration files kept in the **/etc/pam.d** directory determine the method of authentication and contain a list (i.e., stack) of calls to the modules. PAM may also use other files, such as **/etc/passwd**, when necessary.

Instead of building the authentication code into each application, PAM provides shared libraries that keep the authentication code separate from the application code. The techniques of authenticating users stay the same from application to application. In this way, PAM enables a system administrator to change the authentication mechanism for a given application without ever touching the application.

PAM provides authentication for a variety of system-entry services (login, ftp, and so on). You can take advantage of PAM’s ability to stack authentication modules to integrate system-entry services with different authentication mechanisms, such as RSA, DCE, Kerberos, and smartcards.

From login through using `su` to shutting the system down, whenever you are asked for a password (or not asked for a password because the system trusts that you are who you say you are), PAM makes it possible for the system administrator to configure the authentication process. It also makes the configuration process essentially the same for all applications that use PAM for authentication.

The configuration files stored in `/etc/pam.d` describe the authentication procedure for each application. These files usually have names that are the same as or similar to the names of the applications that they authenticate for. For example, authentication for the login utility is configured in `/etc/pam.d/login`. The name of the file is the name of the PAM service<sup>2</sup> that the file configures. Occasionally one file may serve two programs. PAM accepts only lowercase letters in the names of files in the `/etc/pam.d` directory.

### Do not lock yourself out of the system

**caution** Editing PAM configuration files correctly takes care and attention. It is all too easy to lock yourself out of the computer with a single mistake. To avoid this problem, always keep backup copies of the PAM configuration files you edit, test every change thoroughly, and make sure you can still log in once the change is installed. Keep a Superuser session open until you have finished testing. When a change fails and you cannot log in, use the Superuser session to replace the newly edited files with their backup copies.

PAM warns you about errors it encounters, logging them to the `/var/log/messages` or `/var/log/secure` files. Review these files if you are trying to figure out why a changed PAM file is not working properly. To prevent a malicious user from seeing information about PAM unnecessarily, PAM sends error messages to a file rather than to the screen.

## MORE INFORMATION

Local `/usr/share/doc/pam-*/html`

Web *Linux-PAM System Administrators' Guide*: [www.kernel.org/pub/linux/libs/pam/Linux-PAM-html/Linux-PAM\\_SAG.html](http://www.kernel.org/pub/linux/libs/pam/Linux-PAM-html/Linux-PAM_SAG.html)

HOWTO *User Authentication HOWTO*

## CONFIGURATION FILES, MODULE TYPES, AND CONTROL FLAGS

Login module Following is an example of a PAM configuration file. Comment lines begin with a pound sign (#).

---

2. There is no relationship between PAM services and the `/etc/services` file. The name of the PAM service is an arbitrary string that each application gives to PAM; PAM then looks up the configuration file with that name and uses it to control authentication. There is no central registry of PAM service names.

```
$ cat /etc/pam.d/login
#%PAM-1.0
auth [user_unknown=ignore success=ok ignore=ignore default=bad] pam_securetty.so
auth      include      system-auth
account   required      pam_nologin.so
account   include      system-auth
password  include      system-authFipFip99

# pam_selinux.so close should be the first session rule
session   required      pam_selinux.so close
session   optional      pam_keyinit.so force revoke
session   include      system-auth
session   required      pam_loginuid.so
session   optional      pam_console.so
# pam_selinux.so open should only be followed by sessions to be executed in the user
context
session   required      pam_selinux.so open
session   optional      pam_ck_connector.so
```

The first line is a special comment; it will become significant only if another PAM format is released. Do not use `#%` other than in the first line of the preceding example.

The rest of the lines tell PAM to do something as part of the authentication process. Lines that begin with `#` are comments. The first word on each line is a module type indicator: **account**, **auth**, **password**, or **session** (Table 11-5). The second is a control flag (Table 11-6), which indicates the action PAM should take if authentication fails. The rest of the line contains the name of a PAM module (located in `/lib/security`) and any arguments for that module. The PAM library itself uses the `/etc/pam.d` files to determine which modules to delegate work to.

**Table 11-5** Module type indicators

| Module type     | Description           | Controls                                                                                                                                                                                               |
|-----------------|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>account</b>  | Account management    | Determining whether an already authenticated user is allowed to use the service she is trying to use. (That is, has the account expired? Is the user allowed to use this service at this time of day?) |
| <b>auth</b>     | Authentication        | Proving that the user is authorized to use the service. This task may be done using passwords or another mechanism.                                                                                    |
| <b>password</b> | Password modification | Updating authentication mechanisms such as user passwords.                                                                                                                                             |
| <b>session</b>  | Session management    | Setting things up when the service is started (as when the user logs in) and breaking them down when the service is terminated (as when the user logs out).                                            |



You can use one of the control flag keywords listed in Table 11-6 to set the control flags.

**Table 11-6** Control flag keywords

| Keyword           | Flag function                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>required</b>   | Success is required for authentication to succeed. Control and a failure result are returned after all modules in the stack have been executed. The technique of delaying the report to the calling program until all modules have been executed may keep attackers from knowing what caused their authentication attempts to fail and tell them less about the system, making it more difficult for them to break in.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>requisite</b>  | Success is required for authentication to succeed. Further module processing is aborted, and control is returned immediately after a module fails. This technique may expose information about the system to an attacker. However, if it prevents a user from giving a password over an insecure connection, it might keep information out of the hands of an attacker.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>sufficient</b> | Success indicates that this module type has succeeded, and no subsequent required modules of this type are executed. Failure is not fatal to the stack of this module type. This technique is generally used when one form of authentication or another is good enough: If one fails, PAM tries the other. For example, when you use <code>rsh</code> to connect to another computer, <b>pam_rhosts</b> first checks whether your connection can be trusted without a password. If the connection can be trusted, the <b>pam_rhosts</b> module reports success, and PAM immediately reports success to the <code>rsh</code> daemon that called it. You will not be asked for a password. If your connection is not considered trustworthy, PAM starts the authentication again, asking for a password. If this second authentication succeeds, PAM ignores the fact that the <b>pam_rhosts</b> module reported failure. If both modules fail, you will not be able to log in. |
| <b>optional</b>   | Result is generally ignored. An optional module is relevant only when it is the only module on the stack for a particular service.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |

PAM uses each of the module types as requested by the application. That is, the application will ask PAM separately to authenticate, check account status, manage sessions, and change the password. PAM will use one or more modules from the `/lib/security` directory to accomplish each of these tasks.

The configuration files in `/etc/pam.d` list the set of modules to be used for each application to perform each task. Each such set of the same module types is called a *stack*. PAM calls the modules one at a time in order, going from the top of the stack (the first module listed in the configuration file) to the bottom. Each module reports success or failure back to PAM. When all stacks of modules (with some exceptions) within a configuration file have been called, the PAM library reports success or failure back to the application.

## EXAMPLE

A simplified version of the login service's authentication stack follows:

```
$ cat /etc/pam.d/login
#%PAM-1.0
auth      required      pam_securetty.so
auth      include        system-auth
account   required      pam_nologin.so
...
```

The login utility first asks for a username and then asks PAM to run this stack to authenticate the user. Refer to Table 11-5 on page 460 and Table 11-6 on page 461.

1. PAM first calls the **pam\_securetty** (secure tty) module to make sure that the **root** user logs in only from an allowed terminal (by default, **root** is not allowed to run login over the network; this policy helps prevent security breaches). The **pam\_securetty** module is *required* to succeed if the authentication stack is to succeed. The **pam\_securetty** module reports failure only if someone is trying to log in as **root** from an unauthorized terminal. Otherwise (if the username being authenticated is not **root** or if the username is **root** and the login attempt is being made from a secure terminal), the **pam\_securetty** module reports success.

Success and failure within PAM are opaque concepts that apply only to PAM. They do not equate to true and false as used elsewhere in the operating system.

2. The **system-auth** module checks that the user who is logging in is authorized to do so. As part of this task, it verifies the username and password.
3. The **pam\_nologin** module makes sure that if the **/etc/nologin.txt** file exists, only the **root** user is allowed to log in. (That is, the **pam\_nologin** module reports success only if **/etc/nologin.txt** does not exist or if the **root** user is logging in.) Thus, when a shutdown has been scheduled for some time in the near future, the system administrator can keep users from logging in on the system only to experience a shutdown moments later.

The **account** module type works like the **auth** module type but is called after the user has been authenticated; it acts as an additional security check or requirement for a user to gain access to the system. For example, **account** modules might enforce a policy that a user can log in only during business hours.

The **session** module type sets up and tears down the session (perhaps mounting and unmounting the user's home directory). One **session** module commonly found on a Fedora/RHEL system is the **pam\_console** module, which sets the system up especially for users who log in at the physical console, rather than remotely. A local user is able to access the floppy and CD drives, the sound card, and sometimes other devices as defined by the system administrator.

The **password** module type is a bit unusual: All modules in the stack are called once; they are told to get all information they need to store the password to persistent memory, such

as a disk, but not actually to store it. If it determines that it cannot or should not store the password, a module reports failure. If all **password** modules in the stack report success, they are called a second time and told to store to persistent memory the password they obtained on the first pass. The **password** module is responsible for updating the authentication information (i.e., changing the user's password).

Any one module can act as more than one module type; many modules can act as all four module types.

## MODIFYING THE PAM CONFIGURATION

Some UNIX systems require that a user be a member of the **wheel** group to use the **su** command. Although Fedora/RHEL is not configured this way by default, PAM allows you to change the default by editing the `/etc/pam.d/su` file:

```
$ cat /etc/pam.d/su
#%PAM-1.0
auth            sufficient      pam_rootok.so
# Uncomment the following line to implicitly trust users in the "wheel" group.
#auth          sufficient      pam_wheel.so trust use_uid
# Uncomment the following line to require a user to be in the "wheel" group.
#auth          required        pam_wheel.so use_uid
auth            include         system-auth
account         sufficient      pam_succeed_if.so uid = 0 use_uid quiet
account         include         system-auth
password        include         system-auth
session         include         system-auth
session         optional       pam_xauth.so
```

The third through sixth lines of the **su** module contain comments that include the lines necessary to permit members of the **wheel** group to run **su** without supplying a password (sufficient) and to permit only users who are in the **wheel** group to use **su** (required). Uncomment one of these lines when you want the system to follow one of these rules.

### Brackets ([ ]) in the control flags field

**caution** You can set the control flags in a more complex way than described in this section. When you see brackets ([ ]) in the control flags position in a PAM configuration file, the newer, more complex method is in use. Each comma-delimited argument is a **value=action** pair. When the result returned by the function matches **value**, **action** is evaluated. For more information refer to the *PAM System Administrator's Guide* (`/usr/share/doc/pam-*/txts/pam.txt`).

### Do not create `/etc/pam.conf`

**caution** You may have encountered PAM on other systems where all configuration is arranged in a single file (`/etc/pam.conf`). This file does not exist on Fedora/RHEL systems. Instead, the `/etc/pam.d` directory contains individual configuration files, one per application that uses PAM. This setup makes it easy to install and uninstall applications that use PAM because you do not have to modify the `/etc/pam.conf` file each time you make such a change. If you create a `/etc/pam.conf` file on a system that does not use this file, the PAM configuration may become confused. Do not use PAM documentation from a different system. Also, the **requisite** control flag is not available on some systems that support PAM.

## CHAPTER SUMMARY

A system administrator is someone who keeps the system useful and convenient for its users. Much of the work you do as the system administrator requires you to work with **root** privileges. The **root** user, called Superuser, has extensive systemwide powers that normal users do not have. Superuser can read from and write to any file and can execute programs that ordinary users are not permitted to execute.

You can bring up the system in single-user mode. In this mode, only the system console is functional. When the system is in single-user mode, you can back up files and use **fsck** to check the integrity of filesystems before you mount them. The **telinit** utility brings the system to its normal multiuser state. With the system running in multiuser mode, you can still perform many administration tasks, such as adding users and printers.

The system administrator controls system operation, which includes the following tasks: configuring the system; booting up; running init scripts; setting up servers; working in single-user, multiuser, and rescue modes; bringing the system down; and handling system crashes. Fedora/RHEL provides many configuration tools, both graphical and textual. Many of these tools are named **system-config-\***.

Under RHEL, the **xinetd** superserver starts server daemons as needed and can help secure a system by controlling who can use which services. Fedora uses the Upstart **init** daemon. You can also use TCP wrappers to control who can use which system services by editing the **hosts.allow** and **hosts.deny** files in the **/etc** directory. Because it limits the portion of the filesystem a user sees, a **chroot** jail can help control the damage a malicious user can do.

You can set up a DHCP server so you do not have to configure each system on a network manually. This task can entail setting up both static and dynamic IP addresses using DHCP. Whether a system uses NIS, DNS, local files, or a combination (and in what order) as a source of information is determined by **/etc/nsswitch.conf**. Linux-PAM enables you to maintain fine-grained control over who can access the system, how they can access it, and what they can do.

---

## EXERCISES

1. How does single-user mode differ from multiuser mode?
2. How would you communicate each of the following messages?
  - a. The system is coming down tomorrow at 6:00 in the evening for periodic maintenance.
  - b. The system is coming down in 5 minutes.
  - c. Jenny's jobs are slowing the system down drastically, and she should postpone them.
  - d. Alex's wife just had a baby girl.

3. What do the letters of the `su` command stand for? (*Hint:* It is not Super-user.) What can you do with `su` besides give yourself Superuser privileges? How would you log in as Alex if you did not know his password but knew the **root** password? How would you establish the same environment that Alex has when he first logs in?
4. How would you allow a user to execute privileged commands without giving the user the Superuser password?
5. Assume you are working as Superuser. How do you kill process 1648? How do you kill all processes running `kmail`?
6. How can you disable SELinux?
7. Develop a strategy for coming up with a password that an intruder would not be likely to guess but that you will be able to remember.

## ADVANCED EXERCISES

8. Give the command

```
$ /sbin/fuser -uv /
```

What is this a list of? Why is it so long? Give the same command while working with **root** privileges (or ask the system administrator to do so and email you the results). How does this list differ from the first? Why is it different?

9. When it puts files in a **lost+found** directory, `fsck` has lost the directory information for the files and thus has lost the names of the files. Each file is given a new name, which is the same as the inode number for the file:

```
$ ls -lg lost+found
-rw-r--r-- 1 alex pubs   110 Jun 10 10:55 51262
```

What can you do to identify these files and restore them?

10. Take a look at `/usr/bin/lesspipe.sh`. Explain what it does and describe six ways it works.
11. Why are `setuid` shell scripts inherently unsafe?
12. When a user logs in, you would like the system to first check the local `/etc/passwd` file for a username and then check NIS. How do you implement this strategy?
13. Some older kernels contain a vulnerability that allows a local user to gain **root** privileges. Explain how this kind of vulnerability negates the value of a `chroot` jail.

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# 12

## FILES, DIRECTORIES, AND FILESYSTEMS

### IN THIS CHAPTER

|                                                             |     |
|-------------------------------------------------------------|-----|
| Important Files and Directories . .                         | 468 |
| Ordinary Files, Directories,<br>Links, and Inodes . . . . . | 481 |
| Special Files . . . . .                                     | 482 |
| Filesystems . . . . .                                       | 485 |
| mount: Mounts a Filesystem . . .                            | 487 |
| fstab: Keeps Track of<br>Filesystems . . . . .              | 490 |
| fsck: Checks Filesystem<br>Integrity . . . . .              | 492 |

Filesystems hold directories of files. These structures store user data and system data that are the basis of users' work on the system and the system's existence. This chapter discusses important files and directories, various types of files and how to work with them, and the use and maintenance of filesystems.

## IMPORTANT FILES AND DIRECTORIES

This section details the most common files used to administer the system. Also refer to “Important Standard Directories and Files” on page 198.

**~/.bash\_profile** Contains an individual user’s login shell initialization script. The shell executes the commands in this file in the same environment as the shell each time a user logs in. The file must be located in a user’s home directory.

The default Fedora/RHEL **.bash\_profile** file executes the commands in **~/.bashrc**. You can use **.bash\_profile** to specify a terminal type (for vi, terminal emulators, and other programs), run **stty** to establish the terminal characteristics, set up aliases, and perform other housekeeping functions when a user logs in.

A simple **.bash\_profile** file specifying a vt100 terminal and CONTROL-H as the erase key follows:

```
$ cat .bash_profile
export TERM=vt100
stty erase '^h'
```

For more information refer to “Startup Files” on page 281.

**~/.bashrc** Contains an individual user’s interactive, nonlogin shell initialization script. The shell executes the commands in this file in the same environment as the (new) shell each time a user creates a new interactive shell. The **.bashrc** script differs from **.bash\_profile** in that it is executed each time a new shell is spawned, not just when a user logs in. The default Fedora/RHEL **.bash\_profile** file executes the commands in **~/.bashrc** so that these commands are executed when a user logs in. For more information refer to “Startup Files” on page 281.

**/dev** Contains files representing pseudodevices and physical devices that may be attached to the system. The following list explains the naming conventions for some physical devices:

- **/dev/fd0**—The first floppy disk. The second floppy disk is named **/dev/fd1**.
- **/dev/hda**—The master disk on the primary IDE controller. The slave disk on the primary IDE controller is named **/dev/hdb**. This disk may be a CD-ROM drive.
- **/dev/hdc**—The master disk on the secondary IDE controller. The slave disk on the secondary IDE controller is named **/dev/hdd**. This disk may be a CD-ROM drive.
- **/dev/sda**—Traditionally the first SCSI disk; now the first non-IDE drive, including SATA and USB drives. Other, similar drives are named **/dev/sdb**, **/dev/sdc**, etc.



These names, such as `/dev/sda`, represent the order of the devices on the bus the devices are connected to, not the device itself. For example, if you swap the data cables on the disks referred to as `/dev/sda` and `/dev/sdb`, the drive's designations will change. Similarly, if you remove the device referred to as `/dev/sda`, the device that was referred to as `/dev/sdb` will now be referred to as `/dev/sda`.

**/dev/disk/by-id** Holds symbolic links to local devices. The names of the devices in this directory identify the devices. Each entry points to the device in `/dev` that it refers to.

```
$ ls -l /dev/disk/by-id
```

```
lrwxrwxrwx 1 root root 9 Sep  9 08:32 ata-CR-48XGTE_3E30053332_0175 -> ../../hdb
lrwxrwxrwx 1 root root 9 Sep  9 08:32 ata-WDC_WD1600JB-00GVA0_WD-WCAL95325197 -> ../../hda
```

**/dev/disk/by-uuid** Holds symbolic links to local devices. The names of the devices in this directory consist of the *UUID* (page 1114) numbers of the devices. Each entry points to the device in `/dev` that it refers to. See page 490 for more information.

```
$ ls -l /dev/disk/by-uuid
```

```
lrwxrwxrwx 1 root root 10 Jun  4 11:41 39fc600f-91d5-4c9f-8559-727050b27645 -> ../../hda2
lrwxrwxrwx 1 root root 10 Jun  4 11:41 7eb0ba40-d48d-4ded-b4e4-7027cc93629f -> ../../hda5
lrwxrwxrwx 1 root root 10 Jun  4 11:41 8c2e5007-9cea-4bfb-8d26-82f8b376949b -> ../../hda6
...
```

**/dev/null** Also called a *bit bucket*, output sent to this file disappears. The `/dev/null` file is a device file and must be created with `mknod`. Input that you redirect to come from this file appears as nulls, creating an empty file. You can create an empty file named *nothing* by giving the following command:

```
$ cat /dev/null > nothing
```

or

```
$ cp /dev/null nothing
```

or, without explicitly using `/dev/null`,

```
$ > nothing
```

This last command redirects the output of a null command to the file with the same result as the previous commands. You can use any of these commands to truncate an existing file to zero length without changing its permissions. You can also use `/dev/null` to get rid of output that you do not want:

```
$ grep portable * 2>/dev/null
```

This command looks for the string **portable** in all files in the working directory. Any output to standard error (page 284), such as permission or directory errors, is discarded, while output to standard output appears on the screen.

**/dev/pts** The `/dev/pts` pseudofilesystem is a hook into the Linux kernel; it is part of the pseudoterminal support. Pseudoterminals are used by remote login programs, such

as ssh and telnet, and xterm as well as by other graphical terminal emulators. The following sequence of commands demonstrates that the user is logged in on `/dev/pts/1`. After using `who am i` to verify the line the user is logged in on and using `ls` to show that this line exists, the user redirects the output of an `echo` command to `/dev/pts/1`, whereupon the output appears on the user's screen:

```
$ who am i
alex pts/1 2006-02-16 12:30 (bravo.example.com)
$ ls /dev/pts
0 1 2 3 4
$ echo Hi there > /dev/pts/1
Hi there
```

`/dev/random` and `/dev/urandom` These files are interfaces to the kernel's random number generator. You can use either one with `dd` to create a file filled with pseudorandom bytes.

```
$ dd if=/dev/urandom of=randfile2 bs=1 count=100
100+0 records in
100+0 records out
100 bytes (100 B) copied, 0.001241 seconds, 80.6 kB/s
```

The preceding command reads from `/dev/urandom` and writes to the file named `randfile`. The block size is 1 and the count is 100 so `randfile` is 100 bytes long. For bytes that are more random, you can read from `/dev/random`. See the `urandom` and `random` man pages for more information.

### optional

**Wiping a file** You can use a similar technique to wipe data from a file before deleting it, making it almost impossible to recover data from the deleted file. You might want to wipe a file for security reasons.

In the following example, `ls` shows the size of the file named `secret`. With a block size of 1 and a count corresponding to the number of bytes in `secret`, `dd` wipes the file. The `conv=notrunc` argument ensures that `dd` writes over the data in the file and not another place on the disk.

```
$ ls -l secret
-rw-rw-r-- 1 sam sam 3496 Jan 25 21:48 secret
$ dd if=/dev/urandom of=secret bs=1 count=3496 conv=notrunc
3496+0 records in
3496+0 records out
3496 bytes (3.5 kB) copied, 0.029557 seconds, 118 kB/s
$ rm secret
```

For added security, run `sync` to flush the disk buffers after running `dd`, and repeat the two commands several times before deleting the file.

`/dev/zero` Input you take from this file contains an infinite string of zeros (numerical zeros, not ASCII zeros). You can fill a file (such as a swap file, page 479) or overwrite a file with zeros with a command such as the following:

```
$ dd if=/dev/zero of=zeros bs=1024 count=10
10+0 records in
10+0 records out
10240 bytes (10 kB) copied, 0.000195 seconds, 52.5 MB/s

$ od -c zeros
0000000 \0 \0 \0 \0 \0 \0 \0 \0 \0 \0 \0 \0 \0 \0 \0
*
0024000
```

The `od` utility shows the contents of the new file.

When you try to do with `/dev/zero` what you can do with `/dev/null`, you fill the partition you are working in:

```
$ cp /dev/zero bigzero
cp: writing 'bigzero': No space left on device
$ rm bigzero
```

- `/etc/aliases` Used by the mail delivery system (typically `sendmail`) to hold **aliases** for users. Edit this file to suit local needs. For more information refer to `/etc/aliases` on page 675.
- `/etc/at.allow`, By default, users can use the `at` and `crontab` utilities. The **at.allow** file lists the users  
`/etc/at.deny`, who are allowed to use `at`. The **cron.allow** file works in the same manner for  
`/etc/cron.allow`, `crontab`. The **at.deny** and **cron.deny** files specify users who are not permitted to use  
and the corresponding utilities. As Fedora/RHEL is configured, an empty **at.deny** file  
`/etc/cron.deny` and the absence of an **at.allow** file allows anyone to use `at`; the absence of  
**cron.allow** and **cron.deny** files allows anyone to use `crontab`. To prevent anyone  
except Superuser from using `at`, remove the **at.allow** and **at.deny** files. To prevent  
anyone except Superuser from using `crontab`, create a **cron.allow** file with the single  
entry **root**. For more info on `crontab`, refer to “Scheduling Tasks” on page 565.
- `/etc/dumpdates` Contains information about the last execution of `dump`. For each filesystem, it  
stores the time of the last dump at a given dump level. The `dump` utility uses this  
information to determine which files to back up when executing at a particular  
dump level. Refer to “Backing Up Files” on page 558 and the `dump` man page for  
more information. Following is a sample `/etc/dumpdates` file from a system with  
four filesystems and a backup schedule that uses three dump levels:

```
/dev/sda1      5 Thu Apr 20 03:53:55 2009
/dev/sda8      2 Sun Apr 16 08:25:24 2009
/dev/sda9      2 Sun Apr 16 08:57:32 2009
/dev/sda10     2 Sun Apr 16 08:58:06 2009
/dev/sda1      2 Sun Apr 16 09:02:27 2009
/dev/sda1      0 Sun Mar 19 22:08:35 2009
/dev/sda8      0 Sun Mar 19 22:33:40 2009
/dev/sda9      0 Sun Mar 19 22:35:22 2009
/dev/sda10     0 Sun Mar 19 22:43:45 2009
```

The first column contains the device name of the dumped filesystem. The second column contains the dump level and the date of the dump.

**/etc/fstab** **filesystem (mount) table** Contains a list of all mountable devices as specified by the system administrator. Programs do not write to this file but only read from it. Refer to “fstab: Keeps Track of Filesystems” on page 490.

**/etc/group** Groups allow users to share files or programs without giving all system users access to those files or programs. This scheme is useful when several users are working with files that are not public. The **/etc/group** file associates one or more user names with each group (number). Refer to “ACLs: Access Control Lists” on page 207 for another way to control file access.

An entry in the **/etc/group** file has four fields arranged in the following format:

*group-name:password:group-ID:login-name-list*

The *group-name* is the name of the group. The *password* is an optional encrypted password. This field frequently contains an **x**, indicating that group passwords are not used. The **group-ID** is a number, with 1–499 reserved for system accounts. The *login-name-list* is a comma-separated list of users who belong to the group. If an entry is too long to fit on one line, end the line with a backslash (\), which quotes the following RETURN, and continue the entry on the next line. A sample entry from a **group** file follows. The group is named **pubs**, has no password, and has a group ID of 503:

```
pubs:x:503:alex,jenny,scott,hls,barbara
```

You can use the **groups** utility to display the groups that a user belongs to:

```
$ groups alex
alex : alex pubs
```

Each user has a primary group, which is the group that user is assigned in the **/etc/passwd** file. By default, Fedora/RHEL has user private groups: Each user’s primary group has the same name as the user. In addition, a user can belong to other groups, depending on which *login-name-lists* the user appears on in the **/etc/group** file. In effect, you simultaneously belong both to your primary group and to any groups you are assigned to in **/etc/group**. When you attempt to access a file you do not own, the operating system checks whether you are a member of the group that has access to the file. If you are, you are subject to the group access permissions for the file. If you are not a member of the group that has access to the file and you do not own the file, you are subject to the public access permissions for the file.

When you create a new file, it is assigned to the group associated with the directory the file is being written into, assuming that you belong to that group. If you do not belong to the group that has access to the directory, the file is assigned to your primary group.

Refer to page 557 for information on using **system-config-users** to work with groups.

**/etc/hosts** The **/etc/hosts** file stores the name, IP address, and optional aliases of the other systems that the local system knows about. At the very least, this file must have the hostname and IP address that you have chosen for the local system and a special

entry for **localhost**. This entry supports the *loopback service*, which allows the local system to talk to itself (for example, for RPC services). The IP address of the loopback service is always 127.0.0.1. Following is a simple **/etc/hosts** file for the system named **rose** with an IP address of 192.168.0.10:

```
$ cat /etc/hosts
# Do not remove the following line, or various programs
# that require network functionality will fail.
127.0.0.1      rose localhost.localdomain localhost
192.168.0.1    bravo.example.com      bravo
192.168.0.4    mp3server
192.168.0.5    workstation
192.168.0.10   rose
...
```

If you are not using NIS or DNS to look up hostnames (called *hostname resolution*), you must include in **/etc/hosts** all systems that you want the local system to be able to contact. The **hosts** entry in the **/etc/nsswitch.conf** file (page 455) controls the order in which hostname resolution services are checked.

**/etc/inittab** **initialization table** Under RHEL, this file controls how the System V init process (RHEL) behaves. Fedora has replaced the System V **init** daemon with the Upstart **init** daemon; see page 417 for more information. Under Fedora, this file holds the **initdefault** line only. Each line in **inittab** contains four colon-separated fields:

*id:runlevel:action:process*

The *id* uniquely identifies an entry in the **inittab** file. The *runlevel* is the system runlevel(s) at which *process* is executed. The *runlevel* consists of zero or more characters chosen from 0123456S. If more than one runlevel is listed, the associated *process* is executed at each of the specified runlevels. When you do not specify a runlevel, **init** executes *process* at all runlevels. When the system changes runlevels, the *processes* specified by all entries in **inittab** that do not include the new runlevel are sent the SIGTERM signal to allow them to terminate gracefully. After 5 seconds, these *processes* are killed with SIGKILL if they are still running. The *process* is any bash command line.

The *action* is one of the following keywords: **respawn**, **wait**, **once**, **boot**, **bootwait**, **ondemand**, **powerfail**, **powerwait**, **powerokwait**, **powerfailnow**, **ctrlaltdel**, **kbrequest**, **off**, **ondemand**, **initdefault**, or **sysinit**. This keyword controls how the *process* is treated when it is executed. The most commonly used keywords are **wait** and **respawn**.

The **wait** keyword instructs **init** to start the *process* and wait for it to terminate. All subsequent scans of **inittab** ignore this **wait** entry. Because a **wait** entry is started only once (on entering *runlevel*) and is not executed again while the system remains at *runlevel*, it is often used to redirect **init** output to the console.

The **respawn** entry tells **init** to start the *process* if it does not exist but not to wait for it to terminate. If the *process* does exist, **init** moves on to the next entry in **inittab**.

The `init` utility continues to rescan **inittab**, looking for processes that have died. When a *process* dies, a **respawn** entry causes `init` to restart it.

The **initdefault** entry tells `init` which runlevel to bring the system to when it boots (see Table 11-1 on page 424). Without this information, `init` prompts for a runlevel on the system console. The value of the **initdefault** entry is set when you configure the system or when you edit **inittab** directly. By default, Fedora/RHEL sets **initdefault** to 5, which causes the system to come up in graphical multiuser mode.

### Use caution when you edit inittab

**caution** Be careful when you edit **inittab** manually. Always make a backup copy in the same directory before you edit this file. If you make a mistake, you may not be able to boot the system. If you cannot boot the system, refer to “Rescue Mode” on page 411.

---

Each virtual console (page 137) has in **inittab** a **mingetty** entry that includes a unique terminal identifier (such as **tty1**, which is short for **/dev/tty1**). You can add or remove **mingetty** lines to add or remove virtual consoles. Remember to leave a virtual console for each X window that you want to run. Following is the **mingetty** entry for **/dev/tty2**:

```
2:2345:respawn:/sbin/mingetty tty2
```

The *id* on a **mingetty** line corresponds to the **tty** number.

All of the *actions* are documented in the **inittab** man page. For more information refer to “Booting the System” on page 425.

- /etc/motd** Contains the message of the day, which can be displayed each time someone logs in using a textual login. This file typically contains site policy and legal information. Keep this file short because users tend to see the message many times.
- /etc/mtab** When you call `mount` without any arguments, it consults this file and displays a list of mounted devices. Each time you (or an `init` script) call `mount` or `umount`, these utilities make the necessary changes to **mtab**. Although this is an ASCII text file, you should not edit it. See also **/etc/fstab**.

### Fixing mtab

**tip** The operating system maintains its own internal mount table in **/proc/mounts**. You can use `cat` to display the contents of **/proc/mounts** so that you can review the internal mount table. Sometimes the list of files in **/etc/mtab** may not be synchronized with the partitions in this table. To bring the **mtab** file in line with the operating system’s mount table, you can either reboot the system or replace **/etc/mtab** with a symbolic link to **/proc/mounts** (some information may be lost).

```
# rm /etc/mtab
# ln -s /proc/mounts /etc/mtab
```

---

- /etc/netgroup** Defines netgroups, which are used for checking permissions when performing remote logins and remote mounts and when starting remote shells.

`/etc/nsswitch.conf`

Specifies whether a system uses as the source of certain information NIS, DNS, local files, or a combination, and in what order it consults these services (page 455).

`/etc/pam.d` Files in this directory specify the authentication methods used by PAM (page 458) applications.

### Be cautious when changing PAM files

**caution** Unless you understand how to configure PAM, avoid changing the files in `/etc/pam.d`. Mistakes in the configuration of PAM can make the system unusable.

`/etc/passwd` Describes users to the system. Do not edit this file directly; instead, use one of the utilities discussed in “Configuring User and Group Accounts” on page 556. Each line in `passwd` has seven colon-separated fields that describe one user:

*login-name:dummy-password:user-ID:group-ID:info:directory:program*

The *login-name* is the user’s username—the name you enter in response to the **login:** prompt or GUI login screen. The value of the *dummy-password* is the character `x`. An encrypted/hashed password is stored in `/etc/shadow` (page 477). For security reasons, every account should have a password. By convention, disabled accounts have an asterisk (`*`) in this field.

The *user-ID* is a number, with 0 indicating Superuser and 1–499 being reserved for system accounts. The *group-ID* identifies the user as a member of a group. It is a number, with 0–499 being reserved for system accounts; see `/etc/group`. You can change these values and set maximum values in `/etc/login.defs`.

The *info* is information that various programs, such as accounting programs and email, use to identify the user further. Normally it contains at least the first and last names of the user. It is referred to as the *GECOS* (page 1084) field.

The *directory* is the absolute pathname of the user’s home directory. The *program* is the program that runs once the user logs in. If *program* is not present, a value of `/bin/bash` is assumed. You can put `/bin/tcsh` here to log in using the TC Shell or `/bin/zsh` to log in using the Z Shell, assuming the shell you specify is installed. The `chsh` utility (page 439) changes this value.

The *program* is usually a shell, but it can be any program. The following line in the `passwd` file creates a “user” whose only purpose is to execute the `who` utility:

```
who:x:1000:1000:execute who:/usr:/usr/bin/who
```

Using **who** as a username causes the system to log you in, execute the `who` utility, and log you out. The output of `who` flashes by in a hurry because the new login prompt clears the screen immediately after `who` finishes running. This entry in the `passwd` file does not provide a shell, so you cannot stay logged in after `who` finishes executing.

This technique is useful for providing special accounts that may do only one thing. For instance, sites may create an FTP (page 643) account to enable anonymous FTP access to their systems. Because no one logs in on this account, the shell is set to `/bin/false` (which returns a false exit status) or to `/sbin/nologin` (which does not permit the user to log in). When you put a message in `/etc/nologin.txt`, `nologin` displays that message (except it has the same problem as the output of `who`: It is removed so quickly that you cannot see it).

### Do not replace a login shell with a shell script

**security** Do not use shell scripts as replacements for shells in `/etc/passwd`. A user may be able to interrupt a shell script, giving him or her full shell access when you did not intend to do so. When installing a dummy shell, use a compiled program, not a shell script.

---

**/etc/printcap** The printer capability database. This file describes system printers and is derived from 4.3BSD UNIX.

**/etc/profile** Contains a systemwide interactive shell initialization script for environment and start-up programs. When you log in, the shell immediately executes the commands in this file in the same environment as the shell. (For more information on executing a shell script in this manner, refer to the discussion of the `.` [dot] command on page 283.) This file allows the system administrator to establish systemwide environment parameters that individual users can override. For example, you can set shell variables, execute utilities, set up aliases, and take care of other housekeeping tasks. See also `~/.bash_profile` on page 468.

Following is an example of a `/etc/profile` file that displays the message of the day (the `/etc/motd` file), sets the file-creation mask (`umask`, page 440), and sets the interrupt character to `CONTROL-C`:

```
# cat /etc/profile
cat /etc/motd
umask 022
stty intr '^c'
```

See the `/etc/profile` file on the local system for a more complex example.

**/etc/protocols** Provides protocol numbers, aliases, and brief definitions for DARPA Internet TCP/IP protocols. Do not modify this file.

**/etc/rc.d** Holds the system init scripts, also called run command (rc) scripts. The init program executes several init scripts each time the system changes state or runlevel. For more information refer to “Init Scripts: Start and Stop System Services” on page 426.

**/etc/resolv.conf** The resolver (page 776) configuration file, used to provide access to DNS.

The following example shows the `resolv.conf` file for the `example.com` domain. A `resolv.conf` file usually has at least two lines—a domain line and a nameserver line:

```
# cat /etc/resolv.conf
domain example.com
nameserver 10.0.0.50
nameserver 10.0.0.51
```



The first line (optional) specifies the domain name. A **resolv.conf** file may use **search** in place of **domain**: In the simple case, the two perform the same function. In either case, this domain name is appended to all hostnames that are not fully qualified. See *FQDN* on page 1083.

The **domain** keyword takes a single domain name as an argument: This name is appended to all DNS queries, shortening the time needed to query local hosts. When you put **domain example.com** in **resolv.conf**, any reference to a host within the **example.com** domain or a subdomain (such as **marketing.example.com**) can use the abbreviated form of the host. For example, instead of issuing the command **ping speedy.marketing.example.com**, you can use **ping speedy.marketing**.

This **search** keyword is similar to **domain** but can contain up to six domain names. The domains are searched in order in the process of resolving a hostname. The following line in **resolv.conf** causes the **marketing** subdomain to be searched first, followed by **sales**, and finally the entire **example.com** domain:

```
search marketing.example.com sales.example.com example.com
```

It is a good idea to put the most frequently used domain names first to try to out-guess possible conflicts. If both **speedy.marketing.example.com** and **speedy.example.com** exist, the order of the search determines which one is selected when you invoke DNS. Do not overuse this feature. The longer the search path, the more network DNS requests generated, and the slower the response. Three or four names are typically sufficient.

The **nameserver** line(s) indicate which systems the local system should query to resolve hostnames to IP addresses, and vice versa. These machines are consulted in the order they appear with a 10-second timeout between queries. The preceding file causes this machine to query 10.0.0.50, followed by 10.0.0.51 when the first machine does not answer within 10 seconds. The **resolv.conf** file may be automatically updated when a PPP- (Point-to-Point Protocol) or DHCP- (Dynamic Host Configuration Protocol) controlled interface is activated. Refer to the **resolv.conf** and **resolver** man pages for more information.

- /etc/rpc** Maps RPC services to RPC numbers. The three columns in this file show the name of the server for the RPC program, the RPC program number, and any aliases.
- /etc/services** Lists system services. The three columns in this file show the informal name of the service, the port number/protocol the service frequently uses, and any aliases for the service. This file does not specify which services are running on the local system, nor does it map services to port numbers. The **services** file is used internally to map port numbers to services for display purposes.
- /etc/shadow** Contains encrypted or MD5 (page 1093) hashed user passwords. Each entry occupies one line composed of nine fields, separated by colons:

```
login-name:password:last-mod:min:max:warn:inactive:expire:flag
```

The *login-name* is the user's username—the name that the user enters in response to the **login**: prompt or GUI login screen. The *password* is an encrypted or hashed

password that `passwd` puts into this file. When setting up new user accounts manually, run `passwd` as Superuser to assign a password to a new user.

The *last-mod* field indicates when the password was last modified. The *min* is the minimum number of days that must elapse before the password can be changed; the *max* is the maximum number of days before the password must be changed. The *warn* specifies how much advance warning (in days) to give the user before the password expires. The account will be closed if the number of days between login sessions exceeds the number of days specified in the *inactive* field. The account will also be closed as of the date in the *expire* field. The last field in an entry, *flag*, is reserved for future use. You can use the Password Info tab in `system-config-users` (“Modifying a user” on page 556) to modify these fields.

The `shadow` password file should be owned by `root` and should not be publicly readable or writable. Setting ownership and permissions this way makes it more difficult for someone to break into the system by identifying accounts without passwords or by using specialized programs that try to match hashed passwords.

A number of conventions exist for creating special `shadow` entries. An entry of `*LK*` or `NP` in the *password* field indicates *locked* or *no password*, respectively. *No password* is different from an empty password, implying that this is an administrative account that no one ever logs in on directly. Occasionally programs will run with the privileges of this account for system maintenance functions. These accounts are set up under the principle of least privilege (page 406).

Entries in the `shadow` file must appear in the same order as in the `passwd` file. There must be exactly one `shadow` entry for each `passwd` entry.

**/etc/sysconfig** A directory containing a hierarchy of system configuration files. For more information refer to the `/usr/share/doc/initscripts*/sysconfig.txt` file.

**/proc** The `/proc` pseudofilesystem provides a window into the Linux kernel. Through `/proc` you can obtain information on any process running on your computer, including its current state, memory usage, CPU usage, terminal, parent, and group. You can extract information directly from the files in `/proc`. An example follows:

```
$ sleep 1000 &
[1] 4567
$ cd /proc/4567
$ ls -l
total 0
dr-xr-xr-x 2 sam sam 0 Jan 25 21:57 attr
-r----- 1 sam sam 0 Jan 25 21:57 auxv
-r--r--r-- 1 sam sam 0 Jan 25 21:57 cmdline
lrwxrwxrwx 1 sam sam 0 Jan 25 21:57 cwd -> /home/sam
-r----- 1 sam sam 0 Jan 25 21:57 environ
lrwxrwxrwx 1 sam sam 0 Jan 25 21:57 exe -> /bin/sleep
dr-x----- 2 sam sam 0 Jan 25 21:57 fd
...
-r--r--r-- 1 sam sam 0 Jan 25 21:57 status
dr-xr-xr-x 3 sam sam 0 Jan 25 21:57 task
-r--r--r-- 1 sam sam 0 Jan 25 21:57 wchan
```

```

$ cat status
Name:   sleep
State:  S (sleeping)
SleepAVG:      78%
Tgid:   4567
Pid:    4567
PPid:   4548
TracerPid:      0
Uid:    500    500    500    500
Gid:    500    500    500    500
FDSize: 256
Groups: 500
VmPeak:   3584 kB
VmSize:   3584 kB
...

```

In this example, `bash` creates a background process (PID 4567) for `sleep`. Next the user changes directories to the directory in `/proc` that has the same name as the PID of the subject background process (`cd /proc/4567`). This directory holds information about the process for which it is named. In this case, it holds information about the `sleep` process. The `ls -l` command shows that some entries in this directory are links (`cwd` is a link to the directory the process was started from, and `exe` is a link to the executable file that this process is running) and some appear to be ordinary files. All appear to be empty. When you `cat` one of these pseudofiles (`status` in the example), you get the output shown. Obviously this is not an ordinary file.

**/sbin/shutdown** A utility that brings the system down (see page 433).

**swap** Even though `swap` is not a file, swap space can be added and deleted from the system dynamically. Swap space is used by the virtual memory subsystem. When it runs low on real memory (RAM), the system writes memory pages from RAM to the swap space on the disk. Which pages are written and when they are written are controlled by finely tuned algorithms in the Linux kernel. When needed by running programs, these pages are brought back into RAM—a technique called *paging* (page 1098). When a system is running very short on memory, an entire process may be paged out to disk.

Running an application that requires a large amount of virtual memory may result in the need for additional swap space. If you run out of swap space, you can use `mkswap` to create a new swap file and `swapon` to enable it. Normally you use a disk partition as swap space, but you can also use a file. A disk partition provides much better performance than a file.

If you are using a file as swap space, first use `df` to ensure that the partition has adequate space for the file. In the following sequence of commands, the administrator first uses `dd` and `/dev/zero` (page 470) to create an empty file (do not use `cp` as you may create a file with holes, which may not work) in the working directory. Next `mkswap` takes as an argument the name of the file created in the first step to set up the swap space. For security reasons, change the file so that it cannot be read from or written to by anyone but `root`. Use `swapon` with the same argument to turn the

swap file on; then use **swapon -s** to confirm that the swap space is available. The final two commands turn off the swap file and remove it:

```
# dd if=/dev/zero of=swapfile bs=1024 count=65536
65536+0 records in
65536+0 records out
67108864 bytes (67 MB) copied, 0.684039 seconds, 98.1 MB/s
# mkswap swapfile
Setting up swapspace version 1, size = 67104 kB
# chmod 600 swapfile
# swapon swapfile
# swapon -s
Filename                                Type              Size      Used
Priority
/dev/sda5                               partition         1020088 0      -1
/root/swapfile                          file              65528   0      -2
# swaponoff swapfile
# rm swapfile
rm: remove regular file 'swapfile'? y
```

**/sys** The **/sys** pseudofilesystem was added in the Linux 2.6 kernel to make it easy for programs running in kernelspace, such as device drivers, to exchange information with programs running in userspace. Refer to **udev** on page 482.

**/usr/share/magic** Most files begin with a unique identifier called a *magic number*. This file is a text database listing all known magic numbers on the system. When you use the **file** utility, it consults **/usr/share/magic** to determine the type of a file. Occasionally you may acquire a new tool that creates a new type of file that is unrecognized by the **file** utility. In this situation you need to update the **/usr/share/magic** file; refer to the **magic** man page for details. See also “magic number” on page 1092.

**/var/log** Holds system log files.

**/var/log/messages**

Contains messages from daemons, the Linux kernel, and security programs. For example, you will find **filesystem full** warning messages, error messages from system daemons (NFS, rsyslog, printer daemons), SCSI and IDE disk error messages, and more in **messages**. Check **/var/log/messages** periodically to keep informed about important system events. Much of the information displayed on the system console is also sent to **messages**. If the system experiences a problem and you cannot access the console, check this file for messages about the problem.

**/var/log/secure** Holds messages from security-related programs such as **su** and the **sshd** daemon.

## FILE TYPES

Linux supports many types of files. The following sections discuss these types of files:

- Ordinary files, directories, links, and inodes (discussed next)
- Symbolic links (page 481)

- Special files (page 482)
- FIFO special file (named pipe) (page 483)
- Sockets (page 483)
- Block and character devices (page 484)
- Raw devices (page 485)

## ORDINARY FILES, DIRECTORIES, LINKS, AND INODES

**Ordinary and directory files** An *ordinary* file stores user data, such as textual information, programs, or images, such as a **jpeg** or **tiff** file. A *directory* is a standard-format disk file that stores information, including names, about ordinary files and other directory files.

**Inodes** An *inode* is a *data structure* (page 1078), stored on disk, that defines a file's existence and is identified by an inode number. An inode contains critical information, such as the name of the owner of the file, where it is physically located on the disk, and how many hard links point to it. In addition, SELinux (page 414) stores extended information about files in inodes. A directory relates each of the filenames it stores to an inode.

When you move (**mv**) a file within a filesystem, you change the filename portion of the directory entry associated with the inode that describes the file. You do not create a new inode. If you move a file to another filesystem, **mv** first creates a new inode on the destination filesystem and then deletes the original inode. You can also use **mv** to move a directory recursively, in which case all files in the directory are copied and deleted.

When you make an additional hard link (**ln**, page 214) to a file, you create another reference (an additional filename) to the inode that describes the file. You do not create a new inode.

When you remove (**rm**) a file, you delete the directory entry that describes the file. When you remove the last hard link to a file, the operating system puts all blocks the inode pointed to back in the *free list* (the list of blocks that are available for use on the disk) and frees the inode to be used again.

**The . and .. directory entries** Every directory contains at least two entries (**.** and **..**). The **.** entry is a link to the directory itself. The **..** entry is a link to the parent directory. In the case of the root directory, there is no parent and the **..** entry is a link to the root directory itself. It is not possible to create hard links to directories.

**Symbolic links** Because each filesystem has a separate set of inodes, you can create hard links to a file only from within the filesystem that holds that file. To get around this limitation, Linux provides symbolic links, which are files that point to other files. Files that are linked by a symbolic link do not share an inode. As a consequence, you can create a symbolic link to a file from any filesystem. You can also create a symbolic link to a directory, device, or other special file. For more information refer to “Symbolic Links” on page 216.

## SPECIAL FILES

*Special files* represent Linux kernel routines that provide access to an operating system feature. FIFO (first in, first out) special files allow unrelated programs to exchange information. Sockets allow unrelated processes on the same or different computers to exchange information. One type of socket, the UNIX domain socket, is a special file. Symbolic links are another type of special file.

**Device files** Device files, which include both block and character special files, represent device drivers that let you communicate with peripheral devices, such as terminals, printers, and hard disks. By convention, device files appear in the `/dev` directory and its subdirectories. Each device file represents a device: You read from and write to the file to read from and write to the device it represents. For example, using `cat` to send an audio file to `/dev/dsp` plays the file. The following example shows part of the output that an `ls -l` command produces for the `/dev` directory:

```
$ ls -l /dev
total 0
crw-rw---- 1 root root    14, 12 Jan 25 08:33 adsp
crw----- 1 root root   10, 175 Jan 25 08:33 agpgart
crw----- 1 zach root    14,   4 Jan 25 08:33 audio
drwxr-xr-x 3 root root      60 Jan 25 08:33 bus
lrwxrwxrwx 1 root root      3 Jan 25 08:33 cdrom -> hdb
lrwxrwxrwx 1 root root      3 Jan 25 08:33 cdwriter -> hdb
crw----- 1 zach root     5,   1 Jan 25 08:33 console
lrwxrwxrwx 1 root root     11 Jan 25 08:33 core -> /proc/kcore
drwxr-xr-x 6 root root    120 Jan 25 08:33 disk
crw----- 1 zach root    14,   3 Jan 25 08:33 dsp
lrwxrwxrwx 1 root root     13 Jan 25 08:33 fd -> /proc/self/fd
brw-rw---- 1 zach floppy  2,   0 Jan 25 08:33 fd0
brw-rw---- 1 zach floppy  2,  84 Jan 25 08:33 fd0u1040
brw-rw---- 1 zach floppy  2,  88 Jan 25 08:33 fd0u1120
...
lrwxrwxrwx 1 root root      3 Jan 25 08:33 floppy -> fd0
crw-rw-rw- 1 root root     1,   7 Jan 25 08:33 full
brw-r----- 1 root disk    3,   0 Jan 25 00:33 sda
brw-r----- 1 root disk    3,   1 Jan 25 08:33 sda1
brw-r----- 1 root disk    3,   2 Jan 25 08:33 sda2
brw-r----- 1 root disk    3,   3 Jan 25 00:33 sda3
...
```

The first character of each line is always `-`, `b`, `c`, `d`, `l`, or `p`, representing ordinary (plain), block, character, directory, symbolic link, or named pipe (see the following section), respectively. The next nine characters identify the permissions for the file, followed by the number of hard links and the names of the owner and group. Where the number of bytes in a file would appear for an ordinary or directory file, a device file shows *major* and *minor device numbers* (page 484) separated by a comma. The rest of the line is the same as any other `ls -l` listing (page 203).

**udev** The `udev` utility manages device naming dynamically. It replaces the earlier `devfs` and moves the device naming functionality from the kernel to userspace. Because devices are added to and removed from a system infrequently, the performance

penalty associated with this change is minimal. The benefit of the move is that a bug in `udev` cannot compromise or crash the kernel.

The `udev` utility is part of the hotplug system (discussed next). When a device is added to or removed from the system, the kernel creates a device name in the `/sys` pseudofilesystem and notifies hotplug of the event, which is received by `udev`. The `udev` utility then creates the device file, usually in the `/dev` directory, or removes the device file from the system. The `udev` utility can also rename network interfaces. See [docs.fedoraproject.org/udev](http://docs.fedoraproject.org/udev) and [www.kernel.org/pub/linux/utils/kernel/hotplug/udev.html](http://www.kernel.org/pub/linux/utils/kernel/hotplug/udev.html) for more information.

**Hotplug** The hotplug system allows you to plug a device into the system and use it immediately. Although hotplug was available in the Linux 2.4 kernel, the 2.6 kernel integrates hotplug with the unified device driver model framework (the *driver model core*) so that any bus can report an event when a device is added to or removed from the system. User software can be notified of the event so it can take appropriate action. See [linux-hotplug.sourceforge.net](http://linux-hotplug.sourceforge.net) for more information.

## FIFO SPECIAL FILE (NAMED PIPE)

A *FIFO special file*, also called a *named pipe*, represents a pipe: You read from and write to the file to read from and write to the pipe. The term *FIFO* stands for *first in, first out*—the way any pipe works. In other words, the first information that you put in one end is the first information that comes out the other end. When you use a pipe on a command line to send the output of a program to the printer, the printer outputs the information in the same order that the program produced it and sent it to the pipe.

Unless you are writing sophisticated programs, you will not be working with FIFO special files. However, programs that you use on Linux use named pipes for inter-process communication. You can create a pipe using `mkfifo`:

```
$ mkfifo AA
$ ls -l AA
prw-rw-r-- 1 zach zach 0 Apr 26 13:11 AA
```

The `p` at the left end of the output of `ls -l` indicates that the file is a pipe.

The UNIX and Linux systems have included pipes for many generations. Without named pipes, only processes that were children of the same ancestor could use pipes to exchange information. Using named pipes, *any* two processes on a single system can exchange information. When one program writes to a FIFO special file, another program can read from the same file. The programs do not have to run at the same time or be aware of each other's activity. The operating system handles all buffering and information storage. This type of communication is termed *asynchronous* (*async*) because programs on the ends of the pipe do not have to be synchronized.

## SOCKETS

Like a FIFO special file, a socket allows asynchronous processes that are not children of the same ancestor to exchange information. Sockets are the central mechanism of

the interprocess communication that forms the basis of the networking facility. When you use networking utilities, pairs of cooperating sockets manage the communication between the processes on the local computer and the remote computer. Sockets form the basis of such utilities as `ssh` and `scp`.

## MAJOR AND MINOR DEVICE NUMBERS

A *major device number* points to a driver in the kernel that works with a class of hardware devices: terminal, printer, tape drive, hard disk, and so on. In the list of the `/dev` directory on page 482, all of the hard disk partitions have a major device number of 3.

A *minor device number* represents a particular piece of hardware within a class. Although all hard disk partitions are grouped together by their major device number, each has a different minor device number (`sda1` is 1, `sda2` is 2, and so on). This setup allows one piece of software (the device driver) to service all similar hardware yet to be able to distinguish among different physical units.

## BLOCK AND CHARACTER DEVICES

This section describes typical device drivers. Because device drivers can be changed to suit a particular purpose, the descriptions in this section do not pertain to every system.

A *block device* is an I/O (input/output) device that is characterized by

- Being able to perform random access reads.
- Having a specific block size.
- Handling only single blocks of data at a time.
- Accepting only transactions that involve whole blocks of data.
- Being able to have a filesystem mounted on it.
- Having the Linux kernel buffer its input and output.
- Appearing to the operating system as a series of blocks numbered from 0 through  $n - 1$ , where  $n$  is the number of blocks on the device.

Block devices commonly found on a Linux system include hard disks, floppy diskettes, and CDs.

A *character device* is any device that is not a block device. Examples of character devices include printers, terminals, tape drives, and modems.

The device driver for a character device determines how a program reads from and writes to that device. For example, the device driver for a terminal allows a program to read the information you type on the terminal in two ways. First, a program can read single characters from a terminal in *raw* mode—that is, without the driver doing any interpretation of the characters. (This mode has nothing to do with the raw device described in the following section.) Alternatively, a program can read one line at a time. When a program reads one line at a time, the driver handles the erase and kill characters so the program never sees typing mistakes that have been



corrected. In this case, the program reads everything from the beginning of a line to the RETURN that ends a line; the number of characters in a line can vary.

### RAW DEVICES

Device driver programs for block devices usually have two entry points so they can be used in two ways: as block devices or as character devices. The character device form of a block device is called a *raw device*. A raw device is characterized by

- Direct I/O (no buffering through the Linux kernel).
- A one-to-one correspondence between system calls and hardware requests.
- Device-dependent restrictions on I/O.

An example of a utility that uses a raw device is `fsck`. It is more efficient for `fsck` to operate on the disk as a raw device, rather than being restricted by the fixed size of blocks in the block device interface. Because it has full knowledge of the underlying filesystem structure, `fsck` can operate on the raw device using the largest possible units. When a filesystem is mounted, processes normally access the disk through the block device interface, which explains why it is important to allow `fsck` to modify only an unmounted filesystem. On a mounted filesystem, there is the danger that, while `fsck` is rearranging the underlying structure through the raw device, another process could change a disk block using the block device, resulting in a corrupted filesystem.

## FILESYSTEMS

Table 12-1 lists some of the types of filesystems available under Linux.

**Table 12-1** Filesystems

| Filesystem    | Features                                                                                                                                                                                                                                                                                                          |
|---------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>adfs</b>   | Advanced Disc Filing System. Used on Acorn computers. The word <i>Advanced</i> differentiated this filesystem from its predecessor, DFS, which did not support advanced features such as a hierarchical filesystem.                                                                                               |
| <b>affs</b>   | Amiga Fast Filesystem (FFS).                                                                                                                                                                                                                                                                                      |
| <b>autofs</b> | Automounting filesystem (page 744).                                                                                                                                                                                                                                                                               |
| <b>coda</b>   | CODA distributed filesystem (developed at Carnegie Mellon).                                                                                                                                                                                                                                                       |
| <b>devpts</b> | A pseudofilesystem for pseudoterminals (page 469).                                                                                                                                                                                                                                                                |
| <b>ext2</b>   | A standard filesystem for Fedora/RHEL systems, usually with the <b>ext3</b> extension.                                                                                                                                                                                                                            |
| <b>ext3</b>   | A journaling (page 1089) extension to the <b>ext2</b> filesystem. It greatly improves recovery time from crashes (it takes a lot less time to run <code>fsck</code> ), promoting increased availability. As with any filesystem, a journaling filesystem can lose data during a system crash or hardware failure. |

**Table 12-1** Filesystems (continued)

| Filesystem           | Features                                                                                                                                                                                   |
|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>ext4</b>          | An extension of the <b>ext3</b> filesystem. See <a href="http://ext4.wiki.kernel.org">ext4.wiki.kernel.org</a> for more information.                                                       |
| <b>GFS</b>           | Global Filesystem. GFS is a journaling, clustering filesystem. It enables a cluster of Linux servers to share a common storage pool.                                                       |
| <b>hfs</b>           | Hierarchical Filesystem: used by older Macintosh systems. Newer Macintosh systems use <b>hfs+</b> .                                                                                        |
| <b>hpfs</b>          | High-Performance Filesystem: the native filesystem for IBM's OS/2.                                                                                                                         |
| <b>iso9660</b>       | The standard filesystem for CD-ROMs.                                                                                                                                                       |
| <b>minix</b>         | Very similar to Linux, the filesystem of a small operating system that was written for educational purposes by Andrew S. Tanenbaum ( <a href="http://www.minix3.org">www.minix3.org</a> ). |
| <b>msdos</b>         | The filesystem used by DOS and subsequent Microsoft operating systems. Do not use <b>msdos</b> for mounting Windows filesystems; it does not read VFAT attributes.                         |
| <b>ncpfs</b>         | Novell NetWare NCP Protocol Filesystem: used to mount remote filesystems under NetWare.                                                                                                    |
| <b>nfs</b>           | Network Filesystem. Developed by Sun Microsystems, this protocol allows a computer to access remote files over a network as if they were local (page 727).                                 |
| <b>ntfs</b>          | NT Filesystem: the native filesystem of Windows NT.                                                                                                                                        |
| <b>proc</b>          | An interface to several Linux kernel <i>data structures</i> (page 1078) that behaves like a filesystem (page 478).                                                                         |
| <b>qnx4</b>          | QNX 4 operating system filesystem.                                                                                                                                                         |
| <b>reiserfs</b>      | A journaling (page 1089) filesystem, based on balanced-tree algorithms. See <b>ext3</b> for more on journaling filesystems.                                                                |
| <b>romfs</b>         | A dumb, readonly filesystem used mainly for <i>RAM disks</i> (page 1102) during installation.                                                                                              |
| <b>smbfs</b>         | Samba Filesystem (page 749).                                                                                                                                                               |
| <b>software RAID</b> | RAID implemented in software. Refer to “RAID Filesystem” on page 494.                                                                                                                      |
| <b>sysv</b>          | System V UNIX filesystem.                                                                                                                                                                  |
| <b>ufs</b>           | Default filesystem under Sun's Solaris operating system and other UNIXs.                                                                                                                   |
| <b>umsdos</b>        | A full-feature UNIX-like filesystem that runs on top of a DOS FAT filesystem.                                                                                                              |
| <b>vfat</b>          | Developed by Microsoft, a standard that allows long filenames on FAT partitions.                                                                                                           |
| <b>xfs</b>           | SGI's journaled filesystem (ported from Irix).                                                                                                                                             |

## mount: MOUNTS A FILESYSTEM

The `mount` utility connects directory hierarchies—typically filesystems—to the Linux directory hierarchy. These directory hierarchies can be on remote and local disks, CDs, and floppy diskettes. Linux also allows you to mount *virtual filesystems* that have been built inside ordinary files, filesystems built for other operating systems, and the special `/proc` filesystem (page 478), which maps useful Linux kernel information to a pseudodirectory.

**Mount point** The *mount point* for the filesystem/directory hierarchy that you are mounting is a directory in the local filesystem. This directory must exist before you can mount a filesystem; its contents disappear as long as a filesystem is mounted on it and reappear when you unmount the filesystem.

Without any arguments, `mount` lists the currently mounted filesystems, showing the physical device holding each filesystem, the mount point, the type of filesystem, and any options set when each filesystem was mounted:

```
$ mount
proc on /proc type proc (rw)
/dev/hdb1 on / type ext2 (rw)
/dev/hdb4 on /tmp type ext2 (rw)
/dev/hda5 on /usr type ext3 (rw)
/dev/sda1 on /usr/X386 type ext2 (rw)
/dev/sda3 on /usr/local type ext2 (rw)
/dev/hdb3 on /home type ext3 (rw)
/dev/hda1 on /dos type msdos (rw,umask=000)
tuna:/p04 on /p04 type nfs (rw,addr=192.168.0.8)
/dev/scd0 on /mnt/cdrom type iso9660 (ro,noexec,nosuid,nodev)
```

The `mount` utility gets this information from the `/etc/mtab` file (page 474). This section covers mounting local filesystems; refer to page 727 for information on using NFS to mount remote directory hierarchies.

The first entry in the preceding example shows the `/proc` pseudofilesystem (page 478). The next six entries identify disk partitions holding standard Linux `ext2` and `ext3` filesystems. These partitions are found on three disks: two IDE disks (`hda`, `hdb`) and one SCSI disk (`sda`). Disk partition `/dev/hda1` has a DOS (`msdos`) filesystem mounted at the directory `/dos` in the Linux filesystem. You can access the DOS files and directories on this partition as if they were Linux files and directories, using Linux utilities and applications. The line starting with `tuna` shows a mounted, remote NFS filesystem. The last line shows a CD mounted on a SCSI CD drive (`/dev/scd0`).

If the list of filesystems in `/etc/mtab` is not correct, see the tip on page 474.

### Do not mount anything on root (/)

**caution** Always mount network directory hierarchies and removable devices at least one level below the root level of the filesystem. The root filesystem is mounted on `/`; you cannot mount two filesystems in the same place. If you were to try to mount something on `/`, all files, directories, and filesystems that were under the root directory would no longer be available, and the system would crash.

When you add a line for a filesystem to the `/etc/fstab` file (page 472), you can mount that filesystem by giving the associated mount point (or the device) as the argument to `mount`. For example, the SCSI CD listed earlier was mounted using the following command:

```
$ mount /mnt/cdrom
```

This command worked because `/etc/fstab` contains the additional information needed to mount the file:

```
/dev/scd0          /mnt/cdrom          iso9660 user,noauto,ro 0 0
```

You can also mount filesystems that do not appear in `/etc/fstab`. For example, when you insert a floppy diskette that holds a DOS filesystem into the floppy diskette drive, you can mount that filesystem using the following command:

```
# mount -t msdos /dev/fd0 /mnt/floppy
```

The `-t msdos` specifies a filesystem type of `msdos`. You can mount DOS filesystems only if you have configured the Linux kernel (page 543) to accept DOS filesystems. You do not need to mount a DOS filesystem to read from and write to it, such as when you use `mcopy` (page 161). However, you do need to mount a DOS filesystem to use Linux commands (other than Mtools commands) on files on the filesystem (which may be on a diskette).

## MOUNT OPTIONS

The `mount` utility takes many options, which you can specify on the command line or in the `/etc/fstab` file (page 490). For a complete list of mount options for local filesystems, see the `mount` man page; for remote directory hierarchies, see the `nfs` man page.

The `noauto` option causes Linux not to mount the filesystem automatically. The `nosuid` option forces mounted setuid executables to run with regular permissions (no effective user ID change) on the local system (the system that mounted the filesystem).

### Mount removable devices with the `nosuid` option

---

**security** Always mount removable devices with the `nosuid` option so that a malicious user does not, for example, put a setuid copy of `bash` on a disk and have a **root** shell.

---

Unless you specify the `user`, `users`, or `owner` option, only Superuser can mount and unmount a filesystem. The `user` option means that any user can mount the filesystem, but the filesystem can be unmounted only by the same user who mounted it; `users` means that any user can mount and unmount the filesystem. These options are frequently specified for CD and floppy drives. The `owner` option, which is used only under special circumstances, is similar to the `user` option except that the user mounting the device must own the device.

## MOUNTING A LINUX FLOPPY DISKETTE

Mounting a Linux floppy diskette is similar to mounting a partition of a hard disk. Put an entry similar to the following in `/etc/fstab` for a diskette in the first floppy drive:

```
/dev/fd0    /mnt/floppy    auto    noauto,users    0 0
```

Specifying a filesystem type of `auto` causes the system to probe the filesystem to determine its type and allows users to mount a variety of diskettes. Create the `/mnt/floppy` directory if necessary. Insert a diskette and try to mount it. The diskette must be formatted (use `fdformat`). In the following examples, the error message following the first command usually indicates there is no filesystem on the diskette. Use `mkfs` (page 439) to create a filesystem—but be careful, because `mkfs` destroys all data on the diskette:

```
# mount /dev/fd0
mount: you must specify the filesystem type

# mkfs /dev/fd0
mke2fs 1.41.9 (22-Aug-2009)
Filesystem label=
OS type: Linux
Block size=1024 (log=0)
Fragment size=1024 (log=0)
184 inodes, 1440 blocks
72 blocks (5.00%) reserved for the super user
First data block=1
Maximum filesystem blocks=1572864
1 block group
8192 blocks per group, 8192 fragments per group
184 inodes per group

Writing inode tables: done
Writing superblocks and filesystem accounting information: done

This filesystem will be automatically checked every 24 mounts or
180 days, whichever comes first.  Use tune2fs -c or -i to override.
```

Try the mount command again:

```
# mount /dev/fd0
# mount
...
/dev/fd0 on /mnt/floppy type ext2 (rw,noexec,nosuid,nodev)

# df -h /dev/fd0
Filesystem      Size  Used Avail Use% Mounted on
/dev/fd0        1.4M   19K   1.3M   2% /mnt/floppy
```

The mount command without any arguments and `df -h /dev/fd0` show the floppy is mounted and ready for use.

## umount: UNMOUNTS A FILESYSTEM

The `umount` utility unmounts a filesystem as long as it does not contain any files or directories that are in use (open). For example, a logged-in user's working directory must not be on the filesystem you want to unmount. The next command unmounts the CD mounted earlier:

```
$ umount /mnt/cdrom
```

Unmount a floppy or a remote directory hierarchy the same way you would unmount a partition of a hard drive.

The `umount` utility consults `/etc/fstab` to get the necessary information and then unmounts the appropriate filesystem from its server. When a process has a file open on the filesystem that you are trying to unmount, `umount` displays a message similar to the following:

```
umount: /home: device is busy
```

### When you cannot unmount a device because it is in use

**tip** When a process has a file open on a device you need to unmount, use `fuser` to determine which process has the file open and to kill it. For example, when you want to unmount the floppy diskette, give the command `fuser -ki /mnt/floppy` (substitute the mount point for the diskette on the local system for `/mnt/floppy`). After checking with you, this command kills the process using the diskette.

Use the `-a` option to `umount` to unmount all filesystems, except for the one mounted at `/`, which can never be unmounted. You can combine `-a` with the `-t` option to unmount filesystems of a given type (`ext3`, `nfs`, or others). For example, the following command unmounts all mounted `nfs` directory hierarchies that are not being used:

```
# umount -at nfs
```

## fstab: KEEPS TRACK OF FILESYSTEMS

The system administrator maintains the `/etc/fstab` file, which lists local and remote directory hierarchies, most of which the system mounts automatically when it boots. The `fstab` file has six columns, where a hyphen is a placeholder for a column that has no value:

1. **Name**—The name, label, or UUID number of a local block device (page 484) or a pointer to a remote directory hierarchy. When you install the system, Fedora/RHEL uses UUID numbers for fixed devices. It prefaces each line in `fstab` that specifies a UUID with a comment that specifies the device name. Using UUID numbers in `fstab` during installation circumvents the need for consistent device naming. Because `udev` (page 482) manages device naming dynamically, the installer may not be aware, for example, that the first disk is not named `/dev/hda1` but rather `/dev/sda1`, but it always knows the UUID number of a device. Using UUID numbers to identify devices also keeps partitions and mount points correctly correlated

when you remove or swap devices. See `/dev/disk/by-uuid` (page 469) for more information on UUID numbers. You can use the volume label of a local filesystem by using the form `LABEL=xx`, where `xx` is the volume label. Refer to `e2label` on page 439.

A remote directory hierarchy appears as *hostname:pathname*, where *hostname* is the name of the remote system that houses the filesystem, and *pathname* is the absolute pathname (on the remote system) of the directory that is to be mounted.

2. **Mount point**—The name of the directory file that the filesystem/directory hierarchy is to be mounted on. If it does not already exist, create this directory using `mkdir`. See pages 32 and 487.
3. **Type**—The type of filesystem/directory hierarchy that is to be mounted. Local filesystems are generally of type `ext2`, `ext3`, or `iso9660`, and remote directory hierarchies are of type `nfs` or `cifs`. Table 12-1 on page 485 lists filesystem types.
4. **Mount options**—A comma-separated list of mount options, such as whether the filesystem is mounted for reading and writing (`rw`, the default) or readonly (`ro`). See pages 488 and 732, and refer to the `mount` and `nfs` man pages for lists of options.
5. **Dump**—Used by `dump` (page 563) to determine when to back up the filesystem.
6. **Fsck**—Specifies the order in which `fsck` checks filesystems. Root (`/`) should have a 1 in this column. Filesystems that are mounted to a directory just below the root directory should have a 2. Filesystems that are mounted on another mounted filesystem (other than root) should have a 3. For example, if `local` is a separate filesystem from `/usr` and is mounted on `/usr` (as `/usr/local`), then `local` should have a 3. Filesystems and directory hierarchies that do not need to be checked (for example, remotely mounted directory hierarchies and CDs/DVDs) should have a 0.

The following example shows a typical `fstab` file:

```
# cat /etc/fstab
LABEL=/1                /                ext3    defaults    1 1
LABEL=/boot1            /boot            ext3    defaults    1 2
devpts                  /dev/pts         devpts  gid=5,mode=620 0 0
tmpfs                   /dev/shm         tmpfs   defaults    0 0
LABEL=/home1            /home            ext3    defaults    1 2
proc                    /proc            proc    defaults    0 0
sysfs                   /sys             sysfs   defaults    0 0
LABEL=SWAP-hda5          swap             swap    defaults    0 0
/dev/hda3                /oldhome         ext3    defaults    0 0
tuna:/p04                /p04             nfs     defaults    0 0
/dev/fd0                 /mnt/floppy      auto    noauto,users 0 0
```

## fsck: CHECKS FILESYSTEM INTEGRITY

The `fsck` (filesystem check) utility verifies the integrity of filesystems and, if possible, repairs any problems it finds. Because many filesystem repairs can destroy data, particularly on a *nonjournaling filesystem* (page 1089), such as `ext2`, by default `fsck` asks you for confirmation before making each repair.

### Do not run fsck on a mounted filesystem

---

**caution** Do not run `fsck` on a mounted filesystem (except `/`). When you attempt to check a mounted filesystem, `fsck` warns you and asks you whether you want to continue. Reply **no**. You can run `fsck` with the `-N` option on a mounted filesystem as it will not write to the filesystem; as a result, no harm can come of running it.

---

The following command checks all unmounted filesystems that are marked to be checked in `/etc/fstab` (page 472) except for the root filesystem:

```
# fsck -AR
```

The `-A` option causes `fsck` to check filesystems listed in `fstab`. The `-R` option checks the same filesystems as `-A` except it does not check the root filesystem. You can check a specific filesystem with a command similar to one of the following:

```
# fsck /home
```

or

```
# fsck /dev/sda6
```

**Crash flag** The `/etc/rc.d/rc.sysinit` start-up script looks for two flags in the root directory of each partition to determine whether `fsck` needs to be run on that partition before it is mounted. The `.autofsck` flag (the *crash flag*) indicates that the partition should be checked. By default, the person bringing up the system has 5 seconds to respond to a prompt with a `y`; if no response is made, the check is skipped. When the other flag, `forcefsck`, is set, the user is given no choice; `fsck` is automatically run on the partition. These checks are in addition to those established by `tune2fs` (see next section). The `.autofsck` flag is present while the system is running and is removed when the system is properly shut down. When the system crashes, the flag is present when the system is brought up. The `forcefsck` flag is placed on the filesystem when the disk contains an error and must be checked.

## tune2fs: CHANGES FILESYSTEM PARAMETERS

The `tune2fs` utility displays and modifies filesystem parameters on `ext2`, `ext3`, and `ext4` filesystems. This utility can also set up journaling on an `ext2` filesystem, turning it into an `ext3` filesystem. With the introduction of increasingly more reliable hardware and software, systems are rebooted less frequently, so it is important to check filesystems regularly. By default, `fsck` is run on each partition while the system is brought up, before the partition is mounted. (The checks scheduled by `tune2fs` are separate and scheduled differently from the checks that are done following a system crash or hard disk error [see the previous section].) Depending on the flags, `fsck`



may do nothing more than display a message saying that the filesystem is clean. The larger the partition, the more time it takes to check it, assuming a nonjournaling filesystem. These checks are often unnecessary. The `tune2fs` utility helps you to find a happy medium between checking filesystems each time you reboot the system and never checking them. It does so by scheduling when `fsck` checks a filesystem (these checks occur only when the system is booted).<sup>1</sup> You can use two scheduling patterns: time elapsed since the last check and number of mounts since the last check. The following command causes `/dev/sda6` to be checked when `fsck` runs after it has been mounted eight times or after 15 days have elapsed since its last check, whichever happens first:

```
# tune2fs -c 8 -i 15 /dev/sda6
tune2fs 1.41.9 (22-Aug-2009)
Setting maximal mount count to 8
Setting interval between checks to 1296000 seconds
```

The next `tune2fs` command is similar but works on a different partition and sets the current mount count to 4. When you do not specify a current mount count, it is set to zero:

```
# tune2fs -c 8 -i 15 -C 4 /dev/sda6
tune2fs 1.41.9 (22-Aug-2009)
Setting maximal mount count to 8
Setting current mount count to 4
Setting interval between checks to 1296000 seconds
```

The `-l` option displays a list of information about the partition. You can combine this option with others. Below the **Maximum mount count** is `-1`, which means that `fsck` and the kernel ignore the mount count information. A maximum mount count of 0 works the same way:

```
# tune2fs -l /dev/sda6
tune2fs 1.41.9 (22-Aug-2009)
Filesystem volume name:   /home
Last mounted on:          <not available>
Filesystem UUID:          70929327-f5d2-486a-be44-6f7b677ab6b6
Filesystem magic number:  0xEF53
Filesystem revision #:    1 (dynamic)
Filesystem features:      has_journal ext_attr resize_inode dir_index
                           filetype needs_recovery sparse_super large_file
Default mount options:    (none)
Filesystem state:         clean
Errors behavior:          Continue
Filesystem OS type:       Linux
Inode count:              2560864
Block count:              2560359
...
```

---

1. For systems whose purpose in life is to run continuously, this kind of scheduling does not work. You must develop a schedule that is not based on system reboots but rather on a clock. Each filesystem must be unmounted periodically, checked with `fsck` (preceding section), and then remounted.

```
Last mount time:      Wed Jan 24 08:33:30 2009
Last write time:     Wed Jan 24 10:13:27 2009
Mount count:        4
Maximum mount count: 8
Last checked:       Tue Jun 16 03:03:55 2009
Check interval:     1296000 (2 weeks, 1 day)
...
```

Set the filesystem parameters on the local system so that they are appropriate to the way you use it. Using the `-C` option to stagger the checks ensures that all checks do not occur at the same time. Always check new and upgraded filesystems to make sure that they have checks scheduled as you desire.

To change an `ext2` filesystem to an `ext3` filesystem, you must put a *journal* (page 1089) on the filesystem, and the kernel must support `ext3` filesystems. Use the `-j` option to set up a journal on an unmounted filesystem:

```
# tune2fs -j /dev/sda7
tune2fs 1.40.4 (31-Dec-2007)
Creating journal inode: done
This filesystem will be automatically checked every 23 mounts or
180 days, whichever comes first. Use tune2fs -c or -i to override.
```

Before you can use `fstab` (page 472) to mount the changed filesystem, you must modify its entry in the `fstab` file to reflect its new type. Change the third column to `ext3`.

The following command changes an unmounted `ext3` filesystem to an `ext2` filesystem:

```
# tune2fs -O ^has_journal /dev/sda7
tune2fs 1.41.9 (22-Aug-2009)
```

Refer to the `tune2fs` man page for more details.

## RAID FILESYSTEM

RAID (Redundant Arrays of Inexpensive/Independent Disks) spreads information across several disks to combine several physical disks into one larger virtual device. RAID improves performance and creates redundancy. More than six types of RAID configurations exist. Using Fedora/RHEL tools, you can set up *software* RAID. *Hardware* RAID requires hardware that is designed to implement RAID and is not covered here.

### Do not replace backups with RAID

---

**caution** Do not use RAID as a replacement for regular backups. If your system experiences a catastrophic failure, RAID will be useless. Earthquake, fire, theft, or another disaster may leave your entire system inaccessible (if your hard drives are destroyed or missing). RAID does not take care of something as simple as replacing a file when you delete it by accident. In these cases a backup on a removable medium (that has been removed) is the only way you will be able to restore a filesystem.

---

RAID can be an effective *addition* to a backup. Fedora/RHEL offers RAID software that you can install either when you install a Fedora/RHEL system or as an afterthought. The Linux kernel can automatically detect RAID disk partitions at boot time if the partition ID is set to 0xfd, which fdisk recognizes as Linux **raid autodetect**.

Software RAID, as implemented in the kernel, is much cheaper than hardware RAID. Not only does this software avoid specialized RAID disk controllers, but it also works with the less expensive IDE disks as well as SCSI disks. For more information refer to the *Software-RAID HOWTO*.

---

## CHAPTER SUMMARY

Filesystems hold directories of files. These structures store user data and system data that are the basis of users' work on the system and the system's existence. Linux supports many types of files, including ordinary files, directories, links, and special files. Special files provide access to operating system features. The kernel uses major and minor device numbers to identify classes of devices and specific devices within each class. Character and block devices represent I/O devices such as hard disks and printers. Inodes, which are identified by inode numbers, are stored on disk and define a file's existence.

When the system comes up, the `/etc/fstab` file controls which filesystems are mounted and how they are mounted (readonly, read write, and so on). After a system crash, filesystems are automatically verified and repaired if necessary by `fsck`. You can use `tune2fs` to force the system to run `fsck` on a filesystem periodically when the system boots.

---

## EXERCISES

1. What is the function of the `/etc/hosts` file? Which services can you use in place of, or to supplement, the `hosts` file?
2. What does the `/etc/resolv.conf` file do? What does the `nameserver` line in this file do?
3. What is an inode? What happens to the inode when you move a file within a filesystem?
4. What does the `..` entry in a directory point to? What does this entry point to in the root (`/`) directory?
5. What is a device file? Where are device files located?
6. What is a FIFO? What does FIFO stand for? What is another name for a FIFO? How does a FIFO work?

## ADVANCED EXERCISES

7. Write a line for the `/etc/fstab` file that would mount the `/dev/hdb1 ext3` filesystem on `/extra` with the following characteristics: The filesystem will not be mounted automatically when the system boots, and anyone can mount and unmount the filesystem.
8. Without using `rm`, how can you delete a file? (*Hint*: How do you rename a file?)
9. After burning an ISO image file named `image.iso` to a CD on `/dev/hdc`, how can you verify the copy from the command line?
10. Why should `/var` reside on a separate partition from `/usr`?
11. Create a FIFO. Using the shell, demonstrate that two users can use this FIFO to communicate asynchronously.
12. How would you mount an ISO image so that you could copy files from it without burning it to a CD?

# 13

## DOWNLOADING AND INSTALLING SOFTWARE

### IN THIS CHAPTER

|                                                                    |     |
|--------------------------------------------------------------------|-----|
| yum: Keeps the System<br>Up-to-Date .....                          | 498 |
| pirut: Adds and Removes<br>Software Packages ( <i>RHEL</i> ) ..... | 505 |
| BitTorrent.....                                                    | 507 |
| rpm: Red Hat Package<br>Manager.....                               | 510 |
| Keeping Software Up-to-Date....                                    | 515 |
| Red Hat Network ( <i>RHEL</i> ) .....                              | 516 |
| wget: Downloads Files<br>Noninteractively .....                    | 517 |

A software package is the collection of scripts, programs, files, and directories required to run a software application, including utilities and system software. Using packages makes it easier to transfer, install, and uninstall applications. A package contains either executable files or source code files. Executable files are precompiled for a specific processor architecture and operating system, whereas source files need to be compiled but will run on a wide range of machines and operating systems.

Software for a system can come in different package formats, such as rpm (page 510), the GNU Configure and Build System (page 513), tar, compressed tar, and others. The most popular package format is rpm. Other formats (such as tar), which were popular before the introduction of rpm, are used less often today because they require more work on the part of the installer (you) and do not provide the depth of prerequisite and compatibility checking that rpm offers. Newer programs (such as yum, discussed next) not only check for compatibility but also obtain over the Internet additional software required to install and run a given software package.

## yum: KEEPS THE SYSTEM UP-TO-DATE

Early releases of Red Hat Linux did not include a tool for managing updates. Although the `rpm` utility could install or upgrade individual software packages, it was up to the user to locate a package and any packages it was dependent on. When Terra Soft produced its Red Hat–based Linux distribution for the PowerPC, the company created the Yellow Dog Updater to fill this gap. This program has since been ported to other architectures and distributions. The result, named Yellow Dog Updater, Modified (`yum`, [wiki.linux.duke.edu/Yum](http://wiki.linux.duke.edu/Yum)), is included with Fedora/RHEL.

**rpm packages** The `yum` utility works with `rpm` packages. When `yum` installs or upgrades a software package, it also installs or upgrades packages that the package is dependent on. Refer to page 510 for more information on `rpm`.

**Repositories** The `yum` utility downloads package headers and packages from servers called repositories. Although Fedora provides repositories, `yum` is set up to use copies of these repositories that are kept on mirror sites. RHEL uses Red Hat Network (page 516). The next section covers repository selection.

## CONFIGURING yum

You do not need to configure `yum`: As installed, it is ready to use. This section describes the `yum` configuration files for users who want to modify them. The primary configuration file, `/etc/yum.conf`, holds global settings. As distributed with Fedora, secondary files in the `/etc/yum.repos.d` directory define repositories. The first example shows a `yum.conf` file:

```
$ cat /etc/yum.conf
[main]
cachedir=/var/cache/yum/$basearch/$releasever
keepcache=0
debuglevel=2
logfile=/var/log/yum.log
exactarch=1
obsoletes=1
gpgcheck=1
plugins=1
installonly_limit=3
...
# PUT YOUR REPOS HERE OR IN separate files named file.repo
# in /etc/yum.repos.d
```

The section labeled `[main]` defines global configuration options. The `cachedir` specifies the directory where `yum` will store downloaded packages, although with `keepcache` set to 0, `yum` does not store headers and packages after installing them. The amount of information logged is specified by `debuglevel`, with a value of 10 producing the most information. The `logfile` specifies where `yum` keeps its log.

You can also configure yum to install from a specific server, falling back to other servers in case of failure.

Setting **exactarch** to **1** causes yum to update packages only with packages of the same architecture, thereby preventing an i686 package from replacing an i386 package, for example. You can use **retries** to specify the number of times yum will try to retrieve a file before returning an error (the default is 6). Set this parameter to **0** to cause yum to continue trying forever.

Setting **obsoletes** to **1** causes yum to replace obsolete packages when doing an update; it has no effect during an install. When **gpgcheck** is set to **1**, yum checks the GPG (page 1048) signatures on packages it installs. This check verifies the authenticity of the packages. Setting **plugins** to **1** enables yum plugins, which extend yum functionality. (See [wiki.linux.duke.edu/YumPlugins](http://wiki.linux.duke.edu/YumPlugins) and yum in section 8 of the man pages for more information on yum plugins.) The **metadata\_expire** parameter specifies the number of seconds (or minutes if the value is followed by **m**) that yum uses the metadata it downloads from the repository about packages before it downloads the information again. This parameter defaults to 90 minutes.

Although the balance of the yum configuration information, which specifies the yum repositories, can appear in the **yum.conf** file, Fedora/RHEL puts information about each repository in a separate file in the **/etc/yum.repos.d** directory. A parameter set in a repository section overrides the same parameter set in the **[main]** section.

```
$ ls /etc/yum.repos.d
fedora-rawhide.repo      fedora-updates.repo
fedora-updates-testing.repo  fedora.repo
```

Each of these files contains a header, such as **[fedora]**, which provides a unique name for the repository. The name of the file is generally similar to the repository name, with the addition of a **fedora-** prefix and a **.repo** filename extension. Commonly used repositories include **fedora** (held in the **fedora.repo** file), which contains the packages present on the installation DVD; **updates** (held in the **fedora-updates.repo** file), which contains updated versions of the stable packages; and **updates-testing** (held in the **fedora-updates-testing.repo** file), which contains updates that are not ready for release. This last repository is not enabled; do not enable it unless you are testing unstable packages. Never enable the **updates-testing** repository on a production system.

**optional** Each **\*.repo** file includes specifications for several related repositories, which are usually disabled. For example, the **fedora.repo** file holds **[fedora-debuginfo]** and **[fedora-source]** in addition to **[fedora]**. You cannot download source files using yum. Instead, use **yumdownloader** (page 505) for this task.

The next example shows part of the **fedora.repo** file that specifies the parameters for the **fedora** repository:

```
$ cat /etc/yum.repos.d/fedora.repo
[fedora]
name=Fedora $releasever - $basearch
failovermethod=priority
#baseurl=http://download.fedoraproject.org/pub/fedora/linux/releases/$releasever/Everything/$basearch/os/
mirrorlist=https://mirrors.fedoraproject.org/metalink?repo=fedora-$releasever&arch=$basearch
enabled=1
metadata_expire=7d
gpgcheck=1
gpgkey=file:///etc/pki/rpm-gpg/RPM-GPG-KEY-fedora-$basearch
...
```

**Repository specification** Each repository specification contains the name of the repository enclosed in brackets ([ ]), a **name**, a **failovermethod**, a **baseurl**, and a **mirrorlist**. The **name** provides an informal name for the repository that yum displays. The **failovermethod** determines the order in which yum contacts an initial mirror site and additional mirror sites if the first one fails; **priority** selects the sites in the order in which they appear, while **roundrobin** selects sites randomly. The **baseurl** indicates the location of the main repository; it is commented out by default. The **mirrorlist** specifies the URL of a file that holds a list of **baseurls**, or mirrors of the main repository. Only **baseurl** or **mirrorlist** can be enabled at one time. These definitions use two variables: yum sets **\$basearch** to the architecture of the system and **\$releasever** to the version of the release (such as **12** for Fedora 12).

The repository described by the file is enabled (yum will use it) if **enabled** is set to **1** and is disabled if **enabled** is set to **0**. The **metadata\_expire** specifies how long yum considers metadata valid. After this amount of time yum downloads fresh metadata. As described earlier, **gpgcheck** determines whether yum checks GPG signatures on files it downloads. The **gpgkey** specifies the location of the GPG key. Refer to the **yum.conf** man page for more options.

## USING yum TO UPDATE, INSTALL, AND REMOVE PACKAGES

Working as **root**, you can run yum from the command line. The behavior of yum depends on the options you specify. The **update** option, without additional parameters, updates all installed packages. It downloads package headers for installed packages, determines which packages need to be updated, prompts you to continue, and downloads and installs the updated packages.

**Updating packages** In the following example, yum determines that four packages need to be updated and checks dependencies. Once it has determined what it needs to do, yum advises you of the actions it will take, prompts you with **Is this ok [y/N]**, and then downloads and updates the packages.

```
# yum update
Loaded plugins: presto, refresh-packagekit
Setting up Update Process
Resolving Dependencies
--> Running transaction check
----> Package selinux-policy-targeted.noarch 0:3.6.32-46.fc12 set to be updated
----> Package xorg-x11-drv-evdev.i686 0:2.3.0-4.fc12 set to be updated
----> Package xorg-x11-drv-keyboard.i686 0:1.4.0-2.fc12 set to be updated
----> Package xorg-x11-drv-synaptics.i686 0:1.2.0-2.fc12 set to be updated
--> Finished Dependency Resolution
```



Dependencies Resolved

| Package                 | Arch   | Version        | Repository | Size  |
|-------------------------|--------|----------------|------------|-------|
| Updating:               |        |                |            |       |
| selinux-policy-targeted | noarch | 3.6.32-46.fc12 | updates    | 1.9 M |
| xorg-x11-drv-evdev      | i686   | 2.3.0-4.fc12   | updates    | 29 k  |
| xorg-x11-drv-keyboard   | i686   | 1.4.0-2.fc12   | updates    | 17 k  |
| xorg-x11-drv-synaptics  | i686   | 1.2.0-2.fc12   | updates    | 60 k  |

Transaction Summary

Install 0 Package(s)  
Upgrade 4 Package(s)

Total download size: 2.0 M  
Is this ok [y/N]: y  
Downloading Packages:  
Setting up and reading Presto delta metadata  
Processing delta metadata  
Download delta size: 1.5 M  
(1/4): selinux-policy-targeted-3.6.32-41.fc12\_3.6.32-46. | 1.5 MB 00:02  
(2/4): xorg-x11-drv-evdev-2.3.0-1.fc12\_2.3.0-4.fc12.i686 | 11 kB 00:00  
(3/4): xorg-x11-drv-keyboard-1.3.99.1-1.fc12\_1.4.0-2.fc1 | 10 kB 00:00  
(4/4): xorg-x11-drv-synaptics-1.1.99-7.20090907.fc12\_1.2 | 37 kB 00:00  
Finishing rebuild of rpms, from deltarpms  
<delta rebuild> | 2.0 MB 00:04  
Presto reduced the update size by 24% (from 2.0 M to 1.5 M).  
Running rpm\_check\_debug  
Running Transaction Test  
Finished Transaction Test  
Transaction Test Succeeded  
Running Transaction  
Updating : xorg-x11-drv-evdev-2.3.0-4.fc12.i686 1/8  
Updating : xorg-x11-drv-synaptics-1.2.0-2.fc12.i686 2/8  
Updating : selinux-policy-targeted-3.6.32-46.fc12.noarch 3/8  
Updating : xorg-x11-drv-keyboard-1.4.0-2.fc12.i686 4/8  
Cleanup : xorg-x11-drv-evdev-2.3.0-1.fc12.i686 5/8  
Cleanup : xorg-x11-drv-synaptics-1.1.99-7.20090907.fc12.i686 6/8  
Cleanup : selinux-policy-targeted-3.6.32-41.fc12.noarch 7/8  
Cleanup : xorg-x11-drv-keyboard-1.3.99.1-1.fc12.i686 8/8

Updated:  
selinux-policy-targeted.noarch 0:3.6.32-46.fc12  
xorg-x11-drv-evdev.i686 0:2.3.0-4.fc12  
xorg-x11-drv-keyboard.i686 0:1.4.0-2.fc12  
xorg-x11-drv-synaptics.i686 0:1.2.0-2.fc12

Complete!

**optional** Some packages should only be installed; they should not be updated. The parameter **installonlypkgs** identifies these packages. Packages related to the kernel default to **installonlypkgs**. The **tokeep** parameter specifies the number of versions of **install-onlypkgs** packages that yum keeps.

You can update individual packages by specifying the names of the packages on the command line following the word **update**.

Installing packages To install a new package together with the packages it is dependent on, give the command **yum install**, followed by the name of the package. After yum determines

what it needs to do, it asks for confirmation. The next example installs the **tcsh** package:

```
# yum install tcsh
Loaded plugins: presto, refresh-packagekit
Setting up Install Process
Resolving Dependencies
--> Running transaction check
--> Package tcsh.i686 0:6.17-3.fc12 set to be updated
--> Finished Dependency Resolution
```

Dependencies Resolved

| Package     | Arch | Version     | Repository | Size  |
|-------------|------|-------------|------------|-------|
| Installing: |      |             |            |       |
| tcsh        | i686 | 6.17-3.fc12 | fedora     | 375 k |

Transaction Summary

|         |              |
|---------|--------------|
| Install | 1 Package(s) |
| Upgrade | 0 Package(s) |

```
Total download size: 375 k
Is this ok [y/N]: y
Downloading Packages:
Setting up and reading Presto delta metadata
fedora/prestodelta | 1.3 kB 00:00
Processing delta metadata
Package(s) data still to download: 375 k
tcsh-6.17-3.fc12.i686.rpm | 375 kB 00:00
Running rpm_check_debug
Running Transaction Test
Finished Transaction Test
Transaction Test Succeeded
Running Transaction
  Installing      : tcsh-6.17-3.fc12.i686                1/1

Installed:
  tcsh.i686 0:6.17-3.fc12
```

Complete!

You can also use **yum** to remove packages, using a similar syntax. The following example removes the **tcsh** package:

```
# yum remove tcsh
Loaded plugins: presto, refresh-packagekit
Setting up Remove Process
Resolving Dependencies
--> Running transaction check
```

```

---> Package tcsh.i686 0:6.17-3.fc12 set to be erased
--> Finished Dependency Resolution
...
Transaction Summary
=====
Remove          1 Package(s)
Reinstall       0 Package(s)
Downgrade       0 Package(s)

Is this ok [y/N]: y
Downloading Packages:
Running rpm_check_debug
Running Transaction Test
Finished Transaction Test
Transaction Test Succeeded
Running Transaction
  Erasing          : tcsh-6.17-3.fc12.i686                1/1

Removed:
  tcsh.i686 0:6.17-3.fc12

Complete!

```

## yum GROUPS

In addition to working with single packages, yum can work with groups of packages. The next example shows how to display a list of installed and available groups:

```

# yum grouplist
Loaded plugins: presto, refresh-packagekit
Setting up Group Process
Installed Groups:
  Administration Tools
  Arabic Support
  Base
  ...
  Web Server
  X Window System
Available Groups:
  ...
  MySQL Database
  ...
Done

```

The command **yum groupinfo** followed by the name of a group displays information about the group, including a description of the group and a list of mandatory, default, and optional packages. The next example displays information about the MySQL Database group of packages. If the name of the package includes a SPACE, you must quote it.

```
# yum groupinfo "MySQL Database"
```

```
Loaded plugins: presto, refresh-packagekit
```

```
Setting up Group Process
```

```
Group: MySQL Database
```

```
Description: This package group contains packages useful for use with MySQL.
```

```
Mandatory Packages:
```

```
mysql
```

```
Default Packages:
```

```
MySQL-python
```

```
libdbi-dbd-mysql
```

```
mysql-connector-odbc
```

```
mysql-server
```

```
perl-DBD-MySQL
```

```
unixODBC
```

```
Optional Packages:
```

```
mod_auth_mysql
```

```
mysql-bench
```

```
mysql-devel
```

```
mysqlreport
```

```
mysqltuner
```

```
php-mysql
```

```
qt-mysql
```

```
qt3-MySQL
```

To install a group of packages, give the command **yum groupinstall** followed by the name of the group.

## OTHER yum COMMANDS

Many yum commands and options are available. A few of the more useful commands are described here. The yum man page contains a complete list.

**check-update** Lists packages that are installed on the local system and have updates available in the yum repositories.

**clean all** Removes header files that yum uses for resolving dependencies. Also removes cached packages—yum does not automatically remove packages once they have been downloaded and installed, unless you set **keepcache** to 0.

**clean metadata** Removes the files that yum uses to determine remote package availability. Using this option forces yum to download all metadata the next time you run it.

**list available** Lists all packages that can be installed from the yum repositories.

**search word** Searches for *word* in the package description, summary, packager, and name.

## yum-updatesd: RUNS yum AUTOMATICALLY

The **yum-updatesd** daemon notifies you when updates are available for the local system; it is turned on by default. This daemon is configured with the `/etc/yum/yum-updatesd.conf` file. Use **service** (page 427) and **chkconfig** (page 429) to set up and turn on/off this daemon. The log is kept in `/var/log/yum.log` or in the location specified in the configuration file.

## UPGRADING A SYSTEM WITH yum

Using yum to upgrade a system from one release to another can be problematic and is not recommended. See [fedoraproject.org/wiki/YumUpgradeFaq](http://fedoraproject.org/wiki/YumUpgradeFaq) for more information.

## DOWNLOADING rpm PACKAGE FILES WITH yumdownloader

The yumdownloader utility locates and downloads—but does not install—rpm files. If this utility is not available on the local system, use yum to download and install the **yum-utils** package before attempting to run yumdownloader.

The following example downloads the **samba** rpm file to the working directory:

```
$ yumdownloader samba
Loaded plugins: presto, refresh-packagekit
samba-3.4.2-47.fc12.i686.rpm | 4.3 MB 00:04
```

Downloading  
source files

You can use yumdownloader with the **--source** option to download rpm source package files. The yumdownloader utility automatically enables the necessary source repositories. In the following example, the rpm file for the latest version of the kernel source code for the installed release is downloaded in the working directory:

```
$ yumdownloader --source kernel
Loaded plugins: presto, refresh-packagekit
Enabling updates-source repository
Enabling fedora-source repository
kernel-2.6.31.5-127.fc12.src.rpm | 61 MB 01:47
```

Without the **--source** option, yumdownloader downloads the executable kernel rpm file.

---

## ADDING AND REMOVING SOFTWARE PACKAGES

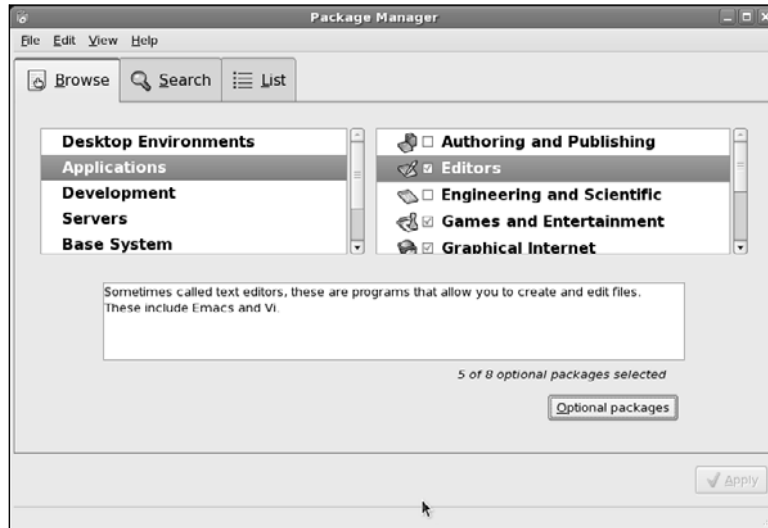
You can use the yum textual utility, as described in the preceding sections, to add, remove, and update software under Fedora/RHEL. This section describes the GUI tools you can use to add and remove software.

**FEDORA** Fedora uses gpk-application, which displays the Add/Remove Software window, to add and remove software to/from the system. For more information see page 123.

**RHEL** RHEL uses pirut, which displays the Package Manager window, to add and remove software to/from the system. For more information see page 123.

### pirut: ADDS AND REMOVES SOFTWARE PACKAGES (RHEL)

RHEL makes the process of graphically adding and removing software packages easier with the pirut package manager utility. This is the same tool you use during installation when you select packages manually. For closer control over the packages you install and remove, use yum (page 500). To display the Package Manager



**Figure 13-1** The pirut Package Manager window

window (Figure 13-1), enter **pirut** on the command line or select **Main menu: Applications**⇒**Add/Remove Software**.

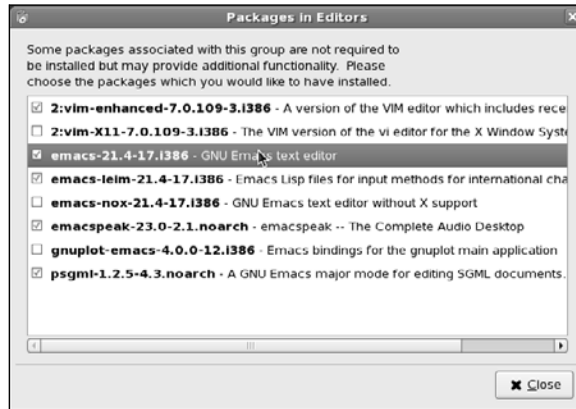
The Package Manager window has three tabs: Browse, Search, and List. With Browse selected (the default), pirut displays two frames toward the top of the window and a text frame below these frames. The left frame displays six categories of software: Desktop Environments, Applications, Development, Servers, Base System, and Languages. When you click one of the categories in the left frame, the right frame displays a list of the package groups in that category.

Figure 13-1 shows five of the seven package groups in the Applications category. When you highlight a package group, pirut displays information about the group in the text frame.

Initially a check mark in the box adjacent to a package group indicates that the package group is installed. To uninstall package groups, remove the check mark; to install them, add a check mark.

**Optional packages** With a check mark in the box adjacent to a highlighted package group, pirut displays the message [*n* of *m* optional packages selected] and activates the **Optional packages** button. Click this button to open a window that lists the optional packages in the package group (Figure 13-2).

The pirut utility does not list the mandatory packages in a package group. To select the optional packages you want installed on the local system, place ticks in the check boxes adjacent to the package names in the optional packages window and then click **Close**.



**Figure 13-2** The Packages in ... window

When you have selected the package groups and packages you want to add and deselected those you want to remove, click **Apply** at the lower-right corner of the Package Manager window (Figure 13-1). The pirut utility displays progress messages as it proceeds and asks you to click **OK** when it is finished installing and removing packages.

## BITTORRENT

The easiest way to download a BitTorrent file is to click the torrent file object in a Web browser such as Firefox or in the Nautilus File Browser. If a graphical client such as transmission (transmissionbt.com) is installed on the system, after checking with you, the browser will start the download automatically using that client. This section describes how BitTorrent works and explains how to download a BitTorrent file from the command line.

The BitTorrent protocol implements a hybrid client/server and *P2P* (page 1097) file transfer mechanism. BitTorrent efficiently distributes large amounts of static data, such as the Fedora installation ISO images. It can replace protocols such as anonymous FTP, where client authentication is not required. Each BitTorrent client that downloads a file provides additional bandwidth for uploading the file, thereby reducing the load on the initial source. In general, BitTorrent downloads proceed faster than FTP downloads. Unlike protocols such as FTP, BitTorrent groups multiple files into a single package—that is, a BitTorrent file.

Tracker, peer, seed,  
and swarm

BitTorrent, like other *P2P* systems, does not use a dedicated server. Instead, the functions of a server are performed by the tracker, peers, and seeds. The *tracker* is a server that allows clients to communicate with one another. Each client—called a *peer* when it has downloaded part of the BitTorrent file and a *seed* once it has downloaded the

entire BitTorrent file—acts as an additional source for the BitTorrent file. Peers and seeds are collectively called a *swarm*. As with a P2P network, a member of a swarm uploads to other clients the sections of the BitTorrent file it has already downloaded. There is nothing special about a seed: It can be removed at any time once the torrent is available for download from other seeds.

**The torrent** The first step in downloading a BitTorrent file is to locate or acquire the *torrent*, a file with the filename extension of **.torrent**. A torrent contains pertinent information (metadata) about the BitTorrent file to be downloaded, such as its size and the location of the tracker. You can obtain a torrent by accessing its URI, or you can acquire it via the Web, an email attachment, or other means. The BitTorrent client can then connect to the tracker to learn the locations of other members of the swarm that it can download the BitTorrent file from.

**Manners** Once you have downloaded a BitTorrent file (the local system has become a seed), it is good manners to allow the local BitTorrent client to continue to run so peers (clients that have not downloaded the entire BitTorrent file) can upload *at least* as much information as you have downloaded.

## PREREQUISITES

If necessary, use yum (page 500) to install the **bittorrent** package. With this package installed, the command **apropos bittorrent** displays a list of BitTorrent utilities. See **/usr/share/doc/bittorrent\*** for more information.

Because the BitTorrent utilities are written in Python and run on any platform with a Python interpreter, they are not dependent on system architecture. Python is installed in **/usr/bin/python** and is available in the **python** package.

## USING BITTORRENT

The **bittorrent-curses** utility is a textual BitTorrent client that provides a pseudo-graphical interface. Once you have a torrent, give a command such as the following, substituting the name of the torrent you want to download for the Fedora torrent in the example:

```
$ bittorrent-curses Fedora-12-i386-DVD.torrent
```

In the preceding command, the torrent specifies that the BitTorrent files be saved in a directory named **Fedora-12-i386-DVD** in the working directory. The name of the BitTorrent file or directory is not always the same as the name of the torrent. Figure 13-3 shows **bittorrent-curses** running. Depending on the speed of the Internet connection and the number of seeds, downloading a large BitTorrent file can take from hours to days.

You can abort the download by pressing **q** or **CONTROL-C**. The download will automatically resume from where it left off when you download the same torrent to the same location again.



```

zach@F12:~
File Edit View Terminal Help
-----
file:      Fedora-12-i386-DVD
size:      3,204,429,287 (3 GiB)
dest:      /home/zach/Fedora-12-i386-DVD
progress:  ##
status:    finishing in 1:23:17 (6.0%)
dl speed:  586.2 KB/s
ul speed:  1.1 KB/s
sharing:    0.004 (0.7 MB up / 184.4 MB down)
seeds:      20 seen now, plus 0 distributed copies(1:48.1
peers:      1 seen now
  
```

**Figure 13-3** bittorrent-curses working with the Fedora DVD torrent

### Make sure you have enough room to download the torrent

**caution** Some torrents are huge. Make sure the partition you are working in has enough room to hold the BitTorrent file you are downloading.

One of the most useful bittorrent-curses options is `--max_upload_rate`, which limits how much bandwidth the swarm can use while downloading the torrent *from you*. The default is 0, meaning there is no limit to the upload bandwidth. The following command prevents BitTorrent from using more than 10 kilobytes per second of upstream bandwidth:

```
$ bittorrent-curses --max_upload_rate 10 Fedora-12-i386-DVD.torrent
```

BitTorrent usually allows higher download rates for members of the swarm that upload more data, so it is to your advantage to increase this value if you have spare bandwidth. You need to leave enough free upstream bandwidth for the acknowledgment packets from your download to get through, however, or else the download will be very slow. By default, bittorrent-curses uploads to a maximum of seven other clients at once. You can change this number by using the `--max_uploads` argument, followed by the number of concurrent uploads you wish to permit. If you are downloading over a modem, try setting `--max_upload_rate` to 3 and `--max_uploads` to 2.

The name of the file or directory that BitTorrent saves a file or files in is specified by the torrent. You can specify a different file or directory name by using the `--saveas` option. The `torrentinfo-console` utility displays the name the BitTorrent file will be saved as, the size of the file, the name of the torrent (**metainfo file**), and other information:

```
$ torrentinfo-console Fedora-12-i386-DVD.torrent
torrentinfo-console 4.4.0 - decode BitTorrent metainfo files

metainfo file.....: Fedora-12-i386-DVD.torrent
info hash.....: 9aae97762960179119dbddfe1cf8de035e6f75f3
directory name.....: Fedora-12-i386-DVD
files.....:
    Fedora-12-i386-CHECKSUM (1511)
    Fedora-12-i386-DVD.iso (3204427776)
archive size.....: 3204429287 (12223 * 262144 + 243175)
tracker announce url: http://torrent.fedoraproject.org:6969/announce
comment.....:
```

---

## rpm: RED HAT PACKAGE MANAGER

The rpm (Red Hat Package Manager) utility works only with software packages that have been built for processing by rpm; it installs, uninstalls, upgrades, queries, and verifies rpm packages. Because Red Hat released rpm under the GPL (page 4), rpm is used by many different distributions. This utility keeps track of the locations where software packages are installed, the versions of the installed packages, and the dependencies between the packages.

Source rpm packages are frequently found in a directory named **SRPMS** (source rpms), whereas binary rpm packages usually reside in **Packages**. When you download binary packages, make sure that they are relevant to the local operating system (both distribution and release—for example, Fedora 12).<sup>1</sup> They should also be compiled for the appropriate architecture:

- **i386** covers all Intel- and most AMD-based systems.
- **i586** covers Pentium-class or higher processors.
- **i686** refers to Pentium II or better, and includes MMX extensions.
- **S390x** is for IBM System/390.
- **ia64** is for the Intel 64-bit Intel Itanium (not compatible with x86\_64)
- **alpha** is for the DEC/Compaq Alpha chip.
- **ppc** and **ppc64** denotes the Power PC 32- and 64-bit processors.
- **x86\_64** is for Intel and AMD 64-bit processors (not Itanium).
- **sparc** covers the Sun Sparc processor.

The name of the rpm file contains almost all the necessary information.

yumdownloader See page 505 for instructions on using yumdownloader to download rpm package files.

---

1. Many rpm packages run on releases and even distributions other than the ones they were compiled for. However, installing packages intended for other distributions can create problems.

## QUERYING PACKAGES AND FILES

The `rpm` utility can be run from the command line. Use `rpm -qa` to display a list of one-line summaries of all packages installed on the system (any user can run this utility). Give the command `rpm -q`, followed by the name of the package, to display more information about a particular package. For instance, `rpm -q nis` tells you whether NIS is installed and, if so, which version. Use the `-ql` options to list the files in a package.

```
$ rpm -q nis
package nis is not installed

$ rpm -ql logrotate
/etc/cron.daily/logrotate
/etc/logrotate.conf
/etc/logrotate.d
/usr/sbin/logrotate
/usr/share/doc/logrotate-3.7.8
/usr/share/doc/logrotate-3.7.8/CHANGES
/usr/share/doc/logrotate-3.7.8/COPYING
/usr/share/man/man8/logrotate.8.gz
/var/lib/logrotate.status
```

With the `-qi` options, `rpm` displays information about a package:

```
$ rpm -qi logrotate
Name       : logrotate                      Relocations: (not relocatable)
Version    : 3.7.8                        Vendor: Fedora Project
Release    : 4.fc12                      Build Date: Thu Sep 17 02:43:34 2009
Install Date: Tue Sep 22 11:40:43 2009    Build Host: x86-4.fedora.phx.redhat.com
Group      : System Environment/Base      Source RPM: logrotate-3.7.8-4.fc12.src.rpm
Size       : 79680                        License: GPL+
Signature  : (none)
Packager   : Fedora Project
Summary    : Rotates, compresses, removes and mails system log files
Description:
The logrotate utility is designed to simplify the administration of
log files on a system which generates a lot of log files. Logrotate
allows for the automatic rotation compression, removal and mailing of
log files. Logrotate can be set to handle a log file daily, weekly,
monthly or when the log file gets to a certain size. Normally,
logrotate runs as a daily cron job.
```

Install the `logrotate` package if you need a utility to deal with the log files on your system.

You can use the `-qf` options to determine which package a file belongs to. The following command shows that `more` is part of the `util-linux` package:

```
$ rpm -qf /bin/more
util-linux-ng-2.16-10.2.fc12.i686
```

Include the `-p` option with other options to query an uninstalled `rpm` package file.

## INSTALLING, UPGRADING, AND REMOVING PACKAGES

Although it is frequently easier to use `yum` (page 500), `gpk-application` (page 123), or `pirut` (page 505), you can use `rpm` to install, upgrade, or remove a package. Log in as (or `su` to) **root**. (Although you can run `rpm` as a nonprivileged user, you will not have permission to write to the necessary directories during an install or uninstall, and the procedure will fail. During a query, you do not need this permission, so you can and should work as a nonprivileged user.) Give the `-U` (upgrade) option, followed by the name of the file that contains the `rpm` version of the package you want to install. The `-U` option upgrades existing packages and installs new packages (as though you had used the `-i` option). For kernels, use `-i` (not `-U`) to leave the old kernel intact when you install a new kernel. Add the `-v` (verbose) option to display more information about what is happening and the `-h` (or `--hash`) option to display hash marks as the package is unpacked and installed. For example, while you are logged in as **root**, give the following command to install the **samba** package on the local system:

```
# ls samba*
samba-3.4.2-47.fc12.i686.rpm
# rpm -Uvh samba-3.4.2-47.fc12.i686.rpm
Preparing...          ##### [100%]
    1:samba            ##### [100%]
```

When you install a package, the `rpm` file must be in the working directory or you must use a pathname that points to the `rpm` file.

To remove the same package, give the following command from any directory:

```
# rpm -e samba
error: Failed dependencies:
    samba is needed by (installed) system-config-samba-1.2.83-1.fc12.noarch
```

When you run this command, `rpm` reports that another package, `system-config-samba`, is dependent on the `samba` package. To remove the `samba` package, you have two choices: You can ignore the dependency by including the `rpm --nodeps` option or you can remove the dependent package and then remove the `samba` package.

```
# rpm -e system-config-samba
# rpm -e samba
```

If you remove the `samba` package without removing the package that is dependent on it, the utilities within the dependent package will not work. In the preceding example, the `system-config-samba` utility will not work.

When you use `rpm` to remove a package, `rpm` queries its database to find the information it needs to uninstall the package and removes links, unloads device drivers, and stops daemons as necessary. Refer to the `rpm` man page for more `rpm` options.

## INSTALLING A LINUX KERNEL BINARY

The following steps install a new Linux kernel binary. Refer to Chapter 15 when you want to configure and rebuild a kernel from source files, rather than installing a new, prebuilt kernel binary.

1. Run `rpm` with the `-i` option to install the new kernel. Do not use the `-U` option: You are installing a new kernel that has a different name than the old kernel; you are not upgrading the existing kernel.
2. Make sure the new kernel works before you remove the old kernel. To verify that the new kernel works, reboot the system using the new kernel. You may want to wait a while before removing the old kernel to make sure that no problems arise with the new one.
3. Remove the old kernel by removing files whose names contain the release number (and EXTRAVERSION number [page 548], if applicable) from `/boot` or `/` (root). Remove information about the old kernel from `grub.conf` (page 551). Instead of removing the old kernel manually, you may be able to remove it with the tool you used to install it (`rpm`, `yum`, or another utility).

---

## INSTALLING NON-rpm SOFTWARE

Most software that is not in `rpm` format comes with detailed instructions on how to configure, build (if necessary), and install it. Some binary distributions (those containing prebuilt executables that run on Fedora/RHEL) require you to unpack the software from the root directory.

### THE `/opt` AND `/usr/local` DIRECTORIES

Some newer application packages include scripts to install themselves automatically into a directory hierarchy under `/opt`, placing files in a `/opt` subdirectory that is named after the package and executables in `/opt/bin` or `/opt/package/bin`. These scripts are relatively new to Fedora/RHEL but have been used by Sun Solaris for a while.

Other software packages allow you to choose where you unpack them. Because many different people develop software for Linux, there is no consistent method for installing it. As you acquire software, install it on the local system in as consistent and predictable a manner as possible. The standard Linux file structure has a directory hierarchy under `/usr/local` for binaries (`/usr/local/bin`), manual pages (`/usr/local/man`), and so forth. To prevent confusion later and to avoid overwriting or losing the software when you install standard software upgrades in the future, avoid installing nonstandard software in standard system directories (such as `/usr/bin`). On a multiuser system, make sure that users know where to find the local software and make an announcement whenever you install, change, or remove local tools.

### GNU CONFIGURE AND BUILD SYSTEM

The GNU Configure and Build System, also called Automake, makes it easy to build a program that is distributed as source code ([www.gnu.org/software/automake/manual/automake.html#Autotools-Introduction](http://www.gnu.org/software/automake/manual/automake.html#Autotools-Introduction)). This two-step process does not

require special tools other than a shell, `make`, and `gcc` (the GNU C compiler). You do not need to work with `root` privileges for either of these steps.

The following example assumes you have downloaded the GNU chess program ([www.gnu.org/software/chess/chess.html](http://www.gnu.org/software/chess/chess.html)) to the working directory. First unpack and decompress the file and `cd` to the new directory:

```
$ tar -xvzf gnuchess*
gnuchess-5.03/
gnuchess-5.03/book/
gnuchess-5.03/book/README
...
$ cd gnuchess*
```

After reading the `README` and `INSTALL` files, run the configure script, which gathers information about the local system and generates the `Makefile` file:

```
$ ./configure
checking for a BSD compatible install... /usr/bin/install -c
checking whether build environment is sane... yes
checking for mawk... mawk
checking whether make sets ${MAKE}... yes
checking for gcc... gcc
checking for C compiler default output... a.out
checking whether the C compiler works... yes
...
checking for memset... yes
configure: creating ./config.status
config.status: creating Makefile
config.status: creating src/Makefile
config.status: creating src/config.h
```

Refer to the configure info page, specifically the `--prefix` option, which causes the install phase to place the software in a directory other than `/usr/local`. The second step is to run `make`:

```
$ make
Making all in src
make[1]: Entering directory '/hdd4/gnuchess-5.03/src'
cd .. \
&& CONFIG_FILES= CONFIG_HEADERS=src/config.h \
/bin/sh ./config.status
config.status: creating src/config.h
config.status: src/config.h is unchanged
make all-am
make[2]: Entering directory '/hdd4/gnuchess-5.03/src'
source='atak.c' object='atak.o' libtool=no \
depfile='.deps/atak.Po' tmpdepfile='.deps/atak.TPo' \
depmode=gcc3 /bin/sh ./depcomp \
gcc -DHAVE_CONFIG_H -I. -I. -I. -g -O2 -c 'test -f atak.c || echo './' atak.c
...
gcc -g -O2 -o gnuchess atak.o book.o cmd.o epd.o eval.o genmove.o hash.o hung.o init.o
iterate.o main.o move.o null.o output.o players.o pgn.o quiesce.o random.o repeat.o
search.o solve.o sort.o swap.o test.o ttable.o util.o version.o -lreadline -lnurses -lm
```

```
make[2]: Leaving directory '/hdd4/gnuchess-5.03/src'
make[1]: Leaving directory '/hdd4/gnuchess-5.03/src'
make[1]: Entering directory '/hdd4/gnuchess-5.03'
make[1]: Nothing to be done for 'all-am'.
make[1]: Leaving directory '/hdd4/gnuchess-5.03'
```

```
$ ls src/gnuchess
src/gnuchess
```

After `make` finishes, the **gnuchess** executable is found in the **src** directory. If you want to install it, give the following command while running with **root** privileges:

```
# make install
Making install in src
make[1]: Entering directory '/hdd4/gnuchess-5.03/src'
make[2]: Entering directory '/hdd4/gnuchess-5.03/src'
/bin/sh ../mkinstalldirs /usr/local/bin
/usr/bin/install -c gnuchess /usr/local/bin/gnuchess
make[2]: Nothing to be done for 'install-data-am'.
...
```

You can run the two steps and install the software with this command:

```
# ./configure && make && make install
```

The Boolean AND operator, `&&`, allows the execution of the second step only if the first step returns a successful exit status.

## KEEPING SOFTWARE UP-TO-DATE

Of the many reasons to keep software up-to-date, one of the most important is security. Although you may hear about software-based security breaches after the fact, you rarely hear about the fixes that were available but never installed before the breach occurred. Timely installation of software updates is critical to maintaining system security. Linux open-source software is the ideal environment in which to find and fix bugs and make repaired software available quickly. When you keep the system and application software up-to-date, you keep abreast of bug fixes, new features, support for new hardware, speed enhancements, and more.

## BUGS

A *bug* is an unwanted and unintended program property, especially one that causes the program to malfunction (definition courtesy of [www.foldoc.org](http://www.foldoc.org)). Bugs have been around forever, in many types of systems, machinery, thinking, and so on. All sophisticated software contains bugs. Bugs in system software or application packages can cause the system to crash or programs not to run correctly. Security holes (a type of bug) can compromise the security of the system, allowing malicious users to read and write files, send mail to your contacts in your name, or destroy all data on the system, rendering the system useless.

Even if the engineers fixed all the bugs, there would still be feature requests as long as anyone used the software. Bugs, feature requests, and security holes are here to stay. Thus they must be properly tracked if developers are to fix the most dangerous/important bugs first, users are to research and report bugs in a logical manner, and administrators are to apply the developers' fixes quickly and easily.

**Bug tracking** Early on, Netscape used an internal bug-tracking system named BugSplat. Later, after Netscape created Mozilla (mozilla.org) as an open-source browser project, the Mozilla team decided that it needed its own bug-tracking system. Netscape's IS department wrote a very short-lived version of Bugzilla. Terry Weissman, who had been maintaining BugSplat, then wrote a new open-source version of Bugzilla in Tcl, rewriting it in Perl a couple of months later.

Bugzilla belongs to a class of programs formally known as *defect-tracking systems*, of which Bugzilla is now preeminent. Almost all Linux developers use this tool to track problems and enhancement requests for their software. Fedora/RHEL uses Bugzilla to track bugs and bug fixes for its Linux distributions; Red Hat Network takes advantage of Bugzilla to notify users of and distribute these fixes. To use Bugzilla, go to [bugzilla.redhat.com](http://bugzilla.redhat.com).

## ERRATA

For both Red Hat Enterprise Linux and Fedora, Red Hat and the Fedora Project process security, bug fix, and new feature (enhancement) updates. The easiest way to learn about, obtain, and install updates is to use `yum` (page 498).

As the Linux community, including Red Hat and the Fedora Project, finds and fixes operating system and software package bugs, including security holes, Red Hat and the Fedora Project generate `rpm` files (page 510) that contain the code that fixes the problems. When you upgrade a system software package, `rpm` renames modified configuration files with a `.rpmsave` extension. You must manually merge the changes you made to the original files into the new files.

The Fedora Announce List ([www.redhat.com/mailman/listinfo/fedora-announce-list](http://www.redhat.com/mailman/listinfo/fedora-announce-list)) holds information about Fedora updates. Under both *FEDORA* and *RHEL*, `yum-updatesd` notifies you automatically when updates are available. See “`yum-updatesd`: Runs `yum` Automatically” on page 504 for more information.

## RED HAT NETWORK (*RHEL*)

Red Hat Network ([rhn.redhat.com](http://rhn.redhat.com)), a service provided by Red Hat (for a fee), is an Internet-based system that can keep the software on one or more *RHEL* systems up-to-date with minimal work on your part. You must subscribe to the RHN service to use it. Red Hat uses the term *entitle* to indicate that a system subscribes to RHN: A system must be entitled before it can take advantage of RHN. You can choose to make RHN more or less automated, giving you varying degrees of control over the update process.

The entitled systems are the clients; Red Hat maintains the RHN server. The RHN server is much more than a single server: It involves many systems and databases



that are replicated and located in different areas. For the purpose of understanding how to use the client tools on the local system, picture the RHN server as a single server. For additional information, refer to the Red Hat Network manuals at [www.redhat.com/docs/manuals/RHNetwork](http://www.redhat.com/docs/manuals/RHNetwork).

Security is a priority with RHN. Whenever you allow a remote system to put a program on a system and run it, the setup must be very close to the theoretical ideal of absolutely secure. Toward this end, RHN never initiates communication with a system. Once a program running on a system sends a message to the RHN server, the server can respond and the system can trust the response.

## rhnsd: THE RHN DAEMON

The RHN daemon (**rhnsd**) is a background service that periodically queries the RHN server to determine whether any new packages are available to be downloaded. This daemon is one of the keys to RHN security: It initiates contact with the RHN server so the server never has to initiate contact with the local system. Refer to “service: Configures Services I” on page 427 for information on how to start, stop, or display the status of **rhnsd** immediately; refer to “system-config-services: Configures Services II” on page 428 or “chkconfig: Configures Services III” on page 429 for information on how to start or stop **rhnsd** at specified runlevels.

---

## wget: DOWNLOADS FILES NONINTERACTIVELY

The **wget** utility is a noninteractive, command-line utility that can retrieve files from the Web using HTTP, HTTPS, or FTP. The following simple example uses **wget** to download Red Hat’s home page, named **index.html**, to a file with the same name:

```
$ wget http://www.redhat.com
--2009-10-16 12:14:24-- http://www.redhat.com/
Resolving www.redhat.com... 96.6.224.112
Connecting to www.redhat.com|96.6.224.112|:80... connected.
HTTP request sent, awaiting response... 200 OK
Length: 20053 (20K) [text/html]
Saving to: `index.html'

100%[=====>] 20,053      --.-K/s   in 0.008s

2009-10-16 12:14:24 (2.28 MB/s) - 'index.html' saved [20053/20053]
```

Use the **-b** option to run **wget** in the background and redirect its standard error to a file named **wget-log**:

```
$ wget -b http://example.com/big_file.tar.gz
Continuing in background, pid 10752.
Output will be written to 'wget-log'.
```

If you download a file that would overwrite a local file, **wget** appends a period followed by a number to the filename. Subsequent background downloads are then logged to **wget-log.1**, **wget-log.2**, and so on.

The `-c` option continues an interrupted download. The next command continues the download from the previous example in the background:

```
$ wget -b -c http://example.com/big_file.tar.gz
```

---

## CHAPTER SUMMARY

As a system administrator, you need to keep applications and system software current. Of the many reasons to keep the software on a system up-to-date, one of the most important is system security. The development of rpm packages has made the process of adding and removing the software packages quite easy.

You can use yum to install and upgrade software packages. The yum utility is installed by default and is easy to configure and use.

In addition, you can use the rpm utility to install, uninstall, upgrade, query, and verify rpm packages. For packages distributed as source code, the GNU Configure and Build System makes it easy to build executable files.

BitTorrent is a handy tool for downloading large static data files such as the Fedora installation ISO images. BitTorrent can replace protocols such as anonymous FTP, where client authentication is not required.

Red Hat Network (RHN), a service provided by Red Hat, is an Internet-based system that can keep the software on one or more Red Hat Enterprise Linux systems up-to-date.

---

## EXERCISES

1. Why would you use HTTP or FTP instead of BitTorrent for downloading large files?
2. Which command would you give to perform a complete upgrade using yum?
3. Why would you build a package from its source code when a (binary) rpm file is available?
4. Suggest two advantages that rpm files have over source distributions.

---

## ADVANCED EXERCISES

5. When you compile a package yourself, rather than from an rpm file, which directory hierarchy should you put it in?
6. What are some steps you should take before performing an upgrade on a mission-critical server?
7. When should you use `rpm -i` instead of `rpm -U`?

# 14

## PRINTING WITH CUPS

### IN THIS CHAPTER

|                                                                                                 |     |
|-------------------------------------------------------------------------------------------------|-----|
| JumpStart I: Configuring a<br>Local Printer . . . . .                                           | 521 |
| system-config-printer:<br>Configuring a Printer . . . . .                                       | 522 |
| JumpStart II: Setting Up a Local<br>or Remote Printer Using<br>the CUPS Web Interface . . . . . | 527 |
| Traditional UNIX Printing . . . . .                                                             | 530 |
| The CUPS Web Interface . . . . .                                                                | 532 |
| CUPS on the Command Line. . . . .                                                               | 533 |
| Printing from Windows . . . . .                                                                 | 538 |
| Printing to Windows . . . . .                                                                   | 540 |

A *printing system* handles the tasks involved in first getting a print job from an application (or the command line) through the appropriate *filters* (page 1082) and into a queue for a suitable printer and then getting it printed. While handling a job, a printing system can keep track of billing information so the proper accounts can be charged for printer use. When a printer fails, the printing system can redirect jobs to other, similar printers.

## INTRODUCTION

**LPD and LPR** Traditionally, UNIX had two printing systems: the BSD Line Printer Daemon (LPD) and the System V Line Printer system (LPR). Linux adopted those systems at first, and both UNIX and Linux have seen modifications to and replacements for these systems. Today CUPS is the default printing system under Fedora/RHEL.

**CUPS** CUPS (Common UNIX Printing System) is a cross-platform print server built around IPP (Internet Printing Protocol), which is itself based on HTTP. CUPS provides many printer drivers and can print different types of files, including PostScript. Because it is built on IPP and written to be portable, CUPS runs under many operating systems, including Linux and Windows. Other UNIX variants, including Mac OS X, use CUPS; recent versions of Windows include the ability to print to IPP printers. Thus CUPS is an ideal solution for printing in a heterogeneous environment. CUPS provides System V and BSD command-line interfaces and, in addition to IPP, supports LPD/LPR, HTTP, SMB, and JetDirect (socket) protocols, among others.

**IPP** The IPP project ([www.pwg.org/ipp](http://www.pwg.org/ipp)) began in 1996, when Novell and several other companies designed a protocol for printing over the Internet. IPP enables users to

- Determine the capabilities of a printer.
- Submit jobs to a printer.
- Determine the status of a printer.
- Determine the status of a print job.
- Cancel a print job.

IPP is a client/server protocol in which the server side can be a print server or a network-capable stand-alone printer.

**Printers and queues** On a modern computing system, when you “send a job to the printer,” you actually add the job to the list of jobs waiting their turn to be printed on a printer. This list is called a *print queue* or simply a *queue*. The phrase *configuring* (or *setting up*) *a printer* is often used to mean *configuring a (print) queue*. This chapter uses these phrases interchangeably.

## PREREQUISITES

**Installation** Install the following packages (both are installed with the base Fedora/RHEL system):

- **cups**
- **system-config-printer** (optional)

To use the CUPS Web interface, you need an X server and a Web browser.

**cups init script** Run `chkconfig` to cause CUPS (the **cupsd** daemon) to start when the system goes into multiuser mode:

```
# /sbin/chkconfig cups on
```

Start CUPS:

```
# /sbin/service cups start
```

## MORE INFORMATION

- Local CUPS Documentation: With the CUPS Web interface up (page 532), point a local browser at localhost:631/help.
- Web [www.linux-foundation.org/en/OpenPrinting](http://www.linux-foundation.org/en/OpenPrinting): Information on printers and printing under Linux. Hosts a support database with details about many printers, including notes and driver information; also offers forums, articles, and a HOWTO document on printing.  
CUPS home page: [www.cups.org](http://www.cups.org)  
IPP information: [www.pwg.org/ipp](http://www.pwg.org/ipp)
- HOWTO The *SMB HOWTO* has a section titled “Sharing a Windows Printer with Linux Machines.”

## NOTES

- SELinux When SELinux is set to use a targeted policy, CUPS is protected by SELinux. You can disable this protection if necessary. For more information refer to “Setting the Targeted Policy with `system-config-securitylevel`” on page 416.
- Firewall A CUPS server normally uses TCP port 631 for an IPP connection and port 80 for an LPR/LPD connection. If the CUPS server system is running a firewall, you need to open one or both of these ports. Using the Firewall Configuration window Trusted Services tab (page 824), put a tick in the check box labeled **Network Printing Server (IPP)** to open port 631 and put a tick in the check box labeled **WWW (HTTP)** to open port 80. For more general information, see Chapter 25 (page 819), which covers `iptables`.

## JUMPSTART I: CONFIGURING A LOCAL PRINTER

In most cases, when you connect a printer to the local system and turn it on, Fedora/RHEL sets up the printer and briefly displays a **Printer added** message (Figure 14-1). This process can take a couple of minutes. If you want to modify the new printer’s configuration, click **Configure** on the message or use the Printer Configuration window (Figure 14-2 on the next page), described in the next section. Both techniques display the Printer Properties window.

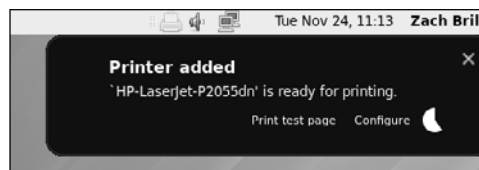
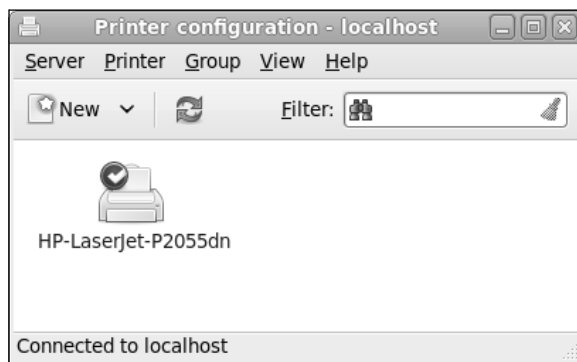


Figure 14-1 Printer added message



**Figure 14-2** The Printer Configuration window

## system-config-printer: CONFIGURING A PRINTER

The Printer Configuration window (Figure 14-2) enables you to add, remove, and configure local and remote printers. To display this window, select **Main menu: System⇒Administration⇒Printing** or give the command **system-config-printer** from a terminal emulator or Run Application window (ALT-F2).

**Default printer** Highlight a printer in the Printer Configuration window and select **Printer⇒Set as Default** from the window menu to specify the highlighted printer as the default printer. If just one printer appears in the Printer Configuration window, it is the default printer; you do not have to set it up as such. The tick on the printer in Figure 14-2 indicates the default printer.

Using **system-config-printer** is very similar to using the CUPS Web interface, which is discussed on page 527. However, **system-config-printer** is a native application, not a Web interface.

Double-click a printer in the Printer Configuration window to display the Printer Properties window (Figure 14-3) for that printer.

**Server Settings** Click **Server⇒Settings** from the Printer Configuration window menu to display the Basic Server Settings window. The top two check boxes specify whether **system-config-printer** displays printers that are shared by other systems and whether the local system publishes printers it shares. You control whether a given printer is shared from the Policies selection (discussed in the next section).

## CONFIGURATION SELECTIONS

This section describes the seven selections found in the frame at the left side of the Printer Properties window. These selections allow you to configure the printer you chose in the Printer Configuration window.

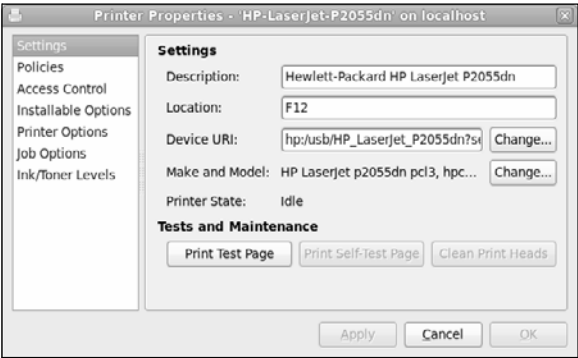


Figure 14-3 The Printer Properties window

- Settings

Figure 14-3 shows the Settings selection for a Hewlett-Packard (HP) printer. The text boxes labeled **Description** and **Location** hold information for your use; the system does not use this information. The text boxes labeled **Device URI** and **Make and Model** specify the location and type of the printer.
- Policies

Under the word **State** are check boxes labeled **Enabled**, **Accepting jobs**, and **Shared**. Table 14-1 describes the effects of putting ticks in the first two check boxes. Putting a tick in the check box labeled **Shared** shares the printer with other systems if the local system publishes shared printers (see “Server Settings,” on the previous page). The Policies tab also controls whether the printer prints banners before and after jobs and what CUPS does when it encounters an error.

Table 14-1 Printer status

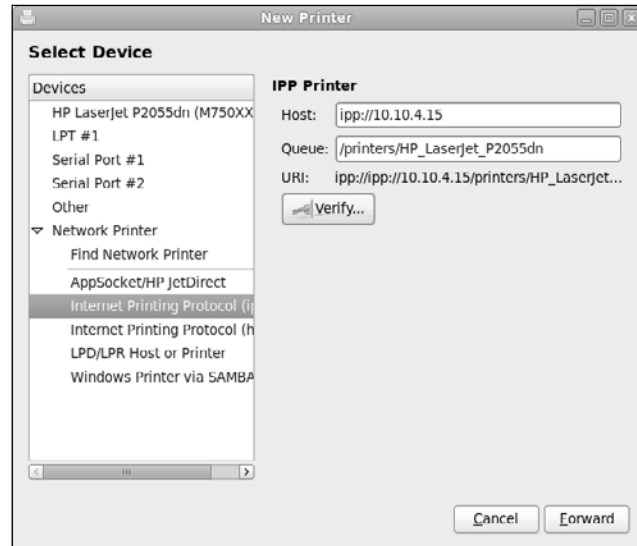
|                       | Enabled                                                         | Disabled                                                                                             |
|-----------------------|-----------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| <b>Accepting jobs</b> | Accepts new jobs into the queue.<br>Prints jobs from the queue. | Accepts new jobs into the queue.<br>Does not print jobs from the queue until the printer is enabled. |
| <b>Rejecting jobs</b> | Rejects new jobs.<br>Prints jobs from the queue.                | Rejects new jobs.<br>Does not print jobs from the queue until the printer is enabled.                |

- Access Control

The Access Control tab enables you to set the policy for printer access. By default, anyone can use the printer. To restrict access, you can create a blacklist of users who *are not* allowed to use it. Alternatively, you can prohibit anyone from using the printer and then create a whitelist of users who *are* allowed to use it.
- Installable Options

The Installable Options selection controls printer-specific options.
- Printer Options

The Printer Options selection controls image quality, paper size and source (tray), and other generic printer options.



**Figure 14-4** The New Printer window

**Job Options** The Job Options selection controls the number of copies, orientation (portrait or landscape), scaling, margins, and more. Options specified by an application sending a job to the printer override options you set in this tab.

**Ink/Toner Levels** The Ink/Toner Levels selection reports on ink/toner levels and displays status messages.

## SETTING UP A REMOTE PRINTER

As explained earlier, `system-config-printer` recognizes and sets up a printer when you connect it to the local system and turn it on. This section describes the process of setting up a printer on another system or on the local network. You can also use the same technique for setting up a printer on the local system. For more information on setting up a remote printer, refer to “JumpStart II: Setting Up a Local or Remote Printer Using the CUPS Web Interface” on page 527. Because of the similarity between `system-config-printer` and the CUPS Web interface, many of the explanations in that section apply here as well.

To add a printer to the local system, click **New** on the toolbar in the Printer Configuration window. The `system-config-printer` utility asks for the **root** password, looks for printers attached to the system or the local network, and then displays the New Printer window (Figure 14-4).

To configure a printer, highlight the printer in the frame labeled **Select Device**. Click the triangle to the left of Network Printers to display network printers. The `system-config-printer` utility displays a description of a local printer and fills in the





**Figure 14-5** Selecting a printer manufacturer

text boxes labeled **Host** and **Port number** (for a local printer) or **Queue** (for a remote printer).

**Specifying a URI** If the printer is not listed, select **Other** (for a local printer) or one of the selections under Network Printing (for a remote printer) from the Select Device list; `system-config-printer` displays an appropriate text box on the right side of the window. The *URI* (page 1113) is the location on the network of the printer; see page 534 for more information. To specify an LPD/LPR printer, use the form `lpd://hostname/printer-name`; for an IPP printer, use the form `ipp://hostname/printers/printer-name`; for an HP JetDirect-compatible network printer, use `socket://hostname`. Replace *hostname* with the name of the host the printer is attached to (the server) or, for a network printer, the name of the printer. You can specify an IP address instead of *hostname*. Replace *printer-name* with the name of the printer on the server. Give the command `lpstat -p` on the server to display the names of all printers on that system. After selecting or specifying a printer, click the button labeled **Verify** (if present) to make sure the printer is accessible and then click **Forward**. The `system-config-printer` utility searches for a driver for the printer.

Next the utility may ask you which printer options you want to install. Specify the options and click **Forward**.

In the Choose Driver screen of the New Printer window (Figure 14-5), you can specify a printer manufacturer (such as HP). Typically `system-config-printer` selects the manufacturer automatically. Alternatively, you can specify a PPD file (page 533) or search for a driver to download. Click **Forward**.



**Figure 14-6** Selecting a printer model and driver

The next screen (Figure 14-6) allows you to specify the model of the printer and select which driver you want to use (if more than one is available). Again, these selections are usually highlighted automatically.

If the model of the printer you are configuring is not listed, check whether the printer can emulate another printer (i.e., if it has an *emulation mode*). If it can, check whether the manufacturer and model of the printer it can emulate are listed and set it up that way. If all else fails, click **Back** and select **Generic** (at the top of the list) as the manufacturer. Then click **Forward** and choose a type of generic printer from the list box labeled **Models**. Choose the **PostScript Printer** from the list if the printer is PostScript capable. Then select a PostScript driver from the list box labeled **Drivers**. If the printer is not PostScript capable, select **text-only printer**; you will not be able to print graphics, but you should be able to print text. Click **Forward**.

The `system-config-printer` utility displays a screen showing installable (printer-specific) options. Generally you do not need to make changes to this screen. Click **Forward**.

On the next screen (Figure 14-7), you must specify a name for the printer; specifying the description and location is optional. The name of the printer must start with a letter and cannot contain SPACES. If you use only one printer, the name you choose is not important. If you use two or more printers, the name should help users distinguish between them. The printer name is the name of the print queue on the local system. Click **Apply**.

At this point, the `system-config-printer` utility closes the New Printer window and the new printer appears in the Printer Configuration window. If you have more than

**Figure 14-7** Specifying the name of the printer

one print queue and want to set up the new print queue to be the default, highlight the printer and select **Printer⇒Set As Default** from the window menu.

## JUMPSTART II: SETTING UP A LOCAL OR REMOTE PRINTER USING THE CUPS WEB INTERFACE

This JumpStart explains how to use the CUPS Web interface to set up a printer connected to the local system or connected to the local network.

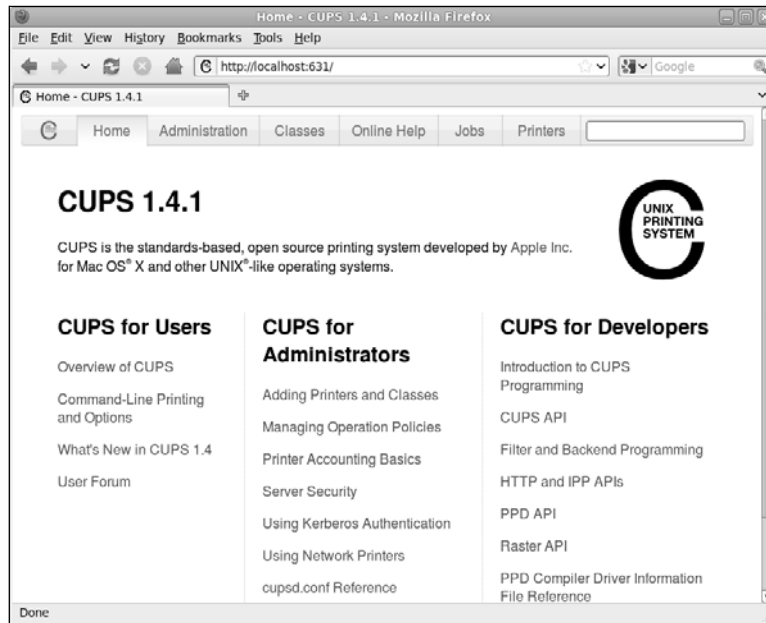
If the printer you are configuring is on an older Linux system or another UNIX-like operating system that does not run CUPS, the system is probably running LPD/LPR. Newer versions of Linux and UNIX variants that support CUPS (including Mac OS X) support IPP. Most devices that connect printers directly to a network support LPR/LPD; some support IPP.

Printers connected directly to a network are functionally equivalent to printers connected to a system running a print server: They listen on the same ports as systems running print servers and queue jobs.

**Username and password** At some point the CUPS Web interface will ask for a username and password. Supply **root** and the **root** password.

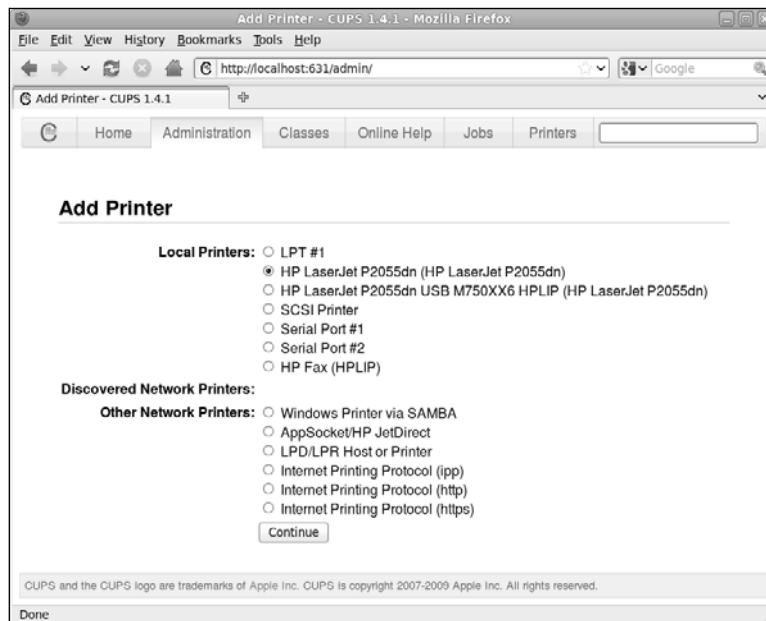
### Remote administration

**security** When you provide a username and password to the CUPS Web interface, they are transmitted in cleartext over HTTP. The lack of encryption is a security issue when you are administrating printers over an unsecure network.



**Figure 14-8** The Welcome page

Display the CUPS Web interface by pointing a Web browser at **localhost:631** on the system on which you are configuring the printer (Figure 14-8).



**Figure 14-9** The first Add Printer page

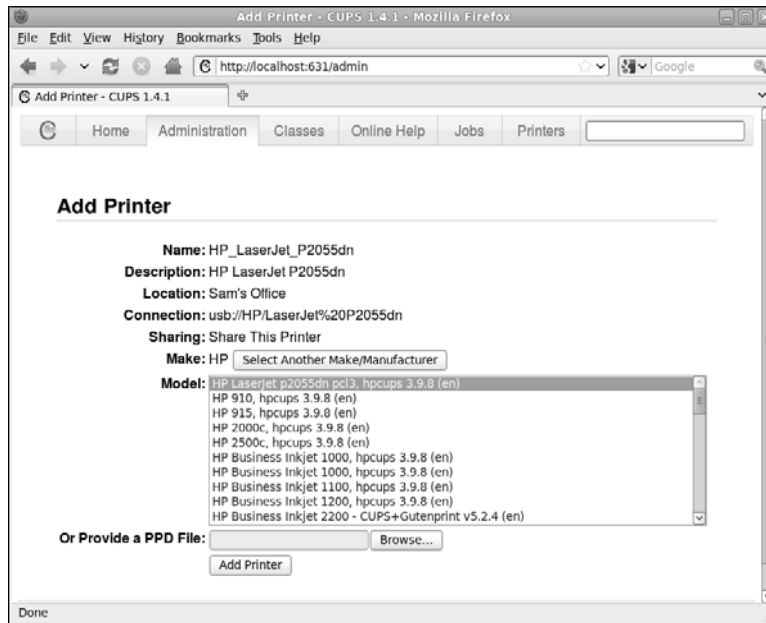
**Figure 14-10** The second Add Printer page

Clicking the **Administration** tab near the top of the page displays the Administration page. On this page click **Add Printer** to display the first Add Printer page (Figure 14-9). Click the printer you want to install and then click **Continue** to display the second Add Printer page (Figure 14-10). Enter the name of the printer in the text box labeled **Name**; this name must start with a letter and not contain any SPACES. You must supply a name—any name you like. Optionally, you can fill in the text boxes labeled **Description** and **Location** with text that will help users identify the printer. Put a tick in the check box labeled **Sharing** if you want to share the printer. Click **Continue**.

**Specifying a device** The next screen asks you to select the model of the printer you want to set up (Figure 14-11, next page). Select the printer you want to use. Click **Add Printer**.

If the printer is PostScript capable but is not listed, select a PostScript printer such as the Apple LaserWriter 12/640ps. If the printer is not PostScript capable and is not listed, check whether the printer supports PCL; if it does, select another, similar PCL printer. If all else fails, determine which listed printer is most similar to the one you are configuring and specify that printer. You can also try configuring the printer using `system-config-printer` (page 522), which offers a different choice of models.

After you click **Add Printer**, the CUPS Web interface briefly displays a message saying that the printer has been successfully added and then displays the Set Default Options page. This page allows you to set printer options and configuration information. Click the buttons at the top of the page, browse through the selections, and make any changes you like. Frequently you need change nothing. Click **Set Printer Default**.



**Figure 14-11** The third Add Printer page

After displaying another brief message, the CUPS Web interface displays the Printer page (Figure 14-12) showing the new printer. Click **Maintenance**⇒**Print Test Page** to confirm the new setup works. If you want to make this printer the default printer, click **Administration**⇒**Set As Server Default**.

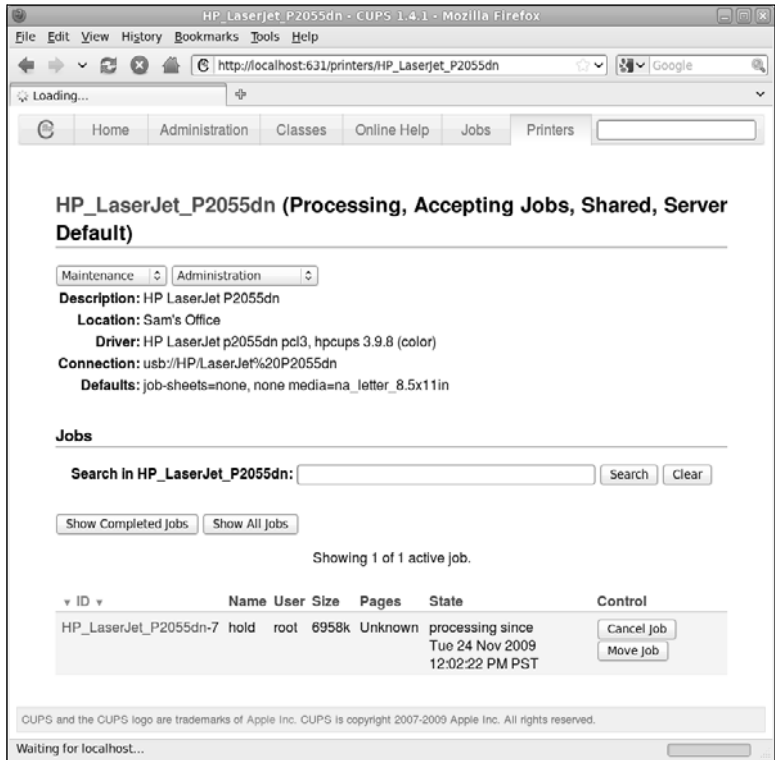
The buttons at the bottom of the Printer page enable you to cancel or move jobs in the print queue. In addition to these tasks, you may be able to reprint jobs. Figure 14-12 shows the Printer page displaying information about a job the printer is printing.

## TRADITIONAL UNIX PRINTING

Before the advent of GUIs and WYSIWYG (page 1116) word processors, UNIX users would create documents using an editor such as `vi` and a typesetting markup language such as TeX or `nroff/troff`, convert the resulting files to PostScript using an interpreter, and send the PostScript files to the printer using `lpr` (BSD) or `lp` (System V). Fedora/RHEL implements both BSD and System V command-line printing utilities for compatibility. However, these utilities are now wrappers around the equivalent functionality in CUPS rather than core components of the printing system. The corresponding utilities are functionally equivalent; use whichever you prefer (Table 14-2).

From the command line, you can print a text, PostScript, or PDF file using `lp`:

```
$ lp memo.txt
request id is MainPrinter-25 (1 file(s))
```



**Figure 14-12** Printer page showing jobs information

**Table 14-2** BSD and System V command-line print utilities

| BSD/SysV    | Purpose                                |
|-------------|----------------------------------------|
| lpr/lp      | Sends job(s) to the printer            |
| lpq/lpstat  | Displays the status of the print queue |
| lprm/cancel | Removes job(s) from the print queue    |

The preceding command adds **memo.txt** to the print queue of the default printer as job 25. When this printer is available, it prints the file. You can specify a printer using the **-d** option:

```
$ lp -d ColorPtr graph.ps
request id is ColorPtr-26 (1 file(s))
```

The **lpr -P** option is equivalent to the **lp -d** option.

Without arguments, **lp** and **lpr** send their standard input to the printer:

```
$ cat memo2.txt | lp
request id is MainPrinter-27 (1 file(s))
```

The **lpq** and **lpstat** commands display information about the print queue:

```
$ lpstat
MainPrinter-25      zach      13312    Sun Feb 22 18:28:38 2009
ColorPtr-26         zach      75776    Sun Feb 22 18:28:48 2009
MainPrinter-27      zach      8192     Sun Feb 22 18:28:57 2009
```

Use `cancel` or `lprm` to remove jobs from the print queue. By default, only the owner of a print job or a user working with `root` privileges can remove a job.

```
$ cancel 27
$ lpstat
MainPrinter-25      zach      13312    Sun Feb 22 18:28:38 2009
ColorPtr-26         zach      75776    Sun Feb 22 18:28:48 2009
```

While working with `root` privileges, give the command `cancel -a` or `lprm -` to remove all jobs from the print queues.

---

## CONFIGURING PRINTERS

You can use the Web interface or the command-line interface to CUPS to manage printers and queues.

### THE CUPS WEB INTERFACE

To connect to the CUPS Web interface (page 527), point a Web browser running on the local system at `localhost:631`. You must supply the username `root` and the `root` password to change the printer configuration using the CUPS Web interface.

#### MODIFYING A PRINTER

“JumpStart II: Setting Up a Local or Remote Printer Using the CUPS Web Interface” (page 527) discusses how to set up a printer using the CUPS Web interface. This section explains how to modify a printer that is already set up.

To modify a printer, click the **Printers** tab near the top of the page and then click the name of the printer you want to modify. The CUPS Web interface displays two drop-down lists near the top of the page: Administration and Maintenance (Figure 14-12, page 531). These lists work with the selected printer. The Administration drop-down list allows you to modify the printer; this selection takes you through the same steps as when you set up a new printer. From this list you can also delete and set default options for the printer as well as set the printer as the default printer and specify which users are allowed to use the printer. From the Maintenance drop-down list, you can print a test page and pause the printer. You can also reject, move, and cancel all jobs.

#### JOBS

Click the **Jobs** tab near the top of the page to display the Jobs page, which lists jobs in the print queues. From this page you can cancel print jobs and move them to other queues. Click **Show Completed Jobs** to display a list of recently completed jobs. In some cases, you can reprint completed jobs from this page. You can perform the same tasks from the Printer page.



## CLASSES

CUPS allows you to organize similar printers into a group called a *class*. To clients, a class of printers appears as a single printer. For each class, you must specify a name; optionally, you can specify a location and description. A printer can belong to more than one class. CUPS prints jobs sent to a class on the first available printer in the class. For example, you may be able to divide your print jobs into black-and-white jobs and color jobs. If more than one printer can fulfill each of these roles, you can allow users to select a printer manually, or you can define two printer classes (black-and-white and color) and have users send their jobs to a certain class of printers.

### Plan for the future

**tip** If you expect to add printers to the network, you may want to configure classes containing the existing printers when you set up the network. You can then add printers later without having to change printer configurations on client systems.

To define a class, first click the **Administration** tab near the top of the page and then click **Add Class**. At a minimum, you must enter a name for the class. You may also enter a description and location. The Members list displays the names of all CUPS printers and classes. Highlight the printers you want to be members of the class you are defining; hold **SHIFT** and click another printer to highlight more than one printer. To define a class that includes printers that are not adjacent in the list, define the class to have a single printer and then modify the class after you create it to add other printers. To modify existing classes, click **Manage Classes** in the Administration tab.

## CUPS ON THE COMMAND LINE

In addition to using the Web interface, you can control CUPS and manage print queues from the command line. This section describes the utilities that enable you to manage printers and print queues and establish printing quotas.

### lpinfo: DISPLAYS AVAILABLE DRIVERS

**PPD files** The `lpinfo` utility provides information about the printer drivers and interfaces available to CUPS. The `-m` option displays the list of available PostScript Printer Definition (PPD) files/drivers.

```
$ lpinfo -m | head
drv:///hp/hpcups.drv/apollo-2100.ppd Apollo 2100, hpcups 3.9.8
drv:///hp/hpcups.drv/apollo-2150.ppd Apollo 2150, hpcups 3.9.8
drv:///hp/hpcups.drv/apollo-2200.ppd Apollo 2200, hpcups 3.9.8
drv:///hp/hpcups.drv/apollo-2500.ppd Apollo 2500, hpcups 3.9.8
drv:///hp/hpcups.drv/apollo-2600.ppd Apollo 2600, hpcups 3.9.8
drv:///hp/hpcups.drv/apollo-2650.ppd Apollo 2650, hpcups 3.9.8
gutenprint.5.2://pcl-apollo-p2100/expert Apollo P-2100 - CUPS+Gutenprint v5.2.4
gutenprint.5.2://pcl-apollo-p2100/simple Apollo P-2100 - CUPS+Gutenprint v5.2.4 Simplified
gutenprint.5.2://pcl-apollo-p2150/expert Apollo P-2150 - CUPS+Gutenprint v5.2.4
gutenprint.5.2://pcl-apollo-p2150/simple Apollo P-2150 - CUPS+Gutenprint v5.2.4 Simplified
```

URIs CUPS uses URIs (page 525) to identify printer ports by type and location, just as a Web browser identifies documents by protocol and location. A parallel port has a URI with the format **parallel:/dev/lp0**; a remote LPD printer uses the format **lpd://192.168.0.101**. When run with **root** privileges, **lpinfo** with the **-v** option provides a list of available connections:

```
# lpinfo -v
network smb
network socket
network lpd
network ipp
network http
network https
direct scsi
direct parallel:/dev/lp0
serial serial:/dev/ttyS0?baud=115200
serial serial:/dev/ttyS1?baud=115200
direct hp
direct hpfax
```

The **-v** option to **lpinfo** does not display every possible network address for the socket, HTTP, IPP, LPD, and SMB protocols because there are more than 4 billion of these addresses in the IPv4 address space.

## lpadmin: CONFIGURES PRINTERS

You can use the **lpadmin** utility to add and remove printers from the system, modify printer configurations, and manage printer classes. This utility has three major options: **-d** (set the default printer), **-x** (remove a printer), and **-p** (add or modify a printer). The first two options are simple; examples follow the next subsection. Each of these three options takes an argument that is the name of a printer. The name of the printer must start with a letter and cannot contain SPACES.

### ADDING OR MODIFYING A PRINTER

Add a printer or modify an existing printer by giving a command in the following format:

```
$ lpadmin -p printer-name options
```

where *printer-name* is the name of the printer and *options* is a combination of options from the following list:

- c class** Adds the printer to the class *class*, creating the class if necessary.
- D info** The *info* is a string that describes the printer for the benefit of users; it has no meaning to the system. Enclose *info* within quotation marks if it contains SPACES.
- E** Enables the printer, instructing CUPS to accept jobs into its print queue.
- L loc** The *loc* is a string that indicates the physical location of the printer (e.g., office, building, floor). It has no meaning to the system. Enclose *loc* within quotation marks if it contains SPACES.

- m *model*** The *model* is the name of the PPD file (page 533) that describes the printer. Use **lpinfo -m** to display a list of installed PPD files. If you have a manufacturer-provided PPD file, copy it to `/usr/share/cups/model`. Use the **-P** option to specify the pathname of the file. Specifying **-m postscript.ppd.gz**, for example, is the same as specifying **-P /usr/share/cups/model/postscript.ppd.gz**.
- P *file*** The *file* is the absolute pathname of the PPD file (page 533) that describes the printer. Use **lpinfo -m** to display a list of installed PPD files. If you have a manufacturer-provided PPD file, copy it to `/usr/share/cups/model`. See **-m** for an alternative way to specify a PPD file.
- r *class*** Removes the printer from the class *class*. This option removes the class if, after removing the printer, the class would be empty.
- v *URI*** The *URI* is the device to which the printer is attached. Use **lpinfo -v** to list possible devices.

### EXAMPLE lpadmin COMMANDS

At a minimum, you need to provide a device and a model when you add a printer to the system. The following command adds an Epson Stylus Color printer to the system and enables it for use. This printer is connected locally to the first parallel port and is named **ColorPtr**.

```
# lpadmin -p ColorPtr -E -v parallel:/dev/lp0 -m stcolor.ppd.gz
```

The printer information generated by the preceding command is stored in the `/etc/cups/printers.conf` file:

```
$ sudo cat /etc/cups/printers.conf
# Printer configuration file for CUPS v1.3.9
# Written by cupsd on 2008-10-18 10:46
<Printer ColorPtr>
Info ColorPtr
DeviceURI parallel:/dev/lp0
State Idle
StateTime 1180495957
Accepting Yes
Shared Yes
JobSheets none none
QuotaPeriod 0
PageLimit 0
KLimit 0
OpPolicy default
ErrorPolicy retry-job
</Printer>
```

The **lpadmin** command decompresses and copies the printer driver information from the `/usr/share/cups/model/stcolor.ppd.gz` file to `/etc/cups/ppd`. The resulting file is given the printer's name: `/etc/cups/ppd/ColorPtr.ppd`.

You can modify a printer configuration with **lpadmin** using the same options that you used to add it. When you specify the name of an existing printer, **lpadmin** modifies the printer rather than creating a new one.

The next command configures an HP LaserJet-compatible printer with a JetDirect interface that is connected directly to the LAN at 192.168.1.103 and names this printer HPLJ. Specifying `socket` in the protocol part of the URI instructs CUPS to use the JetDirect protocol, a proprietary protocol developed by HP for printers connected directly to a network.

```
# lpadmin -p HPLJ -E -v socket://192.168.1.103 -m laserjet.ppd.gz
```

The `lpstat` utility with the `-d` option displays the name of the default printer:

```
$ lpstat -d
system default destination: MainPrinter
```

CUPS automatically makes the first printer you define the default printer. The following command makes HPLJ the default printer:

```
$ lpadmin -d HPLJ
```

The following command removes the configuration for the ColorPtr printer:

```
$ lpadmin -x ColorPtr
```

## PRINTING QUOTAS

CUPS provides rudimentary printing quotas. You can define two forms of quotas: page count and file size. File size quotas are almost meaningless because a small PostScript file can take a long time to interpret and can require a lot more ink to print than a large one. Page quotas are more useful, although their implementation is flawed. To determine the number of pages in a document, CUPS examines the PostScript input. If a job is submitted in the printer's native language, such as PCL, CUPS bypasses this accounting mechanism. Also, if `mpage` is used to create a PostScript file with multiple pages printed on each sheet, CUPS counts each page in the original document, rather than each sheet of paper it prints on.

Use `job-quota-period` and either `job-page-limit` or `job-k-limit` to establish a quota for each user on a given printer. The `job-quota-period` option specifies the number of seconds that the quota remains valid. The following command establishes a quota of 20 pages per day per user for the printer named HPLJ:

```
$ lpadmin -p HPLJ -o job-quota-period=86400 -o job-page-limit=20
```

The `job-k-limit` option works similarly but defines a file size limit in kilobytes. The limit is the total number of kilobytes that each user can print during the quota period. Once a user has exceeded her quota, she will not be allowed to print until the next quota period.

## MANAGING PRINT QUEUES

When a printer is operating normally, it accepts jobs into its print queue and prints those jobs in the order they are received. You can give the command `cupsreject` followed by the name of a printer to cause a printer to not accept jobs into its print queue; give the command `cupsaccept` to reenable it. You can also use `system-config-printer` to

control the print queue; refer to “Settings” on page 523. Two factors determine how a printer handles a job: if the printer is accepting jobs and if it is enabled. Table 14-1 on page 523 describes what happens with the various combinations of the two factors.

The utilities that change these factors are `cupsdisable`, `cupsenable`, `cupsreject`, and `cupsaccept`. Each utility takes the name of a printer as an argument. The following commands first disable and then enable the printer named HPLJ:

```
# cupsdisable HPLJ
# cupsenable HPLJ
```

The next commands cause HPLJ to reject and then accept jobs:

```
# cupsreject HPLJ
# cupsaccept HPLJ
```

## SHARING CUPS PRINTERS

IPP facilitates remote printing. The Listen directive in the CUPS configuration file, `/etc/cups/cupsd.conf`, specifies which IP address and port or which domain socket path CUPS binds to and accepts requests on. The Listen directive has the following format:

*Listen IP:port | path*

where *IP* is the IP address that CUPS accepts connections on, *port* is the port number that CUPS listens on for connections on *IP*, and *path* is the pathname of the domain socket CUPS uses to communicate with printers. CUPS typically uses port 631. By default, it binds to `localhost`. Thus it accepts connections from the loop-back service of the local system only. CUPS uses `/var/run/cups/cups.sock`, a local domain socket, to communicate with local printers. It can also use a Port directive to specify the port number it listens to for HTTP requests.

```
$ grep -i listen /etc/cups/cupsd.conf
# Only listen for connections from the local machine.
Listen localhost:631
Listen /var/run/cups/cups.sock
```

To allow other systems to connect to the CUPS server on the local system, you must instruct CUPS to bind to an IP address that the other systems can reach. The following directive would be appropriate on a CUPS server running on 192.168.0.12:

```
Listen 192.168.0.12:631
```

This directive, when placed after the other Listen directives, would cause CUPS to listen on IP address 192.168.0.12, port 631. When you change `cupsd.conf`, you need to call the `cups` init script to restart the `cupsd` daemon (page 520).

Some directives in `cupsd.conf` use the `@LOCAL` macro, which is internal to CUPS and specifies the local system. This macro accepts communication from any address that resolves to the local system.

Once you restart **cupsd**, remote systems can print on the local system's printers using the IP address and port number specified by the Listen directive. If the server is running a firewall, you need to allow remote systems to connect through it; see page 521. You may also need to modify the SELinux policy (page 416) depending on the system setup.

Alternatively, you can use CUPS's access control list to permit only selected machines to connect to local printers. An access control list is defined inside a `<Location>` container (see page 857 for the Apache equivalent). The following example allows only the system at IP address 192.168.1.101 and the local system to print to the specified printer:

```
<Location /printers>
Order Allow,Deny
Allow from localhost
Allow from 192.168.1.101
</Location>
```

The `/printers` indicates that this container refers to all local printers. Alternatively, you can control access on a per-printer basis by specifying `/printers/printer-name`, where *printer-name* is the printer name, or by specifying `/printers/path.ppd`, where *path.ppd* is the full pathname of the PPD file (page 533) used by the printer.

The Order Deny,Allow directive allows access by default and denies access only to clients specified in Deny from directives. The Order Allow,Deny directive denies print requests by default and allows requests from specified addresses. You can use domain names, including wildcards, and IP ranges with either wildcards or net-masks in Allow from and Deny from directives. These directives work the same way they do in Apache. For more information refer to "Order" on page 870.

With the Order Deny,Allow directive, **Deny from** specifies the only IP addresses CUPS does not accept connections from. When you use the Order Allow,Deny directive, **Allow from** specifies the only IP addresses CUPS accepts connections from.

---

## PRINTING FROM WINDOWS

This section explains how to use printers on Linux CUPS servers from Windows machines. CUPS is easier to manage and can be made more secure than using Samba to print from Windows.

## PRINTING USING CUPS

Modern versions of Windows (2000 and later) support IPP and, as a result, can communicate directly with CUPS. To use this feature, you must have CUPS configured on the Linux print server to allow remote IPP printing; you also need to create a new printer on the Windows system that points to the IP address of the Linux print server.

First set up the `/etc/cups/cupsd.conf` file to allow network printing from a client, as explained in “Sharing CUPS Printers” on page 537. Setting up CUPS to allow printing from a Windows machine is exactly the same as setting it up to allow printing from a Linux client system. If necessary, open the firewall as explained on page 521.

From Windows XP, go to **Control Panel**⇒**Printers and Faxes** and click **Add Printer**. Click **Next** in the introductory window and select **A network printer or a printer attached to another computer**. Click **Next**. Select **Connect to a printer on the Internet or on a home or office network** and enter the following information in the text box labeled **URL**:

*http://hostname:631/printers/printer-name*

where *hostname* is the name or IP address of the Linux CUPS server system and *printer-name* is the name of the printer on that system. For example, for the printer named **dog88** on the system named **dog** at IP address 192.168.0.12, you could enter **http://dog:631/printers/dog88** or **http://192.168.0.12:631/printers/dog88**. If you use a hostname, it must be defined in the **hosts** file on the Windows machine. Windows requests that you specify the manufacturer and model of printer or provide a driver for the printer. If you supply a printer driver, use the Windows version of the driver.

After Windows copies some files, the printer appears in the **Printers and Faxes** window. Right-click the printer and select **Set as Default Printer** to make it the default printer. You can specify comments, a location, and other attributes of the printer by right-clicking the printer and selecting **Properties**.

## PRINTING USING SAMBA

This section assumes that Samba (page 749) is installed and working on the Linux system that controls the printer you want to use from Windows. Samba must be set up so that the Windows user who will be printing is mapped to a Linux user (including mapping the Windows **guest** user to the Linux user **nobody**). Make sure these users have Samba passwords. Refer to “Samba Users, User Maps, and Passwords” on page 752.

Windows supports printer sharing via SMB, which allows a printer to be shared transparently between Windows systems using the same mechanism as file sharing. Samba allows Windows users to use printers connected to Linux systems just as they would use any other shared printers. Because all Linux printers traditionally appear to be PostScript printers, the Linux print server appears to share a PostScript printer. Windows does not include a generic PostScript printer driver. Instead, Windows users must select a printer driver for a PostScript printer. The Apple LaserWriter 12/640ps driver is a good choice.

When you use `rpm` to install Samba, it creates a directory named `/var/spool/samba` that is owned by the **root** account and that anyone can read from and write to. The sticky bit (page 1108) is set for this directory, allowing a Windows user who starts a

print job as a Linux user to be able to delete that job, but denying users the ability to delete the print jobs of other users. Make sure this directory is in place and has the proper ownership and permissions:

```
$ ls -ld /var/spool/samba
drwxrwxrwt 2 root root 4096 2008-10-10 12:29 /var/spool/samba
```

Put the following two lines in the `[global]` section of the `/etc/samba/smb.conf` file:

```
[global]
...
printing = cups
printcap name = cups
```

The printer's share is listed in the `[printers]` section in `smb.conf`. In the following example, the **path** is the path Samba uses as a spool directory and is not a normal share path. The settings allow anyone, including **guest**, to use the printer. The `[printers]` section in the default `smb.conf` file has the following entries, which are appropriate for most setups:

```
[printers]
comment = All Printers
path = /var/spool/samba
browseable = no
guest ok = no
writable = no
printable = yes
```

Ideally each user who plans to print should have an account. Otherwise, when multiple users share the same account (for example, the **nobody** account), they can delete one another's print jobs.

---

## PRINTING TO WINDOWS

CUPS views a printer on a Windows machine exactly the same way it views any other printer. The only difference is the URI you need to specify when connecting it. To configure a printer connected to a Windows machine, go to the Printer page in the CUPS Web interface and select **Add Printer**, just as you would for a local printer.

When you are asked to select the device, choose **Windows Printer via SAMBA**. Enter the URI of the printer in the following format:

```
smb://windows_system/printer_name
```

where *windows\_system* can be an IP address or a hostname. Once you have added the printer, you can use it as you would any other printer.

---

## CHAPTER SUMMARY

A printing system such as CUPS sets up printers. It also moves print jobs from an application or the command line through the appropriate filters and into a queue for a suitable printer and then prints those jobs.



CUPS is a cross-platform print server built around IPP (Internet Printing Protocol). It handles setting up and sending jobs through print queues. The easiest way to configure printers is via the Printer Configuration window (`system-config-printer`). You can also configure CUPS using the Web interface, which you can access by pointing a Web browser at **localhost:631** on the system the printer is connected to. From the Web interface, you can configure print queues and modify print jobs in the queues.

You can use the traditional UNIX commands from a command line to send jobs to a printer (`lpr/lp`), display a print queue (`lpq/lpstat`), and remove jobs from a print queue (`lprm/cancel`). In addition, CUPS provides the `lpinfo` and `lpadmin` utilities, which allow you to configure printers from the command line.

CUPS and Samba enable you to print on a Linux printer from a Windows machine, and vice versa.

---

## EXERCISES

1. Which commands can you use from the command line to send a file to the default printer?
2. Which command would you give to cancel all print jobs on the system?
3. Which commands list your outstanding print jobs?
4. What is the purpose of sharing a Linux printer using Samba?
5. Name three printing protocols that CUPS supports. Which is the CUPS native protocol?

---

## ADVANCED EXERCISES

6. Which command lists the installed printer drivers available to CUPS?
7. How would you send a text file to a printer connected to the first parallel port without using a print queue? Why is doing so a bad idea?
8. Assume you have a USB printer with a manufacturer-supplied PostScript printer definition file named **newprinter.ppd**. Which command would you use to add this printer to the system on the first USB port with the name `USBPrinter`?
9. How would you define a quota that allows each user to print up to 50 pages per week to the printer named `LaserJet`?
10. Define a set of access control rules for a `<Location>` container inside `/etc/cups/cupsd.conf` that would allow anyone to print to all printers as long as they were either on the local system or in the **mydomain.com** domain.

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# 15

## REBUILDING THE LINUX KERNEL

### IN THIS CHAPTER

Locating the Kernel Source Code .....	544
Installing the Kernel Source Code .....	545
Configuring and Compiling the Linux Kernel .....	547
Installing the Kernel and Associated Files .....	550
Boot Loader .....	551
dmesg: Displays Kernel Messages .....	553

Once you have installed Red Hat Enterprise Linux or Fedora, you may want to reconfigure and rebuild the Linux kernel. Fedora/RHEL comes with a prebuilt kernel that simplifies the installation process. This kernel may not be properly configured for all of your system's features, however. By reconfiguring and rebuilding the kernel, you can create one that is customized for your system and your unique needs. Or you may want to build a kernel to learn more about Linux.

Because recent releases of the Linux kernel are modular, you do not usually need to rebuild the kernel. Instead, you can dynamically change many things that used to require rebuilding the kernel. One way to make these changes is by modifying runtime options in `/etc/sysctl.conf`, which is used by `sysctl` when the system boots. You can also modify boot options by appending a string to the `kernel` line in the file `/boot/grub/grub.conf` or to its symbolic link, `/etc/grub.conf`. For example, `norelocate` prevents the substitution of CPU-specific optimizations and `acpi=off` prevents `acpid` (the advanced configuration and power interface daemon) from starting.

### Maybe you just need to install a new Linux kernel binary

**tip** Refer to “Installing a Linux Kernel Binary” on page 512 when you want to install a Linux kernel binary that you do not need to configure or build.

**sysctl** The `sysctl` utility modifies kernel parameters while the system is running. This utility takes advantage of the facilities of `/proc/sys`, which defines the parameters that `sysctl` can modify.

The command `sysctl -a` displays a complete list of `sysctl` parameters. An example of displaying and changing the `domainname` kernel parameter follows. The quotation marks are not required in this example, but you must quote any characters that would otherwise be interpreted by the shell. Changes made using `-w` are not persistent across reboots; you must edit `/etc/sysctl.conf` to ensure persistence.

```
# /sbin/sysctl kernel.domainname
kernel.domainname = (none)
# /sbin/sysctl -w kernel.domainname="example.com"
kernel.domainname = example.com
```

### Have the installation DVD handy when you rebuild the kernel

**caution** When you rebuild the Linux kernel to install a new version or to change the configuration of the existing version, make sure you have the installation DVD handy. This disk allows you to reboot the system, even when a newly compiled kernel does not boot properly. Refer to “Rescue Mode” on page 411 for instructions on bringing the system up in rescue mode.

---

## PREPARING THE SOURCE CODE

Before you can start rebuilding the kernel, you must locate, install, and clean the source code. If you want to compile an original kernel from upstream that has not been customized (patched) by the Fedora Project or Red Hat, download the latest kernel source from [kernel.org](http://kernel.org).

## LOCATING THE KERNEL SOURCE CODE

When you have the kernel source on the system, the `/usr/src` directory will look similar to the following:

```
$ ls -l /usr/src
total 12
drwxr-xr-x. 2 root root 4096 Aug 25 11:06 debug
drwxr-xr-x. 2 root root 4096 Aug 25 11:06 kernels
lrwxrwxrwx. 1 root root 26 Oct 1 18:47 linux -> /usr/src/linux-2.6.31.i686
drwxr-xr-x. 25 root root 4096 Oct 1 20:56 linux-2.6.31.i686
```

In the preceding example, the name `linux-2.6.31.i686` means that the directory contains version 2.6 of the Linux kernel, release 30, and is set up for a Pentium Pro (P6 core) architecture as indicated by `i686`.

The `/usr/src` directory is the traditional location for the kernel source. Also check whether the kernel code appears in `/root/rpmbuild/BUILD/kernel*` (*FEDORA*) or `/usr/src/redhat` (*RHEL*), as that is where it is installed by default. If it is there, see step 4 on page 546.

If the source code is present on the system, skip to “Cleaning the Source Tree” on page 547.

## INSTALLING THE KERNEL SOURCE CODE

When the kernel source code is not present on the system, you need to install it.

*FEDORA* Before you start, install `rpmbuild`. You will need this program to unpack and apply patches to the source files. The `rpmbuild` utility is part of the `rpmdevtools` package. Give the following command to install this package:

```
# yum install rpmdevtools
```

*RHEL* Before you start, install some development tools including the C compiler (`gcc`): Use `pirut` (page 505) to install **Development: Development Tools**. You also need to install two packages:

```
# yum install redhat-rpm-config rpm-build
```

*FEDORA* 1. To download the source code for a Fedora kernel, point a browser at [mirrors.fedoraproject.org](http://mirrors.fedoraproject.org). From the Mirror List Filter in the upper-right corner of the Web page, click the version number of the release of Fedora you want to download (12 in the case of this example). The list is ordered by the country codes that appear in the left column. Find a site near you and click **http** or **ftp** adjacent to the words **Fedora Linux**. Next click **releases** followed by the version number of Fedora (12) and then **fedora**, **source**, and **SRPMS**.

*RHEL* 1. To download the source code for a Red Hat Enterprise Linux kernel, point a browser or FTP client at <ftp://ftp.redhat.com/pub/redhat/linux/enterprise> and select the version of RHEL you want, following the links until you get to the **SRPMS** directory. For the RHEL 5 server kernel, go to

```
ftp://ftp.redhat.com/pub/redhat/linux/enterprise/5Server/en/os/SRPMS
```

*RHEL+FEDORA* From the SRPMS page, click and download the rpm file for the kernel source code. It will have a name similar to **kernel-2.6.31.5-127.fc12.src.rpm** (*FEDORA*) or **kernel-2.6.18-164.2.1.el5.src.rpm** (*RHEL*). The **src** indicates the package contains source files. From Firefox, select **Save file**, which downloads the file to `~/Downloads` (*FEDORA*) or `~/Desktop` (*RHEL*).

Alternatively, you can use `yumdownloader` to download the kernel for the local system. See page 505 for instructions.

2. Working with **root** privileges, use `rpm` to install the package you just downloaded. You need either to `cd` to the directory that holds the rpm file

or to specify the pathname of the rpm file in the following command. You can ignore the warnings about **mockbuild**.

```
# rpm -Uvh kernel*src.rpm
```

3. The preceding command installs the kernel specification file. This file holds the instructions that **rpmbuild** uses to unpack the kernel source files and apply patches to those files. Change directories to the one shown in the following example and run **rpmbuild**:

```
FEDORA      # cd /root/rpmbuild/SPECS
             # rpmbuild -bp --target $(arch) kernel.spec

RHEL        # cd /usr/src/redhat/SPECS
             # rpmbuild -bp --target $(arch) kernel-2.6.spec

RHEL+FEDORA This command takes a few minutes to run and generates a lot of output. If
             rpmbuild lists missing dependencies, install those packages and give the
             preceding command again.
```

4. Traditionally the source for the kernel that the system is running is kept in **/usr/src/linux**. The following commands move the source to the **/usr/src** directory and create a symbolic link to **linux** there. This example shows the name of the kernel directory as **linux-2.6.31.i686**. The name on the system you are working on will be different. Under Fedora the **BUILD** directory is in **/root/rpmbuild**; under RHEL it is in **/usr/src/redhat**.

```
# cd /root/rpmbuild/BUILD/kernel-2.6.31
# ls
linux-2.6.31.i686  vanilla-2.6.31  vanilla-2.6.31-rc5-git2
# mv linux-2.6.31.i686 /usr/src
# cd /usr/src
# ln -s /usr/src/linux-2.6.31.i686 /usr/src/linux
```

After you give these commands, the patched kernel source is located in **/usr/src/linux**. The rest of this chapter assumes that the kernel source is in this location.

### Now the working directory is **/usr/src/linux**

---

**tip** All commands in this section on building a kernel are given relative to the top-level directory that holds the kernel source. Traditionally this directory is **/usr/src/linux**. Make sure that this directory is your working directory before proceeding. If necessary, link the directory holding the kernel source in **/usr/src** to **/usr/src/linux** as explained in step 4.

---

---

## READ THE DOCUMENTATION

The kernel package includes the latest documentation, some of which may not be available in other documents. Review the **/usr/src/linux/README** file and the relevant files in the **Documentation** directory. Download from the Web and read the *Linux Kernel-HOWTO* for a detailed, generic guide to installing and configuring the Linux kernel.

## CONFIGURING AND COMPILING THE LINUX KERNEL

This section describes how to configure and compile the kernel to meet your needs.

### CLEANING THE SOURCE TREE

If you want to save an existing configuration file (`/usr/src/linux/.config`), copy it to another directory (such as your home directory) or rename it before you proceed, because the next command will remove it. Purge the source tree (all subdirectories and files within `/usr/src/linux`) of all configuration and potentially stale `*.o` files by giving the following command:

```
# make mrproper
```

### CONFIGURING THE LINUX KERNEL

Before you can compile the code and create a Linux kernel, you must decide and specify which features you want the kernel to support. You can configure the kernel to support most features in two ways: by building the feature into the kernel or by specifying the feature as a loadable kernel module (page 549), which is loaded into the kernel only as needed. In deciding which method to use, you must weigh the size of the kernel against the time it takes to load a module. Make the kernel as small as possible while minimizing how often modules have to be loaded.

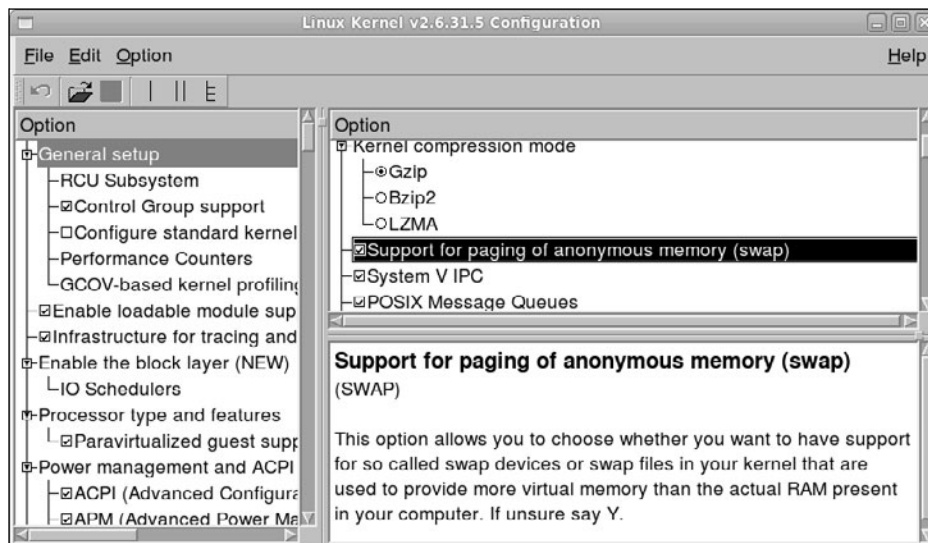
The `configs` directory provides sample configuration files for various processors, multiple processors, and configurations. You may want to look at these files before you get started or even use one of them as your starting point. To use one of these files, copy it from the `linux/configs` directory to the `linux` directory and rename it `.config`.

Four standard commands are used to configure the Linux kernel:

```
# make config
# make menuconfig
# make gconfig
# make xconfig
```

The `make config` command requires no packages other than those installed with the base system; it requires you to answer a lot of yes/no questions. You may need to install the `ncurses-devel` package to run `make menuconfig`. The `make gconfig` command uses GTK+ ([www.gtk.org](http://www.gtk.org)); you may need to install the `libglade2-devel` package. For `make xconfig` you may need to install the `qt-devel`, `qt3-devel`, and `gcc-c++` (*FEDORA*) or `qt-devel` and `gcc-c++` (*RHEL*) packages.

Each command asks the same questions and produces the same result, given the same responses. The first and second commands work in character-based environments; the second and third commands work in graphical environments. For most users, `gconfig` is the easiest to use.



**Figure 15-1** The Linux Kernel Configuration window, split view

The **make gconfig** command displays the Linux Kernel Configuration window. You can view this window in three configurations: single, split, or full view. Choose a view by clicking one of the three icons in the middle of the toolbar. Figure 15-1 shows the split view. In this view, the left frame shows the options and the top-right frame lists the features for each option. The bottom-right frame describes the highlighted option or feature. Figure 15-2 shows the full view.

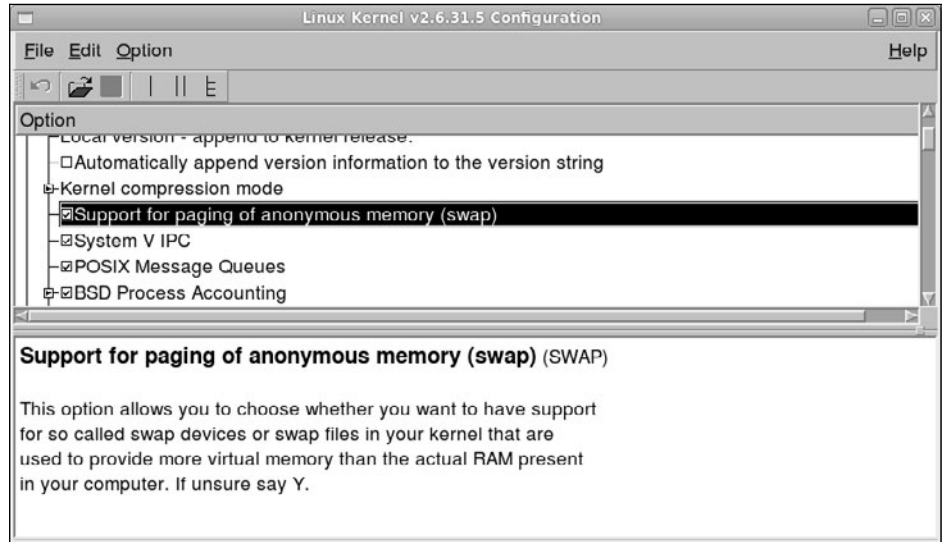
In the split and full views, click the triangles at the left ends of menu lines to expand or collapse feature menus. A small box appears at the left end of those lines that describe features you can change. An empty box indicates the feature is disabled, a check mark indicates it is to be included in the kernel, and a dash means it is to be compiled as a module. Double-click the box to change the state of the feature.

Go through the features and mark each as you would like it configured in the new kernel. At any time during the configuration process, you can store the currently defined configuration to a file, load a configuration from a file, or exit with or without saving your changes. See the selections in File on the Menubar. When you are done, select **Menubar: File⇒Save** and close the window.

## EXTRAVERSION NUMBER

To prevent overwriting existing kernel files and to identify various compilations of the kernel, you can use the **EXTRAVERSION** variable in **Makefile**. This variable is initially set to **.5** (*FEDORA*) or **-prep** (*RHEL*). Whatever value you assign to this variable is placed at the end of the kernel name and release number to identify the kernel. You can make note of patches applied to the kernel in this string to help people track down problems later on.





**Figure 15-2** The Linux Kernel Configuration window, full view

## COMPILING THE KERNEL

Before compiling the kernel, make sure, once again, that no files are in the source tree from previous work:

```
# make clean
```

Then give the following command to compile and install the kernel:

```
# make bzImage
HOSTCC  scripts/basic/fixdep
HOSTCC  scripts/basic/docproc
HOSTCC  scripts/basic/hash
HOSTCC  scripts/kconfig/conf.o
...
Setup is 13500 bytes (padded to 13824 bytes).
System is 3295 kB
CRC 4ae502c
Kernel: arch/x86/boot/bzImage is ready (#1)
```

## USING LOADABLE KERNEL MODULES

A *loadable kernel module* (page 1091), sometimes called a *module*, *loadable module*, or *kmod*, is an object file—part of the kernel—that is linked into the kernel at runtime. Modules are compiled separately from the kernel and can be inserted into and removed from a running kernel at almost any time except when the module is being used. This ability gives the kernel the flexibility to be as small as possible at any given time. Modules are a good way to code some kernel features, including drivers that are not used continually (such as a DVD driver).

When you configure the kernel to support loadable modules, you need to build and install the modules. Give the following command to compile the modules that you specified when you configured the kernel:

```
# make modules
```

Compiling the modules typically takes longer than compiling the kernel. The next command installs the modules in the `/lib/modules/kernel-versionEXTRAVERSION` directory. Run this command with **root** privileges even if you did not build any modules:

```
# make modules_install
```

Table 15-1 lists some of the tools available to help you work with modules. Refer to the corresponding man pages for options and more information.

**Table 15-1**    Tools for working with modules

Tool/utility	Function
depmod	Works with dependencies for modules.
insmod	Loads modules in a running kernel.
lsmod	Lists information about all loaded modules.
modinfo	Lists information about a module.
modprobe	Loads, unloads, and reports on modules. When it loads a module, it also loads dependencies. Looks in <code>/etc/modprobe.d/*.conf</code> for arguments.
rmmod	Unloads modules from a running kernel.

# INSTALLING THE KERNEL AND ASSOCIATED FILES

The next step is to copy the compiled kernel and associated files to the appropriate directory, usually `/boot`. When you have a **boot** partition, the files are kept in the root of this partition (`/boot`). Without a **boot** partition, the files are kept in a subdirectory of the root directory. Run the following command as **root** to install the new kernel files in the proper directory:

```
# make install
```

# REBOOTING THE SYSTEM

Reboot the computer by selecting **Main menu: System⇌Shut Down** and then choosing **Restart**. If you are working at the console, press **CONTROL-ALT-DEL**. You can also give a **reboot** command from any character-based terminal or terminal emulator.

## BOOT LOADER

A boot loader is a very small program that is used in the *bootstrap* (page 1072) process, which brings a computer from off or reset to a fully functional state. The boot loader frequently resides on the starting sectors of a hard disk called the MBR (Master Boot Record).

The *BIOS* (page 1071), stored in an *EEPROM* (page 1081) on the system's motherboard, gains control of a system when you turn on or reset the computer. After testing the hardware, the BIOS transfers control to the MBR, which usually passes control to the partition boot record. This transfer of control starts the boot loader, which is responsible for locating the operating system kernel (kept in the `/boot` directory or a subdirectory of the root directory), loading that kernel into memory, and starting it running. Refer to “Booting the System” on page 425 for more information on what happens from this point forward.

You can place the `/boot` directory on a small filesystem so the root directory (`/`) can be placed on an LVM partition as it is in the default installation.

## grub: THE LINUX LOADER

The name `grub` (see the `grub` info page and [www.gnu.org/software/grub](http://www.gnu.org/software/grub)) stands for Grand Unified Boot Loader. A product of the GNU project, the `grub` loader conforms to the *multiboot specification* (page 1094), which allows it to load many free operating systems directly as well as to *chain load* (page 1074) proprietary operating systems. The `grub` loader can recognize various types of filesystems and kernel executable formats, allowing it to load an arbitrary operating system. You must specify the kernel's filename and location (drive and partition) so `grub` knows where to find the kernel. You can pass this information to `grub` via either the command line or the menu interface. When you boot the system, `grub` displays a menu of choices that is generated by the `/boot/grub/grub.conf` file (with a symbolic link at `/etc/grub.conf`). At this point you can modify the menu, choose which operating system to boot, or do nothing and allow `grub` to boot the default system. When you install `grub` at the time you install Linux, the installation program configures `grub` automatically, so you do not have to.

The `/boot/grub/grub.conf` file is the default `grub` configuration file. The `grub.conf` file in the following example is from a system that had its kernel replaced (there are two versions of `vmlinuz` and `initrd`). The system has a separate `boot` partition so that all kernel and `initrd` (for systems using loadable modules; page 549) image paths are relative to `/boot` (see the NOTICE in the file). Without a separate `boot` partition, the boot files reside in the root partition (`/`) so that kernel and `initrd` paths are relative to `/`.

The file starts with comments that Anaconda, the graphical installer, puts there, followed by four assignments. The `default` is the section number of the default boot specification. This numbering starts with 0. The example includes two boot

specifications: The first, numbered 0, is for the **2.6.31.1-56.fc12.i686.PAE** kernel; the second, numbered 1, is for the **2.6.31.1-48.fc12.i686.PAE** kernel. The **timeout** is the number of seconds that **grub** waits after it has prompted for a boot specification before it boots the system with the default boot specification. The **splashimage** is the **grub** menu interface background you see when you boot the system. When you specify **hiddenmenu**, **grub** boots the default entry and does not display the menu interface unless you press **ESCAPE** while the system is booting.

```
# cat /boot/grub/grub.conf
# grub.conf generated by anaconda
#
# Note that you do not have to rerun grub after making changes to this file
# NOTICE: You have a /boot partition. This means that
#         all kernel and initrd paths are relative to /boot/, eg.
#         root (hd0,0)
#         kernel /vmlinuz-version ro root=/dev/mapper/vg_f12-lv_root
#         initrd /initrd-[generic-]version.img
#boot=/dev/sda
default=1
timeout=0
splashimage=(hd0,0)/grub/splash.xpm.gz
hiddenmenu
title Fedora (2.6.31.5)
    root (hd0,0)
    kernel /vmlinuz-2.6.31.5 ro root=/dev/mapper/vg_f12-lv_root  LANG=en_US.UTF-8
SYSFONT=latacyrheb-sun16 KEYBOARDTYPE=pc KEYTABLE=us rhgb quiet
    initrd /initramfs-2.6.31.5.img
title Fedora (2.6.31.6-166.fc12.i686.PAE)
    root (hd0,0)
    kernel /vmlinuz-2.6.31.6-166.fc12.i686.PAE ro root=/dev/mapper/vg_f12-lv_root
LANG=en_US.UTF-8 SYSFONT=latacyrheb-sun16 KEYBOARDTYPE=pc KEYTABLE=us rhgb quiet
    initrd /initramfs-2.6.31.6-166.fc12.i686.PAE.img
title Fedora (2.6.31.6-162.fc12.i686.PAE)
    root (hd0,0)
    kernel /vmlinuz-2.6.31.6-162.fc12.i686.PAE ro root=/dev/mapper/vg_f12-lv_root
LANG=en_US.UTF-8 SYSFONT=latacyrheb-sun16 KEYBOARDTYPE=pc KEYTABLE=us rhgb quiet
    initrd /initramfs-2.6.31.6-162.fc12.i686.PAE.img
```

Following the **hiddenmenu** assignment in the preceding example are two boot specifications, differentiated by the **title** lines. The three logical lines following the title line in each specification specify the location of the **root** (drive 0, partition 0), **kernel**, and **initrd** images. In this case, because there is a **/boot** partition, the pathnames are relative to **/boot**. For the default boot specification (the first one, numbered 0), the absolute pathname of the kernel is **/boot/vmlinuz-2.6.31.5**, which is specified with options that tell **grub** that it is to be mounted readonly and that root (**/**) is mounted on the specified logical volume. The **rhgb** (Red Hat graphical boot) software generates a graphical display that tells you what is happening as the system boots. The **quiet** option produces less debugging output so it is easier to tell what is happening. You specify the **initrd** (initialize *RAM disk*, page 1102) image in a manner similar to the kernel. Substitute the local kernel and **initrd** names and version numbers for the ones in the example. Make sure when you install a new kernel manually, its **title** line is different from the others in **grub.conf**.

## dmesg: DISPLAYS KERNEL MESSAGES

The `dmesg` utility displays the kernel ring buffer, where the kernel stores messages. When the system boots, the kernel fills this buffer with messages related to hardware and module initialization. Messages in the kernel ring buffer are often useful for diagnosing system problems. When you run `dmesg`, it displays a lot of information. It is frequently easier to pipe the output of `dmesg` through `less` or `grep` to find what you are looking for. For example, if you find that your hard disks are performing poorly, you can use `dmesg` to check that they are running in DMA mode:

```
$ dmesg | grep DMA
...
ata1: PATA max UDMA/33 cmd 0x1f0 ctl 0x3f6 bmdma 0x1050 irq 14
ata2: PATA max UDMA/33 cmd 0x170 ctl 0x376 bmdma 0x1058 irq 15
...
```

The preceding lines tell you which mode each PATA device is operating in. If you are having problems with the Ethernet connection, search the `dmesg` log for `eth`:

```
$ dmesg | grep eth
eth0: registered as PCnet/PCI II 79C970A
eth0: link up
eth0: no IPv6 routers present
```

If everything is working properly, `dmesg` displays the hardware configuration information for each network card. If you have configured a system service incorrectly, the `dmesg` log quickly fills up with errors; it is a good place to start when diagnosing faults.

## CHAPTER SUMMARY

You can build a custom Linux kernel from the source code. In most situations you do not need to build a kernel. Instead, you can make many changes by modifying boot options in `/boot/grub/grub.conf` or runtime options in `/etc/sysctl.conf`.

Before you can build a Linux kernel, you must have the kernel source files on the system. These files are located in `/usr/src/linux`. Once you have the source files, you should clean the source tree, configure the kernel, compile the kernel and the loadable modules, and install the kernel and loadable modules.

The grub boot loader is a very small program that is used in the process of bringing the system up. You must configure the boot loader so that it recognizes the new kernel.

The `dmesg` utility displays the kernel ring buffer, where the kernel stores messages. You can use this utility to help diagnose boot-time problems.

---

## EXERCISES

1. What is the purpose of the kernel?
2. How would you display a list of all loaded modules in the current kernel?
3. Which command would you give to upgrade the kernel from an rpm file, and how is this different from upgrading other packages?
4. How would you display information from the kernel about the hard disk on the first SCSI channel?
5. The **noreplacement** kernel argument tells the kernel not to use CPU-specific sections of code. How would you use this argument?
6. What is a boot loader?

---

## ADVANCED EXERCISES

7. What is the **EXTRAVERSION** variable? Where is it used and what is it used for?
8. You have just installed an Adaptec SCSI card. How can you find out whether it has been recognized and which entry in **/dev** represents it?
9. When you install an experimental kernel for testing, how do you instruct **grub** not to load it by default?
10. How would you obtain a list of all network-related kernel parameters?

# 16

## ADMINISTRATION TASKS

### IN THIS CHAPTER

Configuring User and Group Accounts .....	556
Backing Up Files .....	558
System Reports .....	566
parted: Reports on and Partitions a Hard Disk .....	568
Solving Problems .....	574
Speeding Up the System .....	575
Keeping the System Secure .....	577
logrotate: Manages Log Files .....	579
Disk Quota System .....	582
rsyslogd: Logs System Messages .....	582
MySQL .....	584

The system administrator has many responsibilities. This chapter discusses tasks not covered in Chapter 11, including configuring user and group accounts, backing up files, scheduling tasks, general problem solving, and using the system log daemon, **rsyslogd**. The chapter concludes with a section on installing and using MySQL.

# CONFIGURING USER AND GROUP ACCOUNTS

More than a username is required for a user to be able to log in and use a system. A user must have the necessary files, directories, permissions, and usually a password to log in. At a minimum a user must have an entry in the `/etc/passwd` and `/etc/shadow` files and a home directory. The following sections describe several ways you can work with user accounts. Refer to page 387 and the *NIS-HOWTO* when you want to run NIS to manage the `passwd` database.

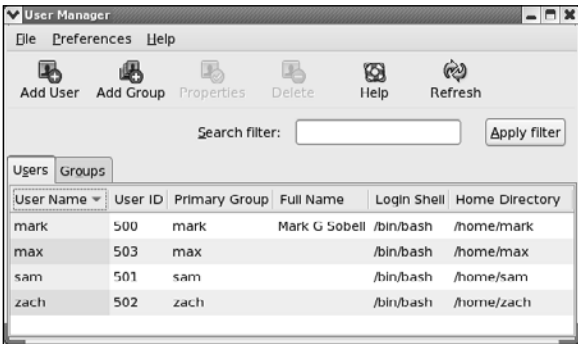
## system-config-users: MANAGES USER ACCOUNTS

The `system-config-users` utility displays the User Manager window and enables you to add, delete, and modify system users and groups. To display the User Manager window, enter `system-config-users` on a command line or select **Main menu: System⇒Administration⇒Users and Groups**. This window has two tabs: Users and Groups, where each tab displays information appropriate to its name. Figure 16-1 shows the Users tab.

**Search filter** The Search filter, located just below the toolbar, selects users or groups whose names match the string, which can include wildcards, that you enter in the Search filter text box. The string matches the beginning of a name. For example, `*nob` matches `nobody` and `nfsnobody`, whereas `nob` matches only `nobody`. After you enter the string, click **Apply filter** or press RETURN. If you have only a few users, you will not need to use the Search filter.

**Adding a user** To create a new user, click the **Add User** button on the toolbar. The User Manager displays the Create New User window, which gathers much of the same information as the User Data tab of the User Properties window (Figure 16-2). Enter the information for the new user and click **OK**. Once you create a user, you can modify the user to add/change/remove information.

**Modifying a user** To modify a user, highlight the user in the User Manager window and click **Properties** on the toolbar; the utility displays the User Properties window (Figure 16-2). The



**Figure 16-1** The User Manager window, Users tab



User Properties window has four tabs: User Data, Account Info, Password Info, and Groups. The User Data tab holds basic user information such as name and password. The Account Info tab allows you to specify an expiration date for the account and to lock the account so the user cannot log in. The Password Info tab allows you to turn on password expiration and specify various related parameters. In the Groups tab, you can specify the groups that the user is a member of.

**Working with groups** Click the **Groups** tab in the User Manager window to work with groups. To create a group, click **Add Group** on the toolbar and specify the name of the group. To change the name of a group or to add or remove users from a group, highlight the group and click **Properties** on the toolbar. Click the appropriate tab, make the changes you want, and click **OK**. See page 472 for more information on groups.

**Help** The User Manager provides extensive help. To access it, click **Help** on the toolbar.

When you are done working with users and groups, close the window.

## useradd: ADDS A USER ACCOUNT

The `useradd` utility (and the link to it, named `adduser`) adds a new user account to the system. By default, `useradd` assigns the next highest unused user ID to a new account and specifies `bash` as the user's login shell. The following example creates the user's home directory (in `/home`), specifies the user's group ID, and puts the user's full name in the comment field:

```
# useradd -g 500 -c "Alex Watson" alex
```

Based on the `/etc/login.defs` file, the system creates a home directory for the new user. When `useradd` creates a home directory, it copies the contents of `/etc/skel`, which contains `bash` and other startup files, to that directory. For more information on adding and modifying user information, see the `useradd` and `usermod` man pages. Once you have added a user, use `passwd` to give the user a password.



**Figure 16-2** The User Properties window, User Data tab

## userdel: REMOVES A USER ACCOUNT

If appropriate, back up the files belonging to the user before deleting them. The `userdel` utility deletes user accounts. The following command removes **alex**'s account and his home directory hierarchy:

```
# userdel -r alex
```

To turn off a user's account temporarily, you can use `usermod` to change the expiration date for the account. Because it specifies that his account expired in the past (December 31, 2009), the following command line prevents **alex** from logging in:

```
# usermod -e "12/31/09" alex
```

## groupadd: ADDS A GROUP

Just as `useradd` adds a new user to the system, `groupadd` adds a new group by adding an entry for it in `/etc/group` (page 472). The following example creates a new group named **rtfm**:

```
# groupadd -g 1024 rtfm
```

Unless you use the `-g` option to assign a group ID, the system picks the next available sequential number greater than 500. The `-o` option allows the group ID to be nonunique if you want to have multiple names for the same group ID.

The analogue of `userdel` for groups is `groupdel`, which takes a group name as an argument. You can also use `groupmod` to change the name or group ID of a group, as in the following examples:

```
# groupmod -g 1025 rtfm
# groupmod -n manuals rtfm
```

The first example gives the previously created **rtfm** group a new group ID number. The second example renames the **rtfm** group **manuals**.

### Group ID cautions

---

**caution** The `groupmod` utility does not change group numbers in `/etc/passwd` when you renumber a group. You must edit `/etc/passwd` and change the entries yourself. If you change the number of a group, files that are associated with the group will no longer be associated with the group. Instead, they may be associated with no group or with another group with the old group ID number.

---

---

## BACKING UP FILES

One of the most neglected tasks of system administration is making backup copies of files on a regular basis. The backup copies are vital in three instances: when the system malfunctions and files are lost, when a catastrophic disaster (fire, earthquake, and so on) occurs, and when a user or the system administrator deletes or corrupts a file by accident. Even when you set up RAID (page 37), you still need to

back up files. Although RAID provides fault tolerance (helpful in the event of disk failure), it does not help when a catastrophic disaster occurs or when a file is corrupted or accidentally removed. It is a good idea to have a written backup policy and to keep copies of backups offsite (in another building, at home, or at a completely different facility or campus) in a fireproof vault or safe.

The time to start thinking about backups is when you partition the disk. Refer to “Setting Up the Hard Disk” on page 30. Make sure the capacity of the backup device and your partition sizes are comparable. Although you can back up a partition onto multiple volumes, it is easier not to and much easier to restore data from a single volume.

You must back up filesystems on a regular basis. Backup files are usually kept on magnetic tape or some other removable media. Exactly how often you should back up which files depends on the system and your needs. Use this criterion when determining a backup schedule: If the system crashes, how much work are you willing to lose? Ideally you would back up all files on the system every few minutes so you would never lose more than a few minutes of work.

Of course, there is a tradeoff: How often are you willing to back up the files? The backup procedure typically slows down the system for other users, takes a certain amount of your time, and requires that you have and store the media (tape or disk) holding the backup. Avoid backing up an active filesystem; the results may be inconsistent, and restoring from the backup may be impossible. This requirement is a function of the backup program and the filesystem you are backing up.

Another question is when to run the backup. Unless you plan to kick users off and bring the system down to single-user mode (not a very user-friendly practice), you want to perform this task when the machine is at its quietest. Depending on the use of the system, sometime in the middle of the night can work well. Then the backup is least likely to affect users, and the files are not likely to change as they are being read for backup.

A *full* backup makes copies of all files, regardless of when they were created or accessed. An *incremental* backup makes copies of those files that have been created or modified since the last (usually full) backup.

The more people using the system, the more often you should back up the filesystems. One popular schedule is to perform an incremental backup one or two times a day and a full backup one or two times a week.

## CHOOSING A BACKUP MEDIUM

If the local system is connected to a network, you can write your backups to a tape drive on another system. This technique is often used with networked computers to avoid the cost of having a tape drive on each computer in the network and to simplify management of backing up many computers in a network. Most likely you want to use a tape system for backups. Because tape drives hold many gigabytes of data, using tape simplifies the task of backing up the system, making it more likely

that you will take care of this important task regularly. Other options for holding backups are writable CDs, DVDs, and removable hard disks. These devices, although not as cost-effective or able to store as much information as tape systems, offer convenience and improved performance over using tapes.

## BACKUP UTILITIES

A number of utilities help you back up the system, and most work with any media. Most Linux backup utilities are based on one of the archive programs—**tar** or **cpio**—and augment these basic programs with bookkeeping support for managing backups conveniently.

You can use any of the **tar**, **cpio**, or **dump/restore** utilities to construct full or partial backups of the system. Each utility constructs a large file that contains, or archives, other files. In addition to file contents, an archive includes header information for each file it holds. This header information can be used when extracting files from the archive to restore file permissions and modification dates. An archive file can be saved to disk, written to tape, or shipped across the network while it is being created.

In addition to helping you back up the system, these programs offer a convenient way to bundle files for distribution to other sites. The **tar** program is often used for this purpose, and some software packages available on the Internet are bundled as **tar** archive files.

The **amanda** utility (Advanced Maryland Automatic Network Disk Archiver; [www.amanda.org](http://www.amanda.org)), one of the more popular backup systems, uses **dump** or **tar** and takes advantage of Samba to back up Windows systems. The **amanda** utility backs up a LAN of heterogeneous hosts to a single tape drive. You can use **yum** to install **amanda**; refer to the **amanda** man page for details.

### tar: ARCHIVES FILES

The **tar** (tape archive) utility stores and retrieves files from an archive and can compress the archive to conserve space. If you do not specify an archive device, **tar** uses standard output and standard input. With the **-f** option, **tar** uses the argument to **-f** as the name of the archive device. You can use this option to refer to a device on another system on the network. Although **tar** has many options, you need only a few in most situations. The following command displays a complete list of options:

```
# tar --help | less
```

Most options for **tar** can be given either in a short form (a single letter) or as a descriptive word. Descriptive-word options are preceded by two hyphens, as in **--help**. Single-letter options can be combined into a single command-line argument and do not need to be preceded by a hyphen (for consistency with other utilities, it is good practice to use the hyphen anyway).

Although the following two commands look quite different, they specify the same **tar** options in the same order. The first version combines single-letter options into a

single command-line argument; the second version uses descriptive words for the same options:

```
# tar -ztvf /dev/st0
# tar --gzip --list --verbose --file /dev/st0
```

Both commands tell tar to generate a (v, **verbose**) table of contents (t, **list**) from the tape on /dev/st0 (f, **file**), using gzip (z, **gzip**) to decompress the files. Unlike the original UNIX tar utility, the GNU version strips the leading / from absolute pathnames. The options in Table 16-1 tell the tar program what to do. You must include exactly one of these options in a tar command.

**Table 16-1** The tar utility

Option	Effect
--append (-r)	Appends files to an archive
--catenate (-A)	Adds one or more archives to the end of an existing archive
--create (-c)	Creates a new archive
--delete	Deletes files in an archive (not on tapes)
--diff (-d)	Compares files in an archive with disk files
--extract (-x)	Extracts files from an archive
--help	Displays a help list of tar options
--list (-t)	Lists the files in an archive
--update (-u)	Like the -r option, but the file is not appended if a newer version is already in the archive

The -c, -t, and -x options are used most frequently. You can use many other options to change how tar operates. The -j option, for example, compresses or decompresses the file by filtering it through bzip2 (page 162).

### cpio: ARCHIVES FILES

The cpio (copy in/out) program is similar to tar but can use archive files in a variety of formats, including the one used by tar. Normally cpio reads the names of the files to insert into the archive from standard input and produces the archive file as standard output. When extracting files from an archive, cpio reads the archive as standard input.

As with tar, some options can be given in both a short, single-letter form and a more descriptive word form. However, unlike tar, the syntax of the two forms differs when the option must be followed by additional information. In the short form, you

must include a `SPACE` between the option and the additional information; with the word form, you must separate the two with an equal sign and no `SPACES`.

Running `cpio` with `--help` displays a full list of options.

## PERFORMING A SIMPLE BACKUP

When you prepare to make a major change to a system, such as replacing a disk drive or updating the Linux kernel, it is a good idea to archive some or all of the files so you can restore any that become damaged if something goes wrong. For this type of backup, `tar` or `cpio` works well. For example, if you have a SCSI tape drive as device `/dev/st0` that is capable of holding all the files on a single tape, you can use the following commands to construct a backup tape of the entire system:

```
# cd /
# tar -cf /dev/st0 .
```

All of the commands in this section start by using `cd` to change to the root directory so you are sure to back up the entire system. The `tar` command then creates an archive (c) on the device `/dev/st0` (f). If you would like to compress the archive, replace the preceding `tar` command with the following command, which uses `j` to call `bzip2`:

```
# tar -cjf /dev/st0 .
```

You can back up the system with a combination of `find` and `cpio`. The following commands create an output file and set the I/O block size to 5120 bytes (the default is 512 bytes):

```
# cd /
# find . -depth | cpio -oB > /dev/st0
```

The next command restores the files in the `/home` directory from the preceding backup. The options extract files from an archive (`-i`) in verbose mode, keeping the modification times and creating directories as needed.

```
# cd /
# cpio -ivmd /home/\* < /dev/st0
```

### Exclude some directories from a backup

---

**tip** In practice, you will likely want to exclude some directories from the backup process. For example, not backing up `/tmp` or `/var/tmp` (or its link, `/usr/tmp`) can save room in the archive. Also, do not back up the files in `/proc`. Because the `/proc` filesystem is not a disk filesystem but rather a way for the Linux kernel to provide information about the operating system and system memory, you need not back up `/proc`; you cannot restore it later. You do not need to back up filesystems that are mounted from disks on other systems in the network. Do not back up FIFOs; the results are unpredictable. If you plan on using a simple method, similar to those just discussed, create a file naming the directories to exclude from the backup, and use the appropriate option with the archive program to read the file.

---

Although all of the archive programs work well for such simple backups, utilities such as **amanda** provide more sophisticated backup and restore systems. For example, to determine whether a file is in an archive, you must read the entire archive. If the archive is split across several tapes, this process is particularly tiresome. More sophisticated utilities, including **amanda**, assist you in several ways, including keeping a table of contents of the files in a backup.

## dump, restore: BACK UP AND RESTORE FILESYSTEMS

The **dump** utility, which first appeared in UNIX version 6, backs up either an entire filesystem or only those files that have changed since the last **dump**. The **restore** utility restores an entire filesystem, an individual file, or a directory hierarchy. You will get the best results if you perform a backup on a quiescent system so that the files are not changing as you make the backup.

The next command backs up all files (including directories and special files) on the **root (/)** partition to SCSI tape 0. Frequently there is a link to the active tape drive, named **/dev/tape**, which you can use in place of the actual entry in the **/dev** directory.

```
# dump -0uf /dev/st0 /
```

The option specifies that the entire filesystem is to be backed up (a full backup). There are ten dump levels: 0–9. Zero is the highest (most complete) level and always backs up the entire filesystem. Each additional level is incremental with respect to the level above it. For example, 1 is incremental to 0 and backs up only files that have changed since the last level 0 dump; 2 is incremental to 1 and backs up only files that have changed since the last level 1 dump; and so on. You can construct a very flexible schedule using this scheme. You do not need to use sequential numbers for backup levels. You can perform a level 0 dump, followed by level 2 and 5 dumps.

The **u** option updates the **/etc/dumpdates** file (page 471) with filesystem, date, and dump level information for use by the next incremental dump. The **f** option and its argument write the backup to the device named **/dev/st0**.

The following command makes a partial backup containing all files that have changed since the last level 0 dump. The first argument is a 1, specifying a level 1 dump:

```
# dump -1uf /dev/st0 /
```

To restore an entire filesystem from a tape, first restore the most recent complete (level 0) backup. Perform this operation carefully because **restore** can overwrite the existing filesystem. When you are logged in as Superuser, **cd** to the directory the filesystem is mounted on and give this command:

```
# restore -if /dev/st0
```

The **i** option invokes an interactive mode that allows you to choose which files and directories to restore. As with **dump**, the **f** option specifies the name of the device that the backup medium is mounted on. When **restore** finishes, load the next lower-level (higher-number) dump tape and issue the same **restore** command. If multiple

incremental dumps have been made at a particular level, always restore with the most recent one. You do not need to invoke `restore` with special arguments to restore an incremental dump; it will restore whatever appears on the tape.

You can also use `restore` to extract individual files from a tape by using the `x` option and specifying the filenames on the command line. Whenever you restore a file, the restored file will appear in the working directory. Before restoring files, make sure you are working in the correct directory. The following commands restore the `/etc/nsswitch.conf` file from the tape on `/dev/st0`. The filename of the dumped file does not begin with `/` because all dumped pathnames are relative to the filesystem that you dumped—in this case `/`. Because the `restore` command is given from the `/` directory, the file will be restored to its original location of `/etc/nsswitch.conf`:

```
# cd /  
# restore -xf /dev/st0 etc/nsswitch.conf
```

If you use the `x` option without specifying a file or directory name to extract, the entire dumped filesystem is extracted. Use the `r` option to restore an entire filesystem without using the interactive interface. The following command restores the filesystem from the tape on `/dev/st0` to the working directory without interaction:

```
# restore -rf /dev/st0
```

You can also use `dump` and `restore` to access a tape drive on another system. Specify the file/directory as *host:file*, where *host* is the hostname of the system the tape drive is on and *file* is the file/directory you want to dump/restore.

Occasionally, `restore` may prompt you with the following message:

```
You have not read any volumes yet.  
Unless you know which volume your file(s) are on you should start  
with the last volume and work towards the first.  
Specify next volume #:
```

Enter `1` (one) in response to this prompt. If the filesystem spans more than one tape or disk, this prompt allows you to switch tapes.

At the end of the dump, you will receive another prompt:

```
set owner/mode for '.'? [yn]
```

Answer `y` to this prompt when you are restoring entire filesystems or files that have been accidentally removed. Doing so will restore the appropriate permissions to the files and directories being restored. Answer `n` if you are restoring a dump to a directory other than the one it was dumped from. The working directory permissions and owner will then be set to those of the person doing the restore (typically `root`).

Various device names can access the `/dev/st0` device. Each name accesses a different minor device number that controls some aspect of how the tape drive is used. After you complete a dump when you use `/dev/st0`, the tape drive automatically rewinds the tape to the beginning. Use the nonrewinding SCSI tape device (`/dev/nst0`) to keep the tape from rewinding on completion. This feature allows you to back up multiple filesystems to one volume. Following is an example of backing up a system where the `/home`, `/usr`, and `/var` directories reside on different filesystems:



```
# dump -0uf /dev/nst0 /home
# dump -0uf /dev/nst0 /usr
# dump -0uf /dev/st0 /var
```

The preceding example uses the nonrewinding device for the first two dumps. If you use the rewinding device, the tape rewinds after each dump, and you are left with only the last dump on the tape.

You can use `mt` (magnetic tape), which is part of the `mt-st` package, to manipulate files on a multivolume dump tape. The following `mt` command positions the tape (`fsf 2` instructs `mt` to skip forward *past* two files, leaving the tape at the start of the third file). The `restore` command restores the `/var` filesystem from the previous example:

```
# mt -f /dev/st0 fsf 2
# restore rf /dev/st0
```

---

## SCHEDULING TASKS

It is a good practice to schedule certain routine tasks to run automatically. For example, you may want to remove old core files once a week, summarize accounting data daily, and rotate system log files monthly.

### crond AND crontab: SCHEDULE ROUTINE TASKS

Using `crontab`, you can submit a list of commands in a format that can be read and executed by `crond`. Working as Superuser, you can put commands in one of the `/etc/cron.*` directories to be run at intervals specified by the directory name, such as `cron.daily`.

When SELinux is set to use a targeted policy, it protects the `cron` daemon. You can disable this protection if necessary. For more information refer to “Setting the Targeted Policy with `system-config-selinux`” on page 416.

#### cron stops for no one; try anacron

**tip** The `crond` daemon assumes the system is always running. A similar utility, `anacron`, does not make that assumption and is well suited to portable and home computers that are frequently turned off. The `anacron` utility takes its instructions from the `/etc/anacrontab` file unless you specify otherwise. Refer to the `anacron` and `anacrontab` man pages for more information.

---

### at: RUNS OCCASIONAL TASKS

Like the `cron` utility, `at` allows you to run a job sometime in the future. Unlike `cron`, `at` runs a job only once. For instance, you can schedule an `at` job that will reboot the system at 3 AM (when all users are probably logged off):

```
# at 3am
at> reboot
at> CONTROL-D <EOT>
job 1 at 2006-02-01 03:00
```

It is also possible to run an `at` job from within an `at` job. For instance, an `at` job might check for new patches every 18 days, something that would be more difficult with `cron`.

# SYSTEM REPORTS

Many utilities report on one thing or another. The `who`, `finger`, `ls`, `ps`, and other utilities generate simple end-user reports. In some cases, these reports can help with system administration. This section describes utilities that generate more in-depth reports that can usually provide more assistance with system administration tasks. Linux has many other report utilities, including (from the `sysstat` package) `sar` (system activity report), `iostat` (input/output and CPU statistics), and `mpstat` (processor statistics); (from the `net-tools` package) `netstat` (network report); and (from the `nfs-utils` package) `nfsstat` (NFS statistics).

## vmstat: REPORTS VIRTUAL MEMORY STATISTICS

The `vmstat` utility (`procp`s package) generates virtual memory information along with (limited) disk and CPU activity data. The following example shows virtual memory statistics in 3-second intervals for seven iterations (from the arguments `3 7`). The first line covers the time since the system was last booted; the rest of the lines cover the period since the previous line.

```
$ vmstat 3 7
procs -----memory----- --swap--  -----io----- --system--  ----cpu----
r  b   swpd   free   buff   cache    si   so    bi    bo    in    cs  us  sy  id  wa
0  2       0 684328 33924 219916     0    0   430   105 1052   134  2  4 86  8
0  2       0 654632 34160 248840     0    0  4897  7683 1142   237  0  5  0 95
0  3       0 623528 34224 279080     0    0  5056  8237 1094   178  0  4  0 95
0  2       0 603176 34576 298936     0    0  3416   141 1161   255  0  4  0 96
0  2       0 575912 34792 325616     0    0  4516  7267 1147   231  0  4  0 96
1  2       0 549032 35164 351464     0    0  4429   77 1120   210  0  4  0 96
0  2       0 523432 35448 376376     0    0  4173  6577 1135   234  0  4  0 95
```

Table 16-2 lists the column heads displayed by `vmstat`.

**Table 16-2**    `vmstat` column heads

procs	Process information
	<b>r</b> Number of waiting, runnable processes
	<b>b</b> Number of blocked processes (in uninterruptable sleep)
memory	Memory information in kilobytes
	<b>swpd</b> Used virtual memory
	<b>free</b> Idle memory
	<b>buff</b> Memory used as buffers
	<b>cache</b> Memory used as cache

**Table 16-2** vmstat column heads (continued)

<b>swap</b>	<b>System paging activity in kilobytes per second</b>
<b>si</b>	Memory swapped in from disk
<b>so</b>	Memory swapped out to disk
<b>io</b>	<b>System I/O activity in blocks per second</b>
<b>bi</b>	Blocks received from a block device
<b>bo</b>	Blocks sent to a block device
<b>system</b>	<b>Values are per second</b>
<b>in</b>	Interrupts (including the clock)
<b>cs</b>	Context switches
<b>cpu</b>	<b>Percentage of total CPU time spent in each of these states</b>
<b>us</b>	User (nonkernel)
<b>sy</b>	System (kernel)
<b>id</b>	Idle
<b>wa</b>	Waiting for I/O

## top: LISTS PROCESSES USING THE MOST RESOURCES

The top utility is a useful supplement to ps. At its simplest, top displays system information at the top and the most CPU-intensive processes below the system information. The top utility updates itself periodically; type **q** to quit. Although you can use command-line options, the interactive commands are often more helpful. Refer to Table 16-3 (on the next page) and to the top man page for more information.

```
$ top
top - 21:30:26 up 18 min,  2 users,  load average: 0.95, 0.30, 0.14
Tasks:  63 total,   4 running, 58 sleeping,   1 stopped,   0 zombie
Cpu(s): 30.9% us, 22.9% sy,  0.0% ni,  0.0% id, 45.2% wa,  1.0% hi,  0.0% si
Mem:   1036820k total, 1032276k used,   4544k free,   40908k buffers
Swap:  2048276k total,    0k used,  2048276k free,   846744k cached
```

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
1285	root	25	0	9272	6892	1312	R	29.3	0.7	0:00.88	bzip2
1276	root	18	0	3048	860	1372	R	3.7	0.1	0:05.25	cp
7	root	15	0	0	0	0	S	0.7	0.0	0:00.27	pdf flush
6	root	15	0	0	0	0	S	0.3	0.0	0:00.11	pdf flush
8	root	15	0	0	0	0	S	0.3	0.0	0:00.06	kswapd0
300	root	15	0	0	0	0	S	0.3	0.0	0:00.24	kjournald
1064	mgs2	16	0	8144	2276	6808	S	0.3	0.2	0:00.69	sshd
1224	root	16	0	4964	1360	3944	S	0.3	0.1	0:00.03	bash
1275	mgs2	16	0	2840	936	1784	R	0.3	0.1	0:00.15	top
1284	root	15	0	2736	668	1416	S	0.3	0.1	0:00.01	tar
1	root	16	0	2624	520	1312	S	0.0	0.1	0:06.51	init

**Table 16-3** top: interactive commands

Command	Function
<b>F</b>	Specify a sort field.
<b>h</b> or <b>?</b>	Displays a Help screen.
<b>k</b>	Prompts for a PID number and type of signal and sends the process that signal. Defaults to signal 15 (SIGTERM); specify 9 (SIGKILL) only when 15 does not work.
<b>M</b>	Sorts processes by memory usage.
<b>O</b>	Specify a sort field.
<b>P</b>	Sorts processes by CPU usage (default).
<b>q</b>	Quits.
<b>s</b>	Prompts for time between updates in seconds. Use 0 for continuous updates.
SPACE	Updates the display immediately.
<b>T</b>	Sorts tasks by time.
<b>W</b>	Writes a startup file named <code>~/.toprc</code> so that next time you start <code>top</code> , it uses the same parameters it is currently using.

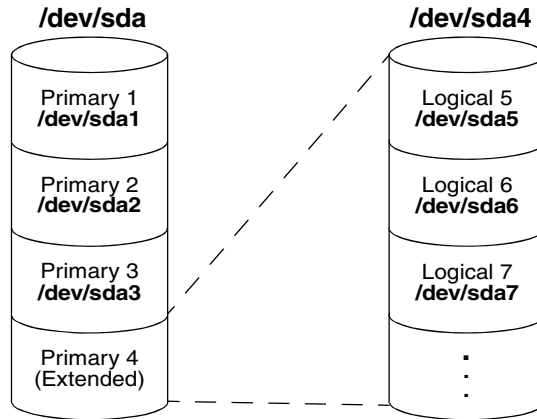
## parted: REPORTS ON AND PARTITIONS A HARD DISK

The `parted` (partition editor) utility reports on and manipulates hard disk partitions. The following example shows how to use `parted` from the command line (see “Running Commands from a Terminal Emulator/Shell” on page 118). It uses the `print` command to display information about the partitions on the `/dev/sda` drive:

```
# parted /dev/sda print
Disk geometry for /dev/sda: 0kB - 165GB
Disk label type: msdos
Number  Start   End     Size    Type     File system  Flags
 1      32kB   1045MB  1045MB  primary  ext3         boot
 2     1045MB 12GB    10GB    primary  ext3
 3      12GB   22GB    10GB    primary  ext3
 4      22GB   165GB   143GB   extended
 5      22GB   23GB    1045MB  logical  linux-swaps
 6      23GB   41GB    18GB    logical  ext3
 7      41GB   82GB    41GB    logical  ext3
Information: Don't forget to update /etc/fstab, if necessary.
```

Figure 16-3 graphically depicts the partitions shown in this example. The first line that `parted` displays specifies the device being reported on (`/dev/sda`) and its size (165 gigabytes). The `print` command displays the following columns:

- **Number**—The minor device number (page 484) of the device holding the partition. This number is the same as the last number in the device name. In the example, 5 corresponds to `/dev/sda5`.



**Figure 16-3** The primary and extended partitions from the example

- **Start**—The location on the disk where the partition starts. The parted utility specifies a location on the disk as the distance (in bytes) from the beginning of the disk. Thus partition 3 starts 12 gigabytes from the beginning of the disk.
- **End**—The location on the disk where the partition stops. Although partition 2 ends 12 gigabytes from the beginning of the disk and partition 3 starts at the same location, parted takes care that the partitions do not overlap at this single byte.
- **Size**—The size of the partition in kilobytes (kB), megabytes (MB), or gigabytes (GB).
- **Type**—The partition type: primary, extended, or logical. See Figure 16-3 and page 31 for information on partition types.
- **File system**—The filesystem type: **ext2**, **ext3**, **fat32**, **linux-swaps**, and so on. See Table 12-1 on page 485 for a list of filesystem types.
- **Flags**—The flags that are turned on for the partition, including **boot**, **raid**, and **lvm**. In the example, partition 1 is bootable.

In the preceding example, partition 4 defines an extended partition that includes 143 gigabytes of the 165-gigabyte disk (Figure 16-3). You cannot make changes to an extended partition without affecting all logical partitions within it.

In addition to reporting on the layout and size of a hard disk, you can use parted interactively to modify the disk layout. Be *extremely* careful when using parted in this manner, and always back up the system before you work with this utility. Changing the partition information (the *partition table*) on a disk can destroy the information on the disk. Read the parted info page before you attempt to modify a partition table.

## parted can destroy everything

**caution** Be as careful with **parted** as you would be with a utility that formats a hard disk. Changes you make with **parted** can easily result in the loss of large amounts of data. If you are using **parted** and have any question about what you are doing, quit with a **q** command before making any changes. Once you give **parted** a command, it immediately makes the change you requested.

To partition a disk, give the command **parted** followed by the name of the device you want to work with. In the following example, after starting **parted**, the user gives a **help** (or just **h**) command, which displays a list of **parted** commands:

```
# parted /dev/hdb
GNU Parted 1.8.6
Using /dev/hdb
Welcome to GNU Parted! Type 'help' to view a list of commands.
(parted) help
  check NUMBER                do a simple check on the file system
  cp [FROM-DEVICE] FROM-NUMBER TO-NUMBER  copy file system to another partition
  help [COMMAND]              prints general help, or help on COMMAND
  mklabel LABEL-TYPE          create a new disklabel (partition table)
  mkfs NUMBER FS-TYPE          make a FS-TYPE file system on partition NUMBER
  mkpart PART-TYPE [FS-TYPE] START END      make a partition
  mkpartfs PART-TYPE FS-TYPE START END      make a partition with a file system
  move NUMBER START END        move partition NUMBER
  name NUMBER NAME              name partition NUMBER as NAME
  print [NUMBER]               display the partition table, or a partition
  quit                          exit program
  rescue START END             rescue a lost partition near START and END
  resize NUMBER START END      resize partition NUMBER and its file system
  rm NUMBER                    delete partition NUMBER
  select DEVICE                 choose the device to edit
  set NUMBER FLAG STATE        change a flag on partition NUMBER
  toggle [NUMBER [FLAG]]       toggle the state of FLAG on partition NUMBER
  unit UNIT                    set the default unit to UNIT
  version                      displays the version of GNU Parted and copyright info
(parted)
```

In response to the **(parted)** prompt, you can give the command **help** followed by the name of the command you want more information about. When you give a **print** (or just **p**) command, **parted** displays current partition information, just as a **print** command on the command line does.

The **parted** utility will not allow you to set up overlapping partitions (except for logical partitions that overlap the extended partition that contains them). Similarly it will not allow you to create a partition that starts at the very beginning of the disk (cylinder 0). Both of these situations can cause loss of data.

Following are guidelines to remember when defining a partition table for a disk. For more information refer to “Setting Up the Hard Disk” on page 30.

- Do not delete or modify the partition that defines the extended partition unless you are willing to lose all data on all logical partitions within the extended partition.

- If you put **/boot** on a separate partition, it is a good idea to put it at the beginning of the drive (partition 1) so there is no issue of Linux having to boot from a partition located too far into the drive. When you can afford the disk space, it is desirable to put each major filesystem on a separate partition. Many people choose to combine **/** (root), **/var**, and **/usr** into a single partition, which generally results in less wasted space but can, on rare occasions, cause problems.
- Although **parted** can create some types of filesystems, it is typically easiest to use this utility to create partitions and then use **mkfs** and **mkswap** to create filesystems on the partitions.

The following sequence of commands defines a 300-megabyte, bootable, Linux partition as partition 1 on a clean disk:

```
# parted /dev/hdb
...
Using /dev/hdb
(parted) mkpart                                (create new partition)
Partition type?  primary/extended? primary      (select primary partition)
File system type? [ext2]?                        (default to an ext2 filesystem)
Start? 1   (start at the beginning of the disk)
End? 300m                                       (specify a 300-megabyte partition)
(parted) help set                               (use help to check the syntax of the set command)
    set NUMBER FLAG STATE                        change a flag on partition NUMBER

    NUMBER is the partition number used by Linux.  On msdos disk labels, the primary
    partitions number from 1 to 4, logical partitions from 5 onwards.
    FLAG is one of: boot, root, swap, hidden, raid, lvm, lba, hp-service, palo,
    prep, msftres
    STATE is one of: on, off
(parted) set 1 boot on                           (turn on the boot flag on partition 1)
(parted) print                                   (verify that the partition is correct)
Disk geometry for /dev/hdb: 0kB - 250GB
Disk label type: msdos
Number  Start  End      Size    Type    File system  Flags
1       1kB   300MB   300MB   primary ext2         boot
(parted) quit
Information: Don't forget to update /etc/fstab, if necessary.
```

When you specify a size within **parted**, you can use a suffix of **k** (kilobytes), **m** (megabytes), or **g** (gigabytes). After creating a partition, give a **print** command to see where the partition ends. Perform this task before you define the next contiguous partition to make sure you do not waste space. After setting up all the partitions, exit from **parted** with a **quit** command.

Next make a filesystem (**mkfs**; page 439) on each partition that is to hold a filesystem (not swap). Make all partitions, except swap and **/boot**, of type **ext3**, unless you have a reason to do otherwise. Make the **/boot** partition of type **ext2**. Use **mkswap** (page 479) to set up a swap area on a partition. You can use **e2label** (page 439) to label partitions.

## KEEPING USERS INFORMED

One of your primary responsibilities as a system administrator is communicating with system users. You need to make announcements, such as when the system will be down for maintenance, when a class on some new software will be held, and how users can access the new system printer. You can even start to fill the role of a small local newspaper, letting users know about new employees, RIFs, births, the company picnic, and so on.

Different communications have different priorities. For example, information about the company picnic in two months is not as time sensitive as the fact that you are bringing the system down in 5 minutes. To meet these differing needs, Linux provides different ways of communicating. The most common methods are described and contrasted in the following list. All of these methods are generally available to everyone, except for the message of the day, which is typically reserved for Superuser.

**write** Use the **write** utility (page 172) to communicate with a user who is logged in on the local system. You might use it, for example, to ask a user to stop running a program that is bogging down the system; the user might reply that he will be done in 3 minutes. Users can also use **write** to ask the system administrator to mount a tape or restore a file. GNOME opens a new window when it receives a message.

**wall** The **wall** (**write all**) utility effectively communicates immediately with all users who are logged in. It works similarly to **write**, except that users cannot use **wall** to write back to only you. Use **wall** when you are about to bring the system down or are in another crisis situation. Users who are not logged in will not get the message.

Use **wall** while you are Superuser *only* in a crisis situation; it interrupts anything anyone is doing.

**Email** Email is useful for communicating less urgent information to one or more systems and/or remote users. When you send mail, you have to be willing to wait for each user to read it. The email utilities are useful for reminding users that they are forgetting to log out, their bills are past due, or they are using too much disk space.

Users can easily make permanent records of messages they receive via email, as opposed to messages received via **write**, so they can keep track of important details. It would be appropriate to use email to inform users about a new, complex procedure, so each user could keep a copy of the information for reference.

**Message of the day** Users see the message of the day each time they log in in a textual environment. You can edit the **/etc/motd** file to change this message as necessary. The message of the day can alert users to upcoming periodic maintenance, new system features, or a change in procedures.

---

## CREATING PROBLEMS

Even experienced system administrators make mistakes; new system administrators just make more mistakes. Although you can improve your odds of avoiding



problems by carefully reading and following the documentation provided with software, many things can still go wrong. A comprehensive list is not possible, no matter how long, as new and exciting ways to create problems are discovered every day. A few of the more common techniques are described here.

## FAILING TO PERFORM REGULAR BACKUPS

Few feelings are more painful to a system administrator than realizing that important information is lost forever. If your system supports multiple users, having a recent backup may be your only protection from a public lynching. If it is a single-user system, having a recent backup certainly keeps you happier when you lose a hard disk.

## NOT READING AND FOLLOWING INSTRUCTIONS

Software developers provide documentation for a reason. Even when you have installed a software package before, carefully read the instructions again. They may have changed, or you may simply remember them incorrectly. Software changes more quickly than books are revised, so no book should be taken as offering fool-proof advice. Instead, look for the latest documentation online.

## FAILING TO ASK FOR HELP WHEN INSTRUCTIONS ARE NOT CLEAR

If something does not seem to make sense, try to find out what does make sense—do not guess. Refer to “Help” on page 1033.

## DELETING OR MISTYPING A CRITICAL FILE

One sure way to give yourself nightmares is to execute the command

```
# rm -rf /etc          ← do not do this
```

Perhaps no other command renders a Linux system useless so quickly. The only recourse is to reboot into rescue mode (page 411) and restore the missing files from a recent backup. Although this example depicts an extreme case, many files are critical to proper operation of a system. Deleting one of these files or mistyping information in one of them is almost certain to cause problems. If you directly edit `/etc/passwd`, for example, entering the wrong information in a field can make it impossible for one or more users to log in. Do not use `rm -rf` with an argument that includes wildcard characters; do pause after typing the command, and read it before you press RETURN. Check everything you do carefully, and make a copy of a critical file before you edit it.

### Be careful when using a wildcard character with `rm`

**caution** When you must use a wildcard character, such as `*`, in an argument to an `rm` command, first use `echo` with the same argument to see exactly which files you will be deleting. This check is especially important when you are working as **root**.

## SOLVING PROBLEMS

As the system administrator, it is your responsibility to keep the system secure and running smoothly. When a user is having a problem, it usually falls to the administrator to help the user get back on track. This section suggests ways to keep users happy and the system functioning at peak performance.

### HELPING WHEN A USER CANNOT LOG IN

When a user has trouble logging in on the system, the source may be a user error or a problem with the system software or hardware. The following steps can help determine where the problem is:

- Determine whether only that one user or only that one user's terminal/workstation has a problem or whether the problem is more widespread.
- Check that the user's CAPSLOCK key is not on.
- Make sure the user's home directory exists and corresponds to that user's entry in the `/etc/passwd` file. Verify that the user owns his or her home directory and startup files and that they are readable (and, in the case of the home directory, executable). Confirm that the entry for the user's login shell in the `/etc/passwd` file is valid (that is, the entry is accurate and the shell exists as specified).
- Change the user's password if there is a chance that he or she has forgotten the correct password.
- Check the user's startup files (`.profile`, `.login`, `.bashrc`, and so on). The user may have edited one of these files and introduced a syntax error that prevents login.
- Check the terminal or monitor data cable from where it plugs into the terminal to where it plugs into the computer (or as far as you can follow it). Try turning the terminal or monitor off and then turning it back on.
- When the problem appears to be widespread, check whether you can log in from the system console. If you can, make sure that the system is in multiuser mode. If you cannot log in, the system may have crashed; reboot it and perform any necessary recovery steps (the system usually does quite a bit automatically).
- Check that the `/etc/event.d/tty[1-6]` files to see if `mingetty` is starting with certain events (*FEDORA*). Check that the `/etc/inittab` file is set up to start `mingetty` at runlevels 2–5 (*RHEL*).
- Check the `/var/log/messages` file. This file accumulates system errors, messages from daemon processes, and other important information. It may indicate the cause or more symptoms of a problem. Also, check the

system console. Occasionally messages about system problems that are not written to `/var/log/messages` (for instance, a full disk) are displayed on the system console.

- If the user is logging in over a network connection, run `system-config-services` (page 428) to make sure that the service the user is trying to use (such as `ssh`) is enabled.
- Use `df` to check for full filesystems. If the `/tmp` filesystem or the user's home directory is full, login sometimes fails in unexpected ways. In some cases you may be able to log in to a textual environment but not a graphical one. When applications that start when the user logs in cannot create temporary files or cannot update files in the user's home directory, the login process itself may terminate.

## SPEEDING UP THE SYSTEM

When the system is running slowly for no apparent reason, perhaps a process did not exit when a user logged out. Symptoms of this problem include poor response time and a system load, as shown by `w` or `uptime`, that is greater than 1.0. Running `top` (page 567) is an excellent way to quickly find rogue processes. Use `ps -ef` to list all processes. One thing to look for in `ps -ef` output is a large number in the **TIME** column. For example, if a Firefox process has a **TIME** field over 100.0, this process has likely run amok. However, if the user is doing a lot of Java work and has not logged out for a long time, this value may be normal. Look at the **STIME** field to see when the process was started. If the process has been running for longer than the user has been logged in, it is a good candidate to be killed.

When a user gets stuck and leaves her terminal unattended without notifying anyone, it is convenient to kill (page 409) all processes owned by that user. If the user is running a window system, such as GNOME or KDE on the console, kill the window manager process. Manager processes to look for include `startkde`, `gnome-session`, or another process name that ends in `wm`. Usually the window manager is either the first or the last thing to be run, and exiting from the window manager logs the user out. If killing the window manager does not work, try killing the X server process itself. This process is typically listed as `/usr/bin/Xorg`. If that fails, you can kill all processes owned by a user by giving the command `kill -1 -1`, or equivalently `kill -TERM -1` *while you are logged in as that user*. Using `-1` (one) in place of the process ID tells `kill` that it should send the signal to all processes that are owned by that user. For example, as `root` you could give the following command:

```
# su jenny -c 'kill -TERM -1'
```

If this does not kill all processes (sometimes `TERM` does not kill a process), you can use the `KILL` signal. The following line will definitely kill all processes owned by Jenny and will not be friendly about it:

```
# su jenny -c 'kill -KILL -1'
```

(If you do not use `su jenny -c`, the same command brings the system down.)

## lsof: FINDS OPEN FILES

The `lsof` (ls open files) utility locates open files. Its options display only certain processes, only certain file descriptors of a process, or only certain network connections (network connections use file descriptors just as normal files do and `lsof` can show these as well). Once you have identified a suspect process using `ps -ef`, give the following command:

```
# lsof -s -p pid
```

Replace *pid* with the process ID of the suspect process; `lsof` displays a list of file descriptors that process *pid* has open. The `-s` option displays the sizes of all open files. Because the `-s` option accepts an argument, you cannot combine it with `-p` (`-sp` does not work). This size information is helpful in determining whether the process has a very large file open. If it does, contact the owner of the process or, if necessary, kill the process. The `-rn` option redisplay the output of `lsof` every *n* seconds.

## KEEPING A MACHINE LOG

A machine log that includes the information shown in Table 16-4 can help you find and fix system problems. Include the time and date for each entry in the log. Avoid the temptation to keep the log *only* on the computer—it will be most useful to you when the system is down. Another good idea is to keep a record of all email about user problems. One strategy is to save this mail to a separate file or folder as you read it. Another approach is to set up a mail alias that users can send mail to when they have problems. This alias can then forward mail to you and also store a copy in an archive file. Following is an example of an entry in the `/etc/aliases` file (page 675) that sets up this type of alias:

```
trouble: admin,/var/spool/mail/admin.archive
```

Email sent to the **trouble** alias will be forwarded to the **admin** user and also stored in the file `/var/mail/admin.archive`.

**Table 16-4** Machine log

Entry	Function
Hardware modifications	Keep track of the system hardware configuration: which devices hold which partitions, the model of the new NIC you added, and so on.
System software modifications	Keep track of the options used when building Linux. Print such files as <code>/usr/src/linux/.config</code> (Linux kernel configuration) and the X11 configuration file <code>/etc/X11/xorg.conf</code> . The file hierarchy under <code>/etc/sysconfig</code> contains valuable information about network configuration, among other things.
Hardware malfunctions	Keep as accurate a list as possible of any problems with the system. Make note of any error messages or numbers that the system displays on the system console and identify what users were doing when the problem occurred.
User complaints	Make a list of all reasonable complaints made by knowledgeable users (for example, “machine is abnormally slow”).

## KEEPING THE SYSTEM SECURE

No system with dial-in lines or public access to terminals is absolutely secure. You can make a system as secure as possible by changing the Superuser password frequently and choosing passwords that are difficult to guess. Do not tell anyone who does not *absolutely* need to know the Superuser password. You can also encourage system users to choose difficult passwords and to change them periodically.

By default, passwords on Fedora/RHEL use MD5 (page 1093) hashing, which makes them more difficult to break than passwords encrypted with DES (page 1046). It makes little difference how well encrypted your password is if you make it easy for someone to find out or guess what it is.

A password that is difficult to guess is one that someone else would not be likely to think you would have chosen. Do not use words from the dictionary (spelled forward or backward); names of relatives, pets, or friends; or words from a foreign language. A good strategy is to choose a couple of short words, include some punctuation (for example, put a ^ between them), mix the case, and replace some of the letters in the words with numbers. If it were not printed in this book, an example of a good password would be **C&yGram5** (candygrams). Ideally you would use a random combination of ASCII characters, but that would be difficult to remember.

You can use one of several excellent password-cracking programs to find users who have chosen poor passwords. These programs work by repeatedly encrypting words from dictionaries, phrases, names, and other sources. If the encrypted password matches the output of the program, then the program has found the password of the user. A program that cracks passwords is **crack**. It and many other programs and security tips are available from CERT ([www.cert.org](http://www.cert.org)), which was originally called the Computer Emergency Response Team. Specifically look at [www.cert.org/tech\\_tips](http://www.cert.org/tech_tips).

Make sure that no one except Superuser can write to files containing programs that are owned by **root** and run in setuid mode (for example, **mail** and **su**). Also make sure that users do not transfer programs that run in setuid mode and are owned by **root** onto the system by means of mounting tapes or disks. These programs can be used to circumvent system security. One technique that prevents users from having setuid files is to use the **nosuid** flag to mount, which you can set in the flags section in the **fstab** file. Refer to “**fstab**: Keeps Track of Filesystems” on page 490.

The BIOS in many machines gives you some degree of protection from an unauthorized person modifying the BIOS or rebooting the system. When you set up the BIOS, look for a section named Security. You can probably add a BIOS password. If you depend on the BIOS password, lock the computer case. It is usually a simple matter to reset the BIOS password by using a jumper on the motherboard.

## LOG FILES AND MAIL FOR root

Users frequently email **root** and **postmaster** to communicate with the system administrator. If you do not forward **root**'s mail to yourself (**/etc/aliases** on page 675), remember to check **root**'s mail periodically. You will not receive reminders about

mail that arrives for **root** when you use **su** to perform system administration tasks. However, after you use **su** to become **root**, you can give the command **mail -u root** to look at **root**'s mail.

Review the system log files regularly for evidence of problems. Two important files are **/var/log/messages**, where the operating system and some applications record errors, and **/var/log/maillog**, which contains errors from the mail system.

The **logwatch** utility (part of the **logwatch** package) **/usr/sbin/logwatch** points to the Perl script named **/usr/share/logwatch/scripts/logwatch.pl** is a report writer that sends email reports on log files. By default, this script is run daily (**/etc/cron.daily/0logwatch** runs the same Perl script) and emails its output to **root**. Refer to the **logwatch** man page and to the script itself for more information.

## MONITORING DISK USAGE

Sooner or later you will probably start to run out of disk space. Do not fill up a disk; Linux can write to files significantly faster if at least 5 to 30 percent of the disk space in a given filesystem remains free. Using more than the maximum optimal disk space in a filesystem can degrade system performance.

**Fragmentation** As a filesystem becomes full, it can become fragmented. This is similar to the DOS concept of fragmentation but is not nearly as pronounced and is typically rare on modern Linux filesystems; by design Linux filesystems are resistant to fragmentation. Keep filesystems from running near full capacity, and you may never need to worry about fragmentation. If there is no space on a filesystem, you cannot write to it at all.

To check for filesystem fragmentation, unmount the filesystem and run **fsck** on it. The output of **fsck** includes a percent fragmentation figure for the filesystem. You can defragment a filesystem by backing it up, using **mkfs** (page 439) to make a clean, empty image, and then restoring the filesystem. Which utility you use to do the backup and restore—**dump/restore**, **tar**, **cpio**, or a third-party backup program—is irrelevant.

**Reports** Linux provides several programs that report on who is using how much disk space on which filesystems. Refer to the **du**, **quota**, and **df** man pages and the **-size** option in the **find** utility man page. In addition to these utilities, you can use the disk quota system to manage disk space.

Four strategies to increase the amount of free space on a filesystem are to compress files, delete files, grow LVM-based filesystems, and condense directories. This section contains some ideas on ways to maintain a filesystem so that it does not become overloaded.

**Files that grow quickly** Some files, such as log files and temporary files, grow over time. Core dump files, for example, take up substantial space and are rarely needed. Also, users occasionally run programs that accidentally generate huge files. As the system administrator, you must review these files periodically so that they do not get out of hand.

If a filesystem is running out of space quickly (that is, over a period of an hour rather than weeks or months), first figure out why it is running out of space. Use a

**ps -ef** command to determine whether a user has created a runaway process that is creating a huge file. When evaluating the output of **ps**, look for a process that has consumed a large amount of CPU time. If such a process is running and creating a large file, the file will continue to grow as you free up space. If you remove the huge file, the space it occupied will not be freed until the process terminates, so you need to kill the process. Try to contact the user running the process, and ask the user to kill it. If you cannot contact the user, log in as **root** and kill the process yourself. Refer to kill on page 409 for more information.

You can also truncate a large log file rather than removing it, although you can better deal with this recurring situation with **logrotate** (discussed in the next section). For example, if the **/var/log/messages** file has become very large because a system daemon is misconfigured, you can use **/dev/null** to truncate it:

```
# cp /dev/null /var/log/messages
```

or

```
# cat /dev/null > /var/log/messages
```

or, without spawning a new process,

```
# : > /var/log/messages
```

If you remove **/var/log/messages**, you have to restart the **rsyslogd** (*FEDORA*) or **syslogd** (*RHEL*) daemon. If you do not restart **rsyslogd**, the space on the filesystem is not released.

When no single process is consuming the disk space but capacity has instead been used up gradually, locate unneeded files and delete them. You can archive these files by using **cpio**, **dump**, or **tar** before you delete them. You can safely remove most files named **core** that have not been accessed for several days. The following command line performs this function without removing necessary files named **core** (such as **/dev/core**):

```
# find / -type f -name core | xargs file | grep 'B core file' | sed 's/:ELF.*//g' | xargs rm -f
```

The **find** command lists all ordinary files named **core** and sends its output to **xargs**, which runs **file** on each of the files in the list. The **file** utility displays a string that includes **B core file** for files created as the result of a core dump. These files need to be removed. The **grep** command filters out from **file** lines that do not contain this string. Finally **sed** removes everything following the colon so that all that is left on the line is the pathname of the **core** file; **xargs** removes the file.

To free up more disk space, look through the **/tmp** and **/var/tmp** directories for old temporary files and remove them. Keep track of disk usage in **/var/mail**, **/var/spool**, and **/var/log**.

## logrotate: MANAGES LOG FILES

Rather than deleting or truncating log files, you may want to keep these files for a while in case you need to refer to them. The **logrotate** utility helps you manage system log (and

other) files automatically by *rotating* (page 1104), compressing, mailing, and removing each as you specify. The `logrotate` utility is controlled by the `/etc/logrotate.conf` file, which sets default values and can optionally specify files to be rotated. Typically, `logrotate.conf` has an **include** statement that points to utility-specific specification files in `/etc/logrotate.d`. Following is a sample `logrotate.conf` file:

```
$ cat /etc/logrotate.conf
# see "man logrotate" for details
# rotate log files weekly
weekly

# keep 4 weeks worth of backlogs
rotate 4

# create new (empty) log files after rotating old ones
create

# use date as a suffix of the rotated file
dateext

# uncomment this if you want your log files compressed
#compress

# RPM packages drop log rotation information into this directory
include /etc/logrotate.d

# no packages own wtmp and btmp -- we'll rotate them here
/var/log/wtmp {
    monthly
    create 0664 root utmp
    minsize 1M
    rotate 1
}

/var/log/btmp {
    missingok
    monthly
    create 0600 root utmp
    rotate 1
}

# system-specific logs may be also be configured here.
```

The `logrotate.conf` file sets default values for common parameters. Whenever `logrotate` reads another value for one of these parameters, it resets the default value. You have a choice of rotating files **daily**, **weekly**, or **monthly**. The number following the **rotate** keyword specifies the number of rotated log files that you want to keep. The **create** keyword causes `logrotate` to create a new log file with the same name and attributes as the newly rotated log file. The **dateext** keyword causes `logrotate` to append the date to the filename of the log. The **compress** keyword (commented out in the default file) causes log files to be compressed using `gzip`. The **include** keyword specifies the standard `/etc/logrotate.d` directory for program-specific `logrotate` specification files. When you install a program using `rpm` (page 510) or an `rpm`-based utility such as `yum` (page 498), `rpm` puts the `logrotate` specification file in this directory.



The last set of instructions in **logrotate.conf** takes care of the **/var/log/wtmp** log file (**wtmp** holds login records; you can view this file with the command **who /var/log/wtmp**). The keyword **monthly** overrides the default value of **weekly** *for this utility only* (because the value is within brackets). The **create** keyword is followed by the arguments establishing the permissions, owner, and group for the new file. Finally **rotate** establishes that one rotated log file should be kept.

The **/etc/logrotate.d/cups** file is an example of a utility-specific logrotate specification file:

```
$ cat /etc/logrotate.d/cups
/var/log/cups/*_log {
    missingok
    notifempty
    sharedscripts
    postrotate
        /etc/init.d/cups condrestart >/dev/null 2>&1 || true
    endscript
}
```

This file, which is incorporated in **/etc/logrotate.d** because of the **include** statement in **logrotate.conf**, works with each of the files in **/var/log/cups** that has a filename that ends in **\_log** (**\*\_log**). The **missingok** keyword means that no error will be issued when the file is missing. The **notifempty** keyword causes logrotate not to rotate the log file if it is empty, overriding the default action of rotating empty log files. The **sharedscripts** keyword causes logrotate to execute the command(s) in the **prerotate** and **postrotate** sections one time only—not one time for each log that is rotated. Although it does not appear in this example, the **copytruncate** keyword causes logrotate to truncate the original log file immediately after it copies it. This keyword is useful for programs that cannot be instructed to close and reopen their log files because they might continue writing to the original file even after it has been moved. The logrotate utility executes the commands between **prerotate** and **endscript** before the rotation begins. Similarly, commands between **postrotate** and **endscript** are executed after the rotation is complete.

The logrotate utility has many keywords, many of which take arguments and have side effects. Refer to the logrotate man page for details.

## REMOVING UNUSED SPACE FROM DIRECTORIES

A directory that contains too many filenames is inefficient. The point at which a directory on an **ext2**, **ext3**, or **ext4** filesystem becomes inefficient varies, depending partly on the length of the filenames it contains. Keep directories relatively small. Having fewer than several hundred files (or directories) in a directory is generally a good idea, and having more than several thousand is generally a bad idea. Additionally, Linux uses a caching mechanism for frequently accessed files to speed the process of locating an inode from a filename. This caching mechanism works only on filenames of up to 30 characters in length, so avoid giving extremely long filenames to frequently accessed files.

When a directory becomes too large, you can usually break it into several smaller directories by moving its contents to those new directories. Make sure that you remove the original directory once you have moved all of its contents.

Because Linux directories do not shrink automatically, removing a file from a directory does not shrink the directory, even though it frees up space on the disk. To remove unused space and make a directory smaller, you must copy or move all the files to a new directory *and* remove the original directory.

The following procedure removes unused directory space. First remove all unneeded files from the large directory. Then create a new, empty directory. Next move or copy all remaining files from the old large directory to the new empty directory. Remember to copy hidden files. Finally, delete the old directory and rename the new directory.

```
# mkdir /home/alex/new
# mv /home/alex/large/* /home/alex/large/. [A-z]* /home/alex/new
# rmdir /home/alex/large
# mv /home/alex/new /home/alex/large
```

## optional DISK QUOTA SYSTEM

The disk quota system limits the disk space and number of files owned by individual users. You can choose to limit each user's disk space, the number of files each user can own, or both. Each resource that is limited has two limits. The lower limit, or *quota*, can be exceeded by the user, although a warning is given each time the user logs in when he is above the quota. After a certain number of days of warnings (set by the system administrator), the system will behave as if the user had reached the upper limit. Once the upper limit is reached or the user has received the specified number of warnings, the user will not be allowed to create any more files or use any more disk space. The user's only recourse at that point is to remove some files.

Users can review their usage and limits with the `quota` utility. Superuser can use `quota` to obtain information about any user. You can turn on quotas only if the filesystem is mounted with the `usrquota` and/or `grpquota` options (`ext3` and `ext4` filesystems).

First you must decide which filesystems to limit and how to allocate space among users. Typically only filesystems that contain users' home directories, such as `/home`, are limited. Use the `edquota` utility to set the quotas, and then use `quotaon` to start the quota system. You will probably want to put a `quotaon` command into the appropriate init script so that the quota system will be enabled when you bring up the system (page 426). Unmounting a filesystem automatically disables the quota system for that filesystem.

## rsyslogd: LOGS SYSTEM MESSAGES

Traditionally UNIX programs sent log messages to standard error. If a more permanent log was required, the output was redirected to a file. Because of the limitations of this approach, 4.3BSD introduced the system log daemon (`rsyslogd`) now used by

Fedora. RHEL uses **syslogd**. This daemon listens for log messages and stores them in the **/var/log** hierarchy. In addition to providing logging facilities, **rsyslogd** allows a single machine to serve as a log repository for a network and allows arbitrary programs to process specific log messages.

**rsyslog.conf** The **/etc/rsyslog.conf** file stores configuration information for **rsyslogd**. Each line in this file contains one or more *selectors* and an *action*, separated by whitespace. The selectors define the origin and type of the messages; the action specifies how **rsyslogd** is to process the message. Sample lines from **rsyslog.conf** follow (a # indicates a comment):

```
# Log all kernel messages to the console.
kern.*                                /dev/console
# Log all the mail messages in one place.
mail.*                               /var/log/maillog
# Log cron stuff
cron.*                               /var/log/cron
# Everybody gets emergency messages
*.emerg                             *
# Save boot messages also to boot.log
local7.*                             /var/log/boot.log
```

**Selectors** A selector is split into two parts, a *facility* and a *priority*, which are separated by a period. The facility indicates the origin of the message. For example, **kern** messages come from the kernel and **mail** messages come from the mail subsystem. Following is a list of facility names used by **rsyslogd** and the systems that generate these messages:

<b>auth</b>	Authorization and security systems including login
<b>authpriv</b>	Same as <b>auth</b> , but should be logged to a secure location
<b>cron</b>	cron
<b>daemon</b>	System and network daemons without their own categories
<b>kern</b>	Kernel
<b>lpr</b>	Printing subsystem
<b>mail</b>	Mail subsystem
<b>news</b>	Network news subsystem
<b>user</b>	Default facility; all user programs use this facility
<b>uucp</b>	The UNIX-to-UNIX copy protocol subsystem
<b>local0 to local7</b>	Reserved for local use

The priority indicates the severity of the message. The following list of the priority names and the conditions they represent is in priority order:

<b>debug</b>	Debugging information
<b>info</b>	Information that does not require intervention
<b>notice</b>	Conditions that may require intervention
<b>warning</b>	Warnings
<b>err</b>	Errors
<b>crit</b>	Critical conditions such as hardware failures
<b>alert</b>	Conditions that require immediate attention
<b>emerg</b>	Emergency conditions

A selector consisting of a single facility and priority, such as **kern.info**, causes the corresponding action to be applied to every message from that facility with that priority *or higher* (more urgent). Use **.=** to specify a single priority; for example, **kern.=info** applies the action to kernel messages of **info** priority. An exclamation point specifies that a priority is not matched, so **kern.!info** matches kernel messages with a priority lower than **info** and **kern.!info** matches kernel messages with a priority other than **info**.

A line with multiple selectors, separated by semicolons, applies the action if any of the selectors is matched. Each of the selectors on a line with multiple selectors constrains the match, with subsequent selectors frequently tightening the constraints. For example, the selectors **mail.info;mail.err** match mail subsystem messages with **info**, **notice**, or **warning** priorities.

You can replace either part of the selector with an asterisk to match anything. The keyword **none** in either part of the selector indicates no match is possible. The selector **\*.crit;kern.none** matches all critical or higher-priority messages, except those from the kernel.

**Actions** The action specifies how **rsyslogd** processes a message that matches the selector. The simplest actions are ordinary files, which are specified by their absolute pathnames; **rsyslogd** appends messages to these files. Specify **/dev/console** if you want messages sent to the system console. If you want a hardcopy record of messages, you can specify a device file that represents a dedicated printer.

You can write important messages to a specific user's terminal by specifying a username, such as **root**, or a comma-separated list of usernames. Very important messages can be written to every logged-in terminal by using an asterisk.

To forward messages to **rsyslogd** on a remote system, specify the name of the system preceded by **@**. It is a good idea to forward critical messages from the kernel to another system because these messages often precede a system crash and may not be saved to the local disk. The following line from **rsyslog.conf** sends critical kernel messages to **grape**:

```
kern.crit      @grape
```

Because **rsyslogd** is not configured by default to enable logging over the network, you must edit the **/etc/sysconfig/rsyslog** file on the remote system (**grape** in this case) so that **rsyslogd** is started with the **-r** option. After you modify the **rsyslog** file, restart **rsyslogd** using the **rsyslog** init script.

---

## MySQL

MySQL (My Structured Query Language) is the world's most popular open-source database. It is the M in LAMP (Linux, Apache, MySQL, PHP/Perl/Python), an open-source enterprise software stack. Many programming languages provide an interface to MySQL (e.g., C, PHP, Perl).

Michael Widenius and David Axmark started development of MySQL in 1994. Today the MySQL database is owned and supported by Sun Microsystems (as of 2009 Oracle Corporation had begun the process of acquiring Sun Microsystems).

**This section explains how to set up and work with MySQL; it does not explain SQL**

**tip** SQL (Structured Query Language) is the language used to work with SQL databases, including MySQL. This chapter explains how to install and set up MySQL in a Fedora/RHEL environment. Although it includes some SQL statements in this explanation, it makes no attempt to explain SQL. See [dev.mysql.com/doc](http://dev.mysql.com/doc) for SQL documentation.

## MORE INFORMATION

Home page: [www.mysql.com](http://www.mysql.com)

MySQL documentation: [dev.mysql.com/doc](http://dev.mysql.com/doc)

Introduction: [dev.mysql.com/tech-resources/articles/mysql\\_intro.html](http://dev.mysql.com/tech-resources/articles/mysql_intro.html)

Backing up databases: [www.webcheatsheet.com/SQL/mysql\\_backup\\_restore.php](http://www.webcheatsheet.com/SQL/mysql_backup_restore.php)

## TERMINOLOGY

This section briefly describes some basic terms used when working with a relational database. See also Figure 16-4 on page 589.

**database** A structured set of persistent data comprising one or more tables.

**table** A collection of rows in a relational database.

**row** An ordered set of columns in a table. Also *record*.

**column** A set of one type of values, one per row in a table. Also *field*.

## SYNTAX AND CONVENTIONS

A MySQL program comprises one or more statements, each terminated with a semicolon (;). Although keywords in statements are not case sensitive, this book shows keywords in uppercase letters for clarity. Database and table names are case sensitive.

The following example shows a multiline MySQL interpreter statement that includes both the primary interpreter prompt (**mysql>**) and the secondary interpreter prompt (**->**). This statement displays the values of three columns from the table named **people** in rows that meet specified criteria.

```
mysql> SELECT person,password,executeperm
-> FROM people
-> WHERE password IS NULL AND executeperm=true;
```

## PREREQUISITES

Install the following packages:

- **mysql**
- **mysql-server**

Run `chkconfig` to cause the MySQL daemon (`mysqld`) to start when the system enters multiuser mode:

```
# /sbin/chkconfig mysqld on
```

`mysqld` init script Start `msqld`:

```
# /sbin/service mysqld start
Initializing MySQL database: Installing MySQL system tables...
091208 11:23:00 [Warning] Forcing shutdown of 2 plugins
OK
Filling help tables...
...
Starting MySQL: [ OK ]
```

## NOTES

Unlike Oracle, when you create a user, MySQL does not automatically create a database. Under MySQL, users and databases are not as rigidly bound as they are under Oracle.

MySQL has a separate set of users from Linux users. As installed, the name of the MySQL administrator is `root`. Because the MySQL `root` user is not the same as the Linux `root` user, it can have a different password.

## JUMPSTART: SETTING UP MYSQL

### You must assign a password to the MySQL user named `root`

---

**tip** The examples in this section will not work unless you use `mysql_secure_installation` to assign a password to the MySQL user named `root`. See the following instructions.

---

MySQL is installed with test databases, an anonymous user, and no password for the MySQL user named `root`. For a more secure setup, remove the anonymous user and assign a password to MySQL `root`. The `mysql_secure_installation` utility asks a series of questions that allows you to assign a password to the MySQL user named `root` and perform other housekeeping tasks. If you have just installed MySQL, enter `RETURN` in response to the prompt for the current password for `root`.

```
# /usr/bin/mysql_secure_installation
...
Enter current password for root (enter for none):
OK, successfully used password, moving on...
...
Set root password? [Y/n] y
New password:
Re-enter new password:
Password updated successfully!
Reloading privilege tables..
... Success!
...
Remove anonymous users? [Y/n] y
...
```

```

Disallow root login remotely? [Y/n] y
...
Remove test database and access to it? [Y/n] y
...
Reload privilege tables now? [Y/n] y
...

```

Alternatively, you can use the following command to assign *mysql-password* as the password for the MySQL user named *root*:

```
# /usr/bin/mysqladmin -u root password 'mysql-password'
```

## OPTIONS

This section describes some of the options you can use on the *mysql* command line. The options preceded by a single hyphen and those preceded by a double hyphen are equivalent.

**--disable-reconnect**

Does not attempt to connect to the server again if the connection is dropped. See **--reconnect**.

**--host=hostname -h hostname**

Specifies the address of the MySQL server as *hostname*. Without this option MySQL connects to the server on the local system (127.0.0.1).

**--password[=passwd]**

**-p[passwd]**

Specifies the MySQL password as *passwd*. For improved security, do not specify the password on the command line; MySQL will prompt for it. By default, MySQL does not use a password. In the short form of this option, do not put a SPACE between the **-p** and *passwd*.

**--reconnect**

Attempts to connect to the server again if the connection is dropped (default). Disable this behavior using **--disable-reconnect**.

**--user=usr -u usr**

Specifies the MySQL user as *usr*. When you first install MySQL, there is one user, *root*, and that user does not have a password.

**--verbose -v**

Increases the amount of information MySQL displays. Use this option multiple times to further increase verbosity.

## THE .my.cnf CONFIGURATION FILE

You can use the *~/.my.cnf* file to set MySQL options. The following example shows Max's *.my.cnf* file. The **[mysql]** specifies the MySQL group. The next line sets Max's password to *mpassword*. With this setup, Max does not have to use **-p** on the command line; MySQL logs him in automatically.

```

$ cat /home/max/.my.cnf
[mysql]
password="mpassword"

```

## WORKING WITH MYSQL

**Adding a user** Before starting to work with the database, create a user so you do not have to work as the MySQL **root** user. If the MySQL username you add is the same as your Linux username, you will not have to specify a username on the MySQL command line. In the following example, Max works as the MySQL **root** (**-u root**) user to create a database named **maxdb** and add the MySQL user named **max** with a password of **mpassword**. The **GRANT** statement gives Max the permissions he needs to work with the **maxdb** database. You must work as the MySQL **root** user to set up a MySQL user. The **-p** option causes MySQL to prompt for the password. When using the MySQL interpreter, **Query OK** indicates that the preceding statement was syntactically correct. You must enclose all character and date data within single quotation marks.

```
$ mysql -u root -p
Enter password:
Welcome to the MySQL monitor.  Commands end with ; or \g.
Your MySQL connection id is 12
Server version: 5.1.40 Source distribution

Type 'help;' or '\h' for help. Type '\c' to clear the current input
statement.

mysql> CREATE DATABASE maxdb;
Query OK, 1 row affected (0.00 sec)

mysql> GRANT ALL PRIVILEGES
-> ON maxdb.* to 'max'
-> IDENTIFIED BY 'mpasswd'
-> WITH GRANT OPTION;
Query OK, 0 rows affected (0.00 sec)

mysql> SELECT user, password
-> FROM mysql.user;
+-----+-----+
| user | password |
+-----+-----+
| root | 4927a5e40a2cca3e |
| max  | 0eb28ca55c1ee9fe |
+-----+-----+
2 rows in set (0.00 sec)

mysql> quit
Bye
$
```

In the preceding example, after creating the database and setting up the new user, Max queries the **user** table of the **mysql** database to display the **user** and **password** columns. Two users now exist: **root** and **max**. Max gives the command **quit** to exit from the MySQL interpreter.



Working as the MySQL user **max**, Max can now set up a simple database to keep track of users. He does not need to use the **-u** option on the command line because his Linux username and his MySQL username are the same.

Specifying the  
default database

For subsequent commands, if you do not tell MySQL which database you are working with, you must prefix the names of tables with the name of the database. For example, you would need to specify the **people** table in the **maxdb** database as **maxdb.people**. When you specify the **maxdb** database with a **USE** statement, you can refer to the same table as **people**. In the following example, Max specifies **maxdb** as the database he is working with:

```
mysql> USE maxdb;
Database changed
```

Creating a table

Next Max creates a table named **people** in the **maxdb** database. This table has six columns of various types. After creating the table, Max uses a **DESCRIBE** statement to display a description of the table.

```
mysql> CREATE TABLE people ( person VARCHAR(20), password CHAR(41),
-> created DATE, readperm BOOL, writeperm BOOL, executeperm BOOL);
Query OK, 0 rows affected (0.01 sec)
```

```
mysql> DESCRIBE people;
```

Field	Type	Null	Key	Default	Extra
person	varchar(20)	YES		NULL	
password	char(41)	YES		NULL	
created	date	YES		NULL	
readperm	tinyint(1)	YES		NULL	
writeperm	tinyint(1)	YES		NULL	
executeperm	tinyint(1)	YES		NULL	

6 rows in set (0.00 sec)

MySQL changed the columns Max specified as **BOOL** (Boolean) to type **tinyint(1)**, an 8-bit integer, because MySQL does not have native (bit) Boolean support. With **tinyint(1)**, 0 evaluates as **FALSE** and 1–255 evaluate as **TRUE**. Figure 16-4 shows part of the **people** table after data has been entered in it.

Columns			
	person	password	created
	topsy	31fdca655659...	2009-12-08
Rows	bailey	NULL	2009-12-08
	percy	NULL	2009-12-08

**Figure 16-4** Part of the **people** table in the **maxdb** database

Modifying a table Max decides that the `readperm`, `writeperm`, and `executeperm` columns should default to 0. He uses an `ALTER TABLE` statement to modify the table so he does not have to delete it and start over. He then checks his work using a `DESCRIBE` statement.

```
mysql> ALTER TABLE people
-> MODIFY readperm BOOL DEFAULT 0,
-> MODIFY writeperm BOOL DEFAULT 0,
-> MODIFY executeperm BOOL DEFAULT 0;
Query OK, 0 rows affected (0.01 sec)
Records: 0 Duplicates: 0 Warnings: 0
```

```
mysql> DESCRIBE people;
+-----+-----+-----+-----+-----+-----+
| Field      | Type      | Null | Key | Default | Extra |
+-----+-----+-----+-----+-----+-----+
| person     | varchar(20) | YES  |     | NULL    |       |
| password   | char(41)    | YES  |     | NULL    |       |
| created    | date        | YES  |     | NULL    |       |
| readperm   | tinyint(1)  | YES  |     | 0       |       |
| writeperm  | tinyint(1)  | YES  |     | 0       |       |
| executeperm| tinyint(1)  | YES  |     | 0       |       |
+-----+-----+-----+-----+-----+-----+
6 rows in set (0.00 sec)
```

Entering data You can enter information into a database using several techniques. The following command adds three rows to `maxdb` from a Linux text file. In the file, each row is on a separate line, a `TAB` separates each column from the next, and `\N` specifies a null character. The file is not terminated with a `NEWLINE`.

```
$ cat /home/max/people_to_add
max      \N      2008-02-17      1      1      1
zach     \N      2009-03-24      1      1      0
sam      \N      2009-01-28      1      0      0

mysql> LOAD DATA LOCAL INFILE '/home/max/people_to_add'
-> INTO TABLE people;
Query OK, 3 rows affected (0.00 sec)
Records: 3 Deleted: 0 Skipped: 0 Warnings: 0
```

The next command adds a row using an `INSERT` statement:

```
mysql> INSERT INTO people
-> VALUES ('topsy',NULL,CURDATE(),1,1,1);
Query OK, 1 row affected (0.01 sec)
```

Within an `INSERT` statement you can specify which columns you want to enter data into:

```
mysql> INSERT INTO people (person,created,readperm)
-> VALUES ('bailey',CURDATE(),1), ('percy',CURDATE(),0);
Query OK, 2 rows affected (0.01 sec)
Records: 2 Duplicates: 0 Warnings: 0
```

```
mysql> SELECT * FROM people;
```

person	password	created	readperm	writeperm	executeperm
max	NULL	2008-02-17	1	1	1
zach	NULL	2009-03-24	1	1	0
sam	NULL	2009-01-28	1	0	0
topsy	NULL	2009-12-08	1	1	1
bailey	NULL	2009-12-08	1	0	0
percy	NULL	2009-12-08	0	0	0

6 rows in set (0.00 sec)

The CURDATE() function returns today's date. Because the default values for **readperm**, **writeperm**, and **executeperm** are 0, you do not have to specify values for those fields.

Deleting rows using  
a WHERE clause

Next a DELETE FROM statement deletes rows that meet the specified criteria. Here the criteria are specified using equalities in a WHERE clause:

```
mysql> DELETE FROM people
-> WHERE person='bailey' OR person='percy';
Query OK, 2 rows affected (0.02 sec)
```

Selecting rows  
using LIKE

You can also use a LIKE clause to specify criteria. The following SELECT statement displays all rows that contain the letter **m**. The % operators are wildcards; they match any characters.

```
mysql> SELECT * FROM people
-> WHERE person LIKE '%m%';
```

person	password	created	readperm	writeperm	executeperm
max	NULL	2008-02-17	1	1	1
sam	NULL	2009-01-28	1	0	0

2 rows in set (0.00 sec)

Modifying data

In the next example, the PASSWORD() function returns a *hash* (page 1085) from the text given as its argument. The UPDATE statement assigns this hash to the **password** column in rows in which the **person** column holds a value of **sam**. This example does not change the MySQL password information because that information is kept in the database named **mysql**; this statement works with the **maxdb** database.

```
mysql> UPDATE people
-> SET password=PASSWORD("sampass")
-> WHERE person='sam';
Query OK, 1 row affected (0.00 sec)
Rows matched: 1 Changed: 1 Warnings: 0
```

More queries

The next query searches for rows where the **password** is null (IS NULL) and (AND) **executeperm** is true (=true).

```
mysql> SELECT person,password,executeperm
-> FROM people
-> WHERE password IS NULL AND executeperm=true;
```

person	password	executeperm
max	NULL	1
topsy	NULL	1

```
2 rows in set (0.00 sec)
```

Because PASSWORD() is a *one-way hash function* (page 1097), you cannot retrieve the plaintext password from the password hash. However, you can check whether any users have their username as their password:

```
mysql> SELECT * FROM people
-> WHERE password=PASSWORD(person);
```

person	password	created	readperm	writeperm	executeperm
topsy	31fdca655659d93d	2009-12-08	1	1	1

```
1 row in set (0.00 sec)
```

Use an UPDATE statement to give Topsy a NULL password:

```
mysql> UPDATE people
-> SET password=NULL
-> WHERE person="topsy";
```

Query OK, 1 row affected (0.00 sec)  
Rows matched: 1 Changed: 1 Warnings: 0

```
mysql> SELECT person,password
-> FROM people
-> WHERE password IS NULL;
```

person	password
max	NULL
zach	NULL
topsy	NULL

```
3 rows in set (0.00 sec)
```

## CHAPTER SUMMARY

The system-config-users utility adds new users and groups to the system and modifies existing users' accounts. You can also use the equivalent command-line tools (useradd, usermod, userdel, groupadd, and groupmod) to work with user accounts. Backing up files on the system is a critical and often overlooked part of system administration. Linux includes the tar, cpio, dump, and restore utilities to back up

and restore files. You can also use more sophisticated packages such as `amanda` and various commercial products.

The system scheduling daemon, `cron`, periodically executes scheduled tasks. You can schedule tasks using `crontab` and `at`. System reports present information on the health of the system. Two useful tools that generate these reports are `vmstat`, which details virtual memory, I/O, and CPU statistics, and `top`, which reports on how the system is performing from moment to moment and can help you figure out what might be slowing it down.

Another aspect of system administration is solving problems. Linux includes several tools that can help you track down system problems. One of the most important of these tools is `rsyslogd`, the system log daemon. Using `/etc/rsyslogd.conf`, you can control which error messages appear on the console and which go to one of several log files.

System administrators are frequently called upon to set up and administrate MySQL databases. MySQL is the M in LAMP (Linux, Apache, MySQL, PHP/Perl/Python), an open-source enterprise software stack. Many programming languages provide an interface to MySQL (e.g., C, PHP, Perl).

---

## EXERCISES

1. How would you list all the processes running `vi`?
2. How would you use `kill` to cause a server process to reread its configuration files?
3. From the command line, how would you create a user named John Doe who has the username `jd` and who belongs to group `65535`?
4. How would you notify the users of the system that you are going to reboot the system in 10 minutes?
5. Give a command that will create a level 0 dump of the `/usr` filesystem on the first tape device on the system. Which command would you use to take advantage of a drive that supports compression? Which command would place a level 3 dump of the `/var` filesystem immediately after the level 0 dump on the tape?

---

## ADVANCED EXERCISES

6. If the system is less responsive than normal, what is a good first step in figuring out where the problem is?
7. A process stores its PID in a file named `process.pid`. Write a command line that will terminate the process.

8. Working as **root**, you are planning to delete some files but want to make sure that the wildcard expression you will use is correct. Suggest two ways you could make sure that you deleted the correct files.
9. Create a cron file that will regularly perform the following backups:
  - a. Performs a level 0 backup once per month.
  - b. Performs a level 2 dump one day per week.
  - c. Performs a level 5 dump every day that neither a level 0 nor a level 2 dump is performed.

In the worst case, how many restores would you have to perform to recover a file that was dumped using the preceding schedule?

# 17

## CONFIGURING AND MONITORING A LAN

### IN THIS CHAPTER

Setting Up the Hardware . . . . .	596
Gateways and Routers . . . . .	597
NIC: Network Interface Card . . . . .	597
Configuring the Systems . . . . .	598
The Network Configuration Window (system-config-network) . . . . .	601
iwconfig: Configures a Wireless NIC . . . . .	605
Setting Up Servers . . . . .	606
Introduction to Cacti . . . . .	607

Networks allow computers to communicate and share resources. A local area network (LAN) connects computers at one site, such as an office, home, or library, and can allow the connected computers to share an Internet connection and a printer. Of course, one of the most important reasons to set up a LAN is to allow systems to communicate while users enjoy multiplayer games.

This chapter covers the two aspects of configuring a LAN: setting up the hardware and configuring the software. This chapter is not necessarily organized in the order you will perform the tasks involved in setting up a particular LAN: Read the chapter through, figure out how you will set up your LAN, and then read the parts of the chapter in the order appropriate to your setup. The final section discusses how to monitor a network using Cacti.

## SETTING UP THE HARDWARE

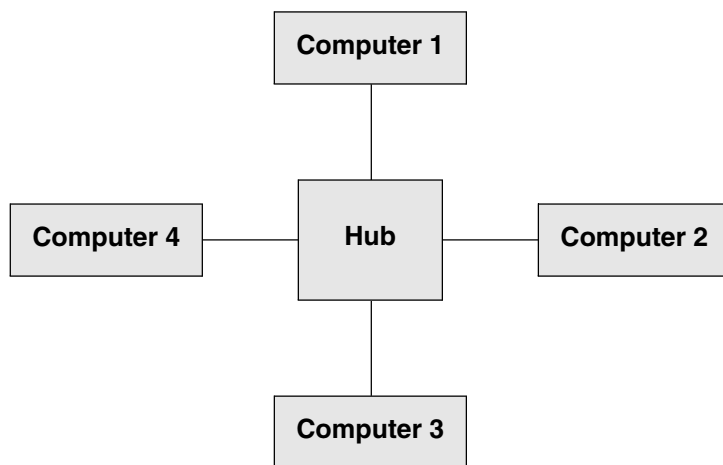
Each system, or node, on a LAN must have a network interface card (NIC). NICs can be connected to the network with cables or radio waves (wireless); in either case, each system must connect to a central hub. If the network is connected to another network, such as the Internet, it must also have a router, or gateway. The router can be either one of the systems on the LAN or a dedicated piece of hardware.

## CONNECTING THE COMPUTERS

A modern Ethernet-based LAN has a connection between each computer and a central hub. Two kinds of hubs exist: passive (sometimes just called a *hub*) and switching (called a *switch*). A passive hub simply connects all systems together and shares the network bandwidth among the systems. A switching hub puts each system on its own network with the switch and routes packets between those networks, providing each system with the full network bandwidth.

In the simple network shown in Figure 17-1, four computers are connected to a single hub. Assuming the hub is passive, when computers 1 and 2 are communicating at the same time as computers 3 and 4, each conversation is limited to a maximum of half the network bandwidth. If the hub were a switch, each conversation could use the full network bandwidth.

Usually hubs are less expensive than switches. If you plan to use the network for sharing an Internet connection and light file sharing, a hub is likely to be fast enough. If systems on the network will exchange files regularly, a switch may be more appropriate. Refer to “Ethernet” on page 361 for a discussion of switches, hubs, and cables.



**Figure 17-1** A simple network



Each computer on a LAN must be connected to the hub. If you are using more than one hub, connect the port labeled **uplink** on one hub to a normal port on another hub.

Wireless access  
point (WAP)

A wireless access point (WAP) connects a wireless network to a wired one. Typically a WAP acts as a transparent bridge, forwarding packets between the two networks as if they were one. If you connect multiple WAPs in different locations to the same wired network, wireless clients can roam transparently between the WAPs.

Wireless networks do not require a hub, although a WAP can optionally fill a similar role. In a wireless network, the bandwidth is shared among all nodes within range of one another; the maximum speed is limited by the slowest node.

## GATEWAYS AND ROUTERS

If the LAN you are setting up is connected to another network, such as the Internet, you need a router, sometimes called a gateway. A router can perform several functions, the most common of which is allowing several systems to share a single Internet connection and IP address (NAT; page 820). When a router uses NAT, the packets from each system on the LAN appear to come from a single IP address; return packets are passed back to the correct system.

You have several choices for routers:

- A simple hardware router is relatively cheap and does most things required by a small network.
- You can set up a Fedora/RHEL system as a router. The Linux kernel can use `iptables` (page 819) to route packets between network adapters.
- You can use a Linux distribution tailored for use as a router. For example, SmoothWall ([www.smoothwall.org](http://www.smoothwall.org)) provides a browser-based configuration in the style of a hardware router.

## NIC: NETWORK INTERFACE CARD

Each system's NIC may be a separate Ethernet card (wired or wireless) or the NIC may be built in to the motherboard.

Supported NICs

Linux supports most wired Ethernet NICs. Fewer wireless NICs are supported. See "More Information" on page 617 for references.

Unsupported  
wireless NICs

If a wireless network card is not supported under Linux directly, you may be able to get it to work using `NdisWrapper` ([ndiswrapper.sourceforge.net](http://ndiswrapper.sourceforge.net); also available as an rpm file from the Fedora and RHEL5 repositories at [rpmfusion.org](http://rpmfusion.org)), which uses Win32 drivers. `NdisWrapper` is a kernel module that provides a subset of the Windows network driver API. No Fedora/RHEL package contains this program.

Wireless bridge

An alternative to a wireless NIC is a wireless bridge. A wireless bridge forwards packets between wired and wireless interfaces, eliminating the need for wireless drivers. This simple device contains an Ethernet port that plugs into a NIC and an 802.11 (wireless) controller. While carrying a bridge around is usually not feasible for mobile users, it is an easy way to migrate a desktop computer to a wireless configuration.

**Mode** Wireless networks operate in either ad hoc or infrastructure mode. In ad hoc mode, individual nodes in the network communicate directly with each other. In infrastructure mode, nodes communicate via a WAP (page 597). Infrastructure mode is generally more reliable if the wireless LAN communicates with a wired LAN.

If you do not want to use a WAP, it may be possible to set up a WLAN card so it acts as a WAP; consult the NIC/driver documentation for more information.

---

## CONFIGURING THE SYSTEMS

**FEDORA** Once the hardware is in place, each system needs to be configured so that it knows about the NIC that connects it to the network. By default, Fedora uses the **Network-Manager** daemon (discussed in the next section) to collect information about and to activate the NIC.

**RHEL** The kudzu utility detects and configures new hardware and gives a RHEL system the information it needs about the NIC. The kudzu utility probes the NIC when you install RHEL or the first time you boot the system after you install a NIC. When it prompts you for information, kudzu allows you to specify only one nameserver. It is a good idea to specify at least two or three nameservers; you can use `system-config-network` to add nameservers.

**System information** In addition to information about the NIC, each system needs the following information:

- The system's IP address
- The netmask (subnet mask) for the system's address (pages 371 and 443)
- The IP address of the gateway
- The IP addresses of the nameservers (DNS addresses)
- The system's hostname (set when you install Fedora/RHEL)

If you set up a DHCP server (page 451) to distribute network configuration information to systems on the LAN, you do not need to specify the preceding information on each system; you just specify that the system is using DHCP to obtain this information. You need to specify this information when you set up the DHCP server.

**Private address space** When you set up a LAN, the IP addresses of the systems on the LAN are generally not made public on the Internet. Some special IP addresses, which are part of the *private address space* defined by IANA (page 1087), are reserved for private use and are appropriate to use on a LAN (Table 17-1). Unless you have been assigned IP addresses for the systems on the LAN, choose addresses from the private address space.

**Table 17-1** Private IP ranges (defined in RFC 1918)

Range of IP addresses	From IP address	To IP address
10.0.0.0/8	10.0.0.1	10.255.255.254
172.16.0.0/12	172.16.0.1	172.31.255.254
192.168.0.0/16	192.168.0.1	192.168.255.254

## NETWORKMANAGER: CONFIGURES NETWORK CONNECTIONS

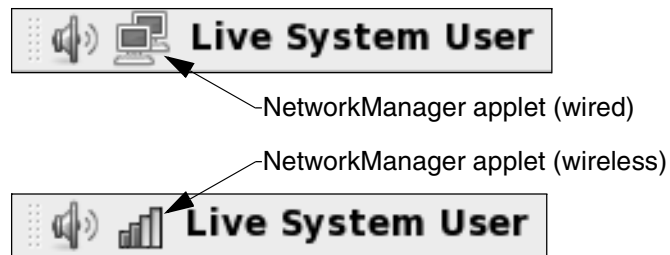
By default, the **NetworkManager** daemon manages the network. When it detects a new wired or wireless connection, it starts the appropriate interface. For a wireless connection it prompts for and stores keys and passphrases. It also detects new hardware—for example, when you plug a USB wireless adapter into the system. NetworkManager is designed for personal systems, not server systems, so it brings up the network only when a user logs in. See page 605 for information on setting up networking for server systems.

### THE NETWORKMANAGER APPLET

Under Fedora, the NetworkManager applet appears toward the right end of the Top panel. It appears as a double monitor when the system is using a wired connection and as a series of vertical bars when the system is using a wireless connection (Figure 17-2). Exactly what appears when you click the NetworkManager applet depends on the system hardware and the items that you have previously set up. Right- and left-clicking the NetworkManager applet display different menus.

#### THE NETWORKMANAGER APPLET RIGHT-CLICK MENU

Right-click the NetworkManager applet to display a menu that allows you to turn on/off networking and, if available, wireless (networking). Click either selection to

**Figure 17-2** The NetworkManager applet on the Top panel



**Figure 17-3** The Network Connections window

place or remove a tick in the check box next to the entry. A tick indicates the service is enabled. You can also select **Connection Information** to display a window showing information about the active connection or you can select **Edit Connections** (next).

### THE NETWORK CONNECTIONS WINDOW (nm-connection-editor)

Selecting **Edit Connections** from the NetworkManager applet right-click menu runs the nm-connection-editor utility, which opens the Network Connections window (Figure 17-3). Alternatively, you can give the command **nm-connection-editor** from a terminal emulator or Run Application window (ALT-F2). From this window you can modify the configuration of NICs.

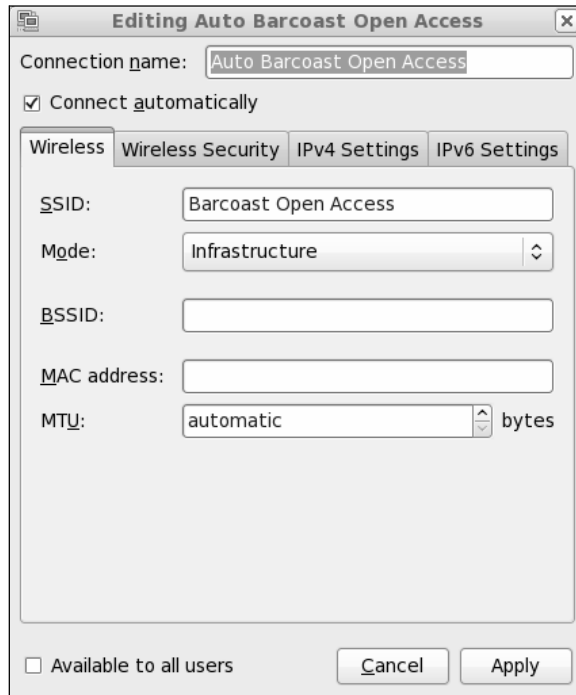
The Network Connections window has tabs that allow you to configure wired, wireless, and other types of network connections. After the system identifies and configures new network hardware, you can use this window to modify the configuration.

To modify the configuration of a NIC, select the appropriate tab, highlight the description of the connection you want to configure, and click **Edit**; nm-connection-editor displays the Editing window (Figure 17-4). The IPv4 Settings tab allows you to select DHCP or manual configuration of the connection. When you are finished working in the Editing window, click **Apply**.

**Wireless settings** It is usually easier to configure a wireless connection using the Network Configuration window (page 601) than it is to use the Editing window. To use the Editing window to configure wireless settings, click the Wireless tab and enter the appropriate information. When you are finished entering information in the Network Connections window, click **Apply**.

### THE NETWORKMANAGER APPLET LEFT-CLICK MENU

Left-clicking the NetworkManager applet displays a menu that lists the available wireless networks. It also displays selections labeled **More networks**, **Connect to**



**Figure 17-4** The Editing window (wireless connection)

**Hidden Wireless Networks**, and **Create New Wireless Network** (if the system has a wireless connection), **Wired Network**, **Disconnect**, and **VPN Connections**. In Figure 17-5 (on the next page), **Auto eth0** appears below **Wired Network** and **dis-connected** appears below **Wireless Networks**, meaning that the system is using the **eth0** wired connection and is not using a wireless connection.

Click the name of the wired network (e.g., **Auto eth0**) or the name of a wireless network (under the word **Available**) to connect to a network. The NetworkManager applet changes to two dots with a tail going around them in circles while it connects to the new network. It then displays the wireless or wired icon, as is appropriate (Figure 17-2, page 599). To disable a network, click **Disconnect** below the name of a connection you want to disable.

## THE NETWORK CONFIGURATION WINDOW (system-config-network)

To display the Network Configuration window (Figure 17-6, next page), select **Main menu: System⇒Administration⇒Network** or give the command **system-config-network** from a terminal emulator or Run Application window (ALT-F2). The **system-config-network** utility ([projects.gnome.org/NetworkManager](http://projects.gnome.org/NetworkManager); part of the package named **system-config-network**) configures network hardware. The

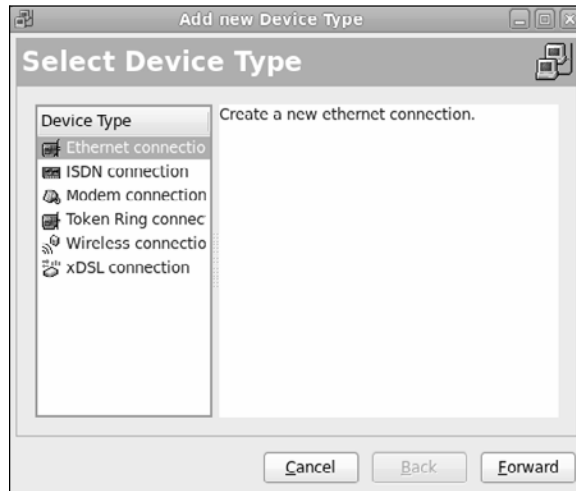


**Figure 17-5** The NetworkManager applet window

Network Configuration window has tabs on which you can specify hosts (/etc/hosts, page 472) and DNS servers (/etc/resolv.conf, page 476), as well as configure network hardware and logical devices associated with the hardware. If it is a wireless device, a tab labeled **Wireless** presents selections such as mode, ssid, channel, transmit rate, and key. Make changes in these tabs as necessary.



**Figure 17-6** The Network Configuration window, Devices tab



**Figure 17-7** The Select Device Type window

## ADDING A DEVICE

Normally the **NetworkManager** daemon identifies and adds new hardware to the system. You can then use **system-config-network** to edit the configuration information. If you need to add a NIC to the system manually, click the **Devices** tab; then click **New** on the toolbar. The utility displays the Select Device Type window (Figure 17-7).

The Select Device Type window can set up six types of connections (most of which do not pertain to setting up a LAN): Ethernet (page 361), ISDN (page 1089), modem, *token ring* (page 1111), wireless, and xDSL (page 1116). ISDN, modem, wireless, and xDSL are PPP (Point-to-Point Protocol) connections. PPP is a serial line protocol that establishes a connection between two systems, putting them on the same network. It is capable of handling several protocols, the most common of which is TCP/IP, which provides compression for increased efficiency. The two systems can then run *ssh*, *X*, or any other network application between them. Ethernet and token ring are used to connect to LANs.

Choose the type of connection you want to establish and click **Forward**. Some selections probe for information at this point. You can accept entries in the filled-in text boxes in the following window; fill in blank text boxes as appropriate. When you have finished setting up the device, click **Apply**. The Select Device Type window closes, and the Network Configuration window displays the device you just added. Follow the instructions in the next paragraph to edit the configuration information. If you are finished, click the **Devices** tab, highlight the new device, click **Menubar: File⇒Save**, and click **Activate** to bring the new device online.

## EDITING A DEVICE

To modify the device name of network hardware, such as a NIC, click the **Hardware** tab of the Network Configuration window, highlight the description of the



**Figure 17-8** The Ethernet Device window

hardware, and click **Edit** on the toolbar. The utility displays the Network Adapters Configuration window. In this window, you can change the name of the device (e.g., `eth0`). Click **OK** to accept the changes and close the window.

To modify the device represented by a piece of hardware, click the **Devices** tab, highlight the device, and click **Edit** on the toolbar. The utility displays a window appropriate to the device you are editing. For example, if you are working with an Ethernet NIC, `system-config-network` displays the Ethernet Device window (Figure 17-8).

From this window, you can set up the device to use DHCP or manually specify the necessary IP addresses. The **Hardware Device** tab allows you to associate the device with a piece of hardware and specify a *MAC address* (page 1092). When you are finished making changes, click **OK**, click the **Devices** tab, highlight the new device, and click **Menubar: File⇒Save**. Click **Activate** on the toolbar to activate the device if necessary.

The **Activate** and **Deactivate** buttons apply changes you have made to the interface. **Saving** covers only the next time the interface starts. If you have applied changes to



an active interface, you must deactivate and activate it to cause the changes to take effect immediately.

## SETTING UP NETWORKING FOR A SERVER

By default, Fedora runs NetworkManager, which brings up the network only when a user logs in on the system. The network for a server system has to be active regardless of whether anyone is logged in on the system. To set up a network that is up whenever the system is up, you must make two changes in the General tab of the Ethernet Device window: Remove the tick from the check box labeled **Controlled by NetworkManager** and put a tick in the check box labeled **Activate device when computer starts**. The first of these changes turns off NetworkManager (by giving the commands `chkconfig NetworkManager off;` `service NetworkManager stop`) and the second changes the line `onboot=no` to `onboot=yes` in `/etc/sysconfig/network-scripts/ifcfg-eth0`. With the NetworkManager disabled, the NetworkManager will have an X through it even when the network connection is up.

---

## iwconfig: CONFIGURES A WIRELESS NIC

You can configure a wireless NIC using either `nm-connection-editor` (page 600), `system-config-network` (page 601), or `iwconfig`. The `iwconfig` utility is based on `ifconfig` and configures elements of a wireless NIC not supported by `ifconfig`, such as setting up Master mode and binding a card to a WAP.

The parameters you will most commonly change with `iwconfig` are the encryption key, the mode, and the name of the network. Most devices support a minimum of 40-bit Wired Equivalent Privacy (WEP) encryption. The encryption key is defined by a string of 10 hexadecimal digits. The contents of the string are arbitrary, but must be the same on all nodes:

```
# iwconfig eth1 key 19FEB47A5B
```

The algorithm used by WEP is known to be flawed; using it does not provide much protection. If you require privacy, use an encrypted protocol, such as SSH or HTTPS. If you have difficulty connecting, disable encryption on all nodes:

```
# iwconfig eth1 key off
```

The `mode` defines whether you are connecting to an ad hoc or an infrastructure network. Normally you can set `mode` to `Auto`, which selects the correct mode automatically:

```
# iwconfig eth1 mode Auto
```

The exception occurs when you want to use the NIC as a WAP, in which case you need to set `mode` to `Master`:

```
# iwconfig eth1 mode Master
```

Not all wireless NICs are capable of acting as masters.

The network name is defined by the ESSID (Extended Service Set ID), an arbitrary string. With the ESSID set (it must be the same on every node, including the WAP), you should be able to roam between any set of nodes with the same network name:

```
# iwconfig eth1 essid "My Wireless Network"
```

See the `iwconfig` man page for more information.

---

## SETTING UP SERVERS

Setting up local clients and servers can make a LAN both easier to use and more useful. Be sure to turn off NetworkManager on server systems; see page 605. The following list briefly describes some of these tools and references the pages that describe them in detail.

- **NIS**—NIS can provide a uniform login regardless of which system you log in on. The NIS authentication server is covered on page 703 and the client on page 699. NIS is often combined with home directories mounted using NFS.
- **NFS**—NFS allows you to share directory hierarchies. Sharing directories using NFS requires that the server export the directory hierarchy (page 738) and the clients mount the hierarchy (page 730).

Using NFS, you can store all home directories on one system and mount them from other systems as needed. This configuration works well with NIS login authentication. With this setup, it can be convenient to create a world-writable directory—for example, `/home/shared`—through which users can exchange files. If you set the sticky bit (page 1108) on this directory (`chmod 1777 /home/shared`), users can delete only files they created. If you do not set the sticky bit, any user can delete any file.

- **OpenSSH**—OpenSSH tools include `ssh` (logs in on a remote system; page 627) and `scp` (copies files to/from a remote system; page 630). You can also set up automatic logins with OpenSSH: If you set up a shared home directory with NFS, each user's `~/.ssh` directory (page 623) is the same on each system. A user who sets up a personal authentication key (page 634) will be able to use OpenSSH tools between systems without entering a password. See page 633 for information on how to set up an OpenSSH server. You can just use the `ssh` and `scp` clients—you do not have to set them up.
- **DNS cache**—Setting up a local cache can reduce the traffic between the LAN and the outside world and improve response times. For more information refer to “JumpStart I: Setting Up a DNS Cache” on page 787.

- **DHCP**—DHCP enables a client system to retrieve network configuration information from a server each time it connects to a network. See page 451 for more information.
- **Samba**—Samba allows Linux systems to participate in a Windows network, sharing directories and printers, and accessing those shared by Windows systems. Samba includes a special share for accessing users' home directories. For more information refer to "The [homes] Share: Sharing Users' Home Directories" on page 765.

You can also use Samba to set up a shared directory similar to the one described under "NFS." To share a Linux directory with Windows computers, place the following code in `/etc/smb.conf` (page 760):

```
[public]
comment = Public file space
path = /home/shared
read only = no
public = yes
browseable = yes
```

Any Windows user can access this share; it can be used to exchange files between users and between Linux and Windows systems.

---

## INTRODUCTION TO CACTI

Cacti ([cacti.net](http://cacti.net)) is a network monitoring tool that graphs system and network information over time (*time-series data*) and provides a comprehensive Web interface for browsing and examining the ongoing performance of the devices on a network.

For example, you can configure Cacti to monitor the network traffic passing through the network ports on local servers and the switch and router ports on the local network. Cacti graphs provide information on traffic levels on the various parts of the network. When the network is slow, you can refer to the historical graphs and see if anything out of the ordinary has occurred. In addition to network traffic levels, Cacti can collect data on CPU utilization, disk space usage, page views on a Web server, and almost any other data points available on the local network.

Cacti collects baseline (typical) data over time. You can use that information to gain insight into the behavior of a system and network over time and help you resolve problems. The information can even predict what may happen in the future (e.g., when a disk is likely to become full).

Once installed and configured, Cacti periodically polls devices on a network for the data it needs and stores the data in RRD files for use with RRDtool (round-robin database tool; [oss.oetiker.ch/rrdtool](http://oss.oetiker.ch/rrdtool)). The Cacti Web interface allows you to browse a list of devices and graphs, and see visual representations of the devices over time.

Cacti is part of the next generation of monitoring tools. It builds on the lessons learned from tools such as MRTG ([oss.oetiker.ch/mrtg](http://oss.oetiker.ch/mrtg); page 882) and Cricket ([sourceforge.net/projects/cricket](http://sourceforge.net/projects/cricket)). Each of these tools:

- Periodically polls tracked devices for data. The method most commonly used to collect this data is via SNMP (Simple Network Management Protocol; [www.net-snmp.org](http://www.net-snmp.org)).
- Stores the data in an RRD file.
- Has a Web interface that allows you to examine graphs generated from the stored data. These graphs typically display daily, weekly, monthly, and yearly information.

Cacti's configuration is performed through its Web interface, whereas MRTG and Cricket are configured by editing text files.

RRD files and RRDtool are the key to much of Cacti's functionality. The Cacti Web site describes Cacti as "the complete RRDtool-based graphing solution." RRD files store time-series data efficiently, and through the use of aggregation functions make it easy to keep a lot of detail for recent time periods but progressively less detail as the data in the files ages. RRDtool easily generates both simple and complex graphs from RRD files.

Extending Cacti Many extensions and plugins are available for Cacti. Once you are familiar with the basic use and operation of Cacti, visit [cacti.net/additional\\_scripts.php](http://cacti.net/additional_scripts.php) for a partial list. Also visit the documentation and the user forums for more information about Cacti and how you can add functionality and support for different devices and data sources.

## CONFIGURING SNMP

If you want to monitor data sources on the local system, install and run SNMP on the local system as explained under "Setting Up a Remote Data Source" on page 614.

## SETTING UP LAMP

Cacti is a LAMP (Linux, Apache, MySQL, PHP) application; you must install and configure these applications before you can configure Cacti. This section explains how to set up the software on the system running Cacti. See "Setting Up a Remote Data Source" on page 614 for an explanation of how to set up a system that Cacti will query and report on. By default, Cacti sets up the local system to run Cacti *and* be a data source.

### NOTES

When you set up LAMP, you set up three accounts: two MySQL accounts and one Cacti account. Each of these accounts should have a password:

- A MySQL account for user named **root**. This account must be named **root**.
- A MySQL account for user named **cactiuser**. You can change this username, but as installed, Cacti is set up to use **cactiuser**.
- A Cacti administrative account for user named **admin** (initially the password is **admin**). You can set up additional Cacti user accounts.

As of this writing, the latest stable version of Cacti is 0.8.7e. Do not be misled by the pre-1.0 version number: Cacti is stable and in use on many systems.

## PREREQUISITES

Install the following packages (yum will also install many dependencies):

- **cacti**
- **mysql** (page 584)
- **mysql-server** (page 584)
- **php**
- **httpd** (Apache; page 841)
- **net-snmp** (optional; needed only to monitor the local system)
- **net-snmp-utils** (optional; includes **snmpwalk**)

**Firewall** The **snmpd** daemon, which runs on systems monitored by Cacti, uses UDP port 161. If the monitored system is running a firewall, you need to open this port (page 825). If you want to work with Cacti from a browser on a system other than the one running Cacti, you need to open TCP port 80 on the system running Cacti. For more information refer to “Firewall” on page 844. For more general information, see Chapter 25, which details the **iptables** utility.

**SELinux** When SELinux is set to use a targeted policy, both **httpd** (on the system running Cacti) and **snmpd** (on the systems being monitored) are protected by SELinux. You can disable this protection if necessary. For more information refer to “Setting the Targeted Policy with **system-config-selinux**” on page 416.

## CONFIGURING MYSQL

Install and start MySQL as explained starting at “Prerequisites” on page 585. Be sure to assign a password to the MySQL user named **root** by using either **mysql\_secure\_installation** or **mysqladmin**.

Next, use the following commands to create a database named **cacti**, create a MySQL user named **cactiuser**, grant that user the necessary privileges, and assign a password to that user. Replace *cactipassword* in the following example with your choice of a password. Although the **FLUSH PRIVILEGES** statement is not required, it is good practice to include it.

```
# mysql -p
Enter password:
Welcome to the MySQL monitor.  Commands end with ; or \g.
Your MySQL connection id is 5
Server version: 5.1.39 Source distribution

Type 'help;' or '\h' for help. Type '\c' to clear the current
input statement.

mysql> CREATE DATABASE cacti;
Query OK, 1 row affected (0.00 sec)

mysql> GRANT ALL ON cacti.*
-> TO cactiuser@localhost
-> IDENTIFIED BY 'cactipassword';
Query OK, 0 rows affected (0.00 sec)

mysql> FLUSH PRIVILEGES;
Query OK, 0 rows affected (0.00 sec)

mysql> exit
Bye
```

Give the following command to set up and populate the database named **cacti**. When MySQL prompts for a password, provide the password for the MySQL user named **root** (not the MySQL user named **cacti**).

```
# mysql -p cacti < /usr/share/doc/cacti*/cacti.sql
Enter password:
```

Most of the information in the `/etc/cacti/db.php` file is correct as installed. Edit this file to change the value assigned to `$database_password` from **cactiuser** to the same value as *cactipassword* in the preceding step (the password for the MySQL user named **cacti**). Do not change the value assigned to `$database_username`.

```
$database_type = "mysql";
$database_default = "cacti";
$database_hostname = "localhost";
$database_username = "cactiuser";
$database_password = "cactiuser";
$database_port = "3306";
```

## CONFIGURING APACHE

Install Apache as explained under “About Apache” on page 842. Modify the **httpd.conf** file as explained on page 845; if you do not make this modification, Apache will display errors when it starts but will work anyway. Run **chkconfig** and start the **httpd** daemon. Cacti supplies the content.

The `/etc/httpd/conf.d/cacti.conf` file controls the location and accessibility of Cacti on the Apache server. By default, Cacti is available as **127.0.0.1/cacti** (based on the **Alias** statement) and only a user on **127.0.0.1** (and not **localhost**; based on the **Allow from** statement) can access Cacti. The default **cacti.conf** file follows:

```
$ cat /etc/httpd/conf.d/cacti.conf
#
# Cacti: An rrd based graphing tool
```

```
#
Alias /cacti    /usr/share/cacti

<Directory /usr/share/cacti/>
    Order Deny,Allow
    Deny from all
    Allow from 127.0.0.1
</Directory>
```

To follow the example in this section, add an **Allow from localhost** line immediately below the **Allow from 127.0.0.1** line. You can add additional lines to allow access from other systems. The following `<Directory>` container allows access from 127.0.0.1, localhost, and the remote system at 10.10.4.98:

```
<Directory /usr/share/cacti/>
    Order Deny,Allow
    Deny from all
    Allow from 127.0.0.1
    Allow from localhost
    Allow from 10.10.4.98
</Directory>
```

See “Alias” (page 862), “<Directory>” (page 855), and “Allow” (page 868) for more information.

## ENABLING THE CACTI POLLER

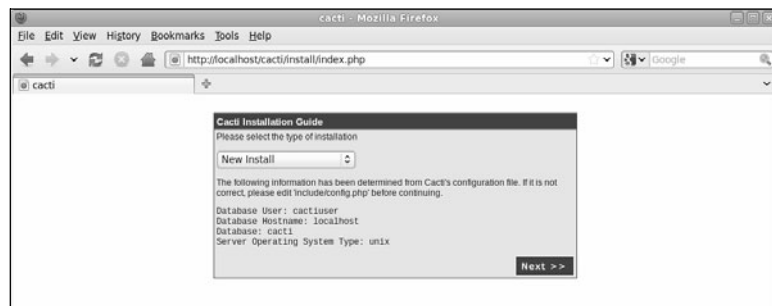
Enable the Cacti poller by removing the hash mark from the left end of the line in the `/etc/cron.d/cacti` file. The `*/5` causes **crond** to execute the script every five minutes.

```
$ cat /etc/cron.d/cacti
*/5 * * * * cacti /usr/bin/php /usr/share/cacti/poller.php > /dev/null 2>&1
```

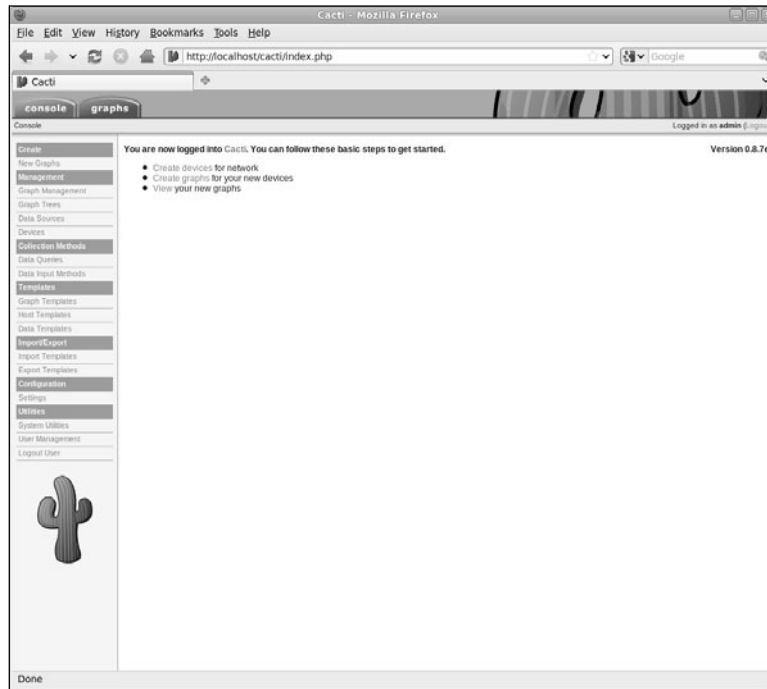
## CONFIGURING CACTI

After starting or restarting Apache, point a Web browser on the machine running Cacti at **localhost/cacti**; Apache redirects the browser to the Cacti installation page at `localhost/cacti/install` and displays the Cacti Installation Page screen. Click **Next**.

Confirm the information on the Cacti Installation Guide screen (Figure 17-9) and click **Next**.



**Figure 17-9** The Cacti Installation Guide screen



**Figure 17-10** The Cacti main Console screen

The next screen displays several file pathnames and information about which versions of Net-SNMP and RRDTool are installed. Review this information and click **Finish**.

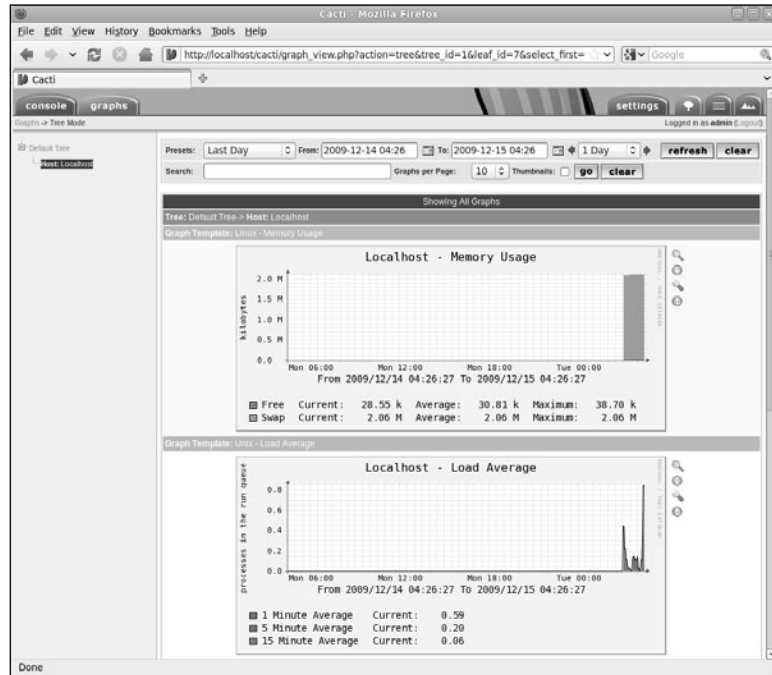
Next Cacti displays the User Login screen. Log in with the username **admin** and the password **admin**. Cacti then forces you to change the password for the Cacti user named **admin**. After you change the password, Cacti displays the main Console screen (Figure 17-10). The name of the screen appears just below the red Console tab at the upper-left corner of the screen.

## BASIC CACTI ADMINISTRATION

By default, Cacti collects data from **localhost** (the system it is installed on). Once a few poller cycles have passed (approximately 15 minutes after you added the **crond** job for Cacti), Cacti will display this information. From the main Console screen, click on **View your new graphs** or click the Graphs tab at the top of the screen. Cacti displays the default graphs in tree mode for **localhost** (Figure 17-11).

Cacti creates graphs for the following data sources: memory usage, load average, logged-in users, and number of processes. If you click one of the graphs, Cacti displays a page with four graphs for the data source you clicked: daily, weekly, monthly, and yearly. These graphs will mostly be blank until Cacti collects more data.





**Figure 17-11** Default graphs for localhost

Cacti uses RRDTool to store the data it collects and to display graphs. Cacti graphs show more detail over short time spans, and less detail (averaged, or otherwise aggregated) over longer time spans.

To zoom in on a graph, click the magnifying glass icon on the right side of a graph; Cacti displays a single graph and the mouse pointer changes to a cross hairs. Drag the cross hairs horizontally over the part of the graph that represents the time period you are interested in; Cacti regenerates the graph for that time period.

You can control the graphs using the tabs along the upper-right edge of the screen. The Settings tab allows you to set your preferences for displaying graphs; the Tree View tab displays a hierarchy of graphs, allowing you to select the devices or graphs you are interested in; the List View tab displays a list of all available graphs; and the Preview tab displays small previews of all available graphs. The List View and Preview tabs provide a filter at the top of the screen that allows you to display a subset of graphs.

## THE CACTI CONSOLE TAB

Clicking the red Console tab displays the main Console screen (Figure 17-10, page 612), from which you can manage Cacti. The main Console screen has a menu on the left side and shows the pathname of the screen it is displaying just below the red Console tab. At the upper-right corner of the screen is the name of the user (**admin**) and a Logout button.

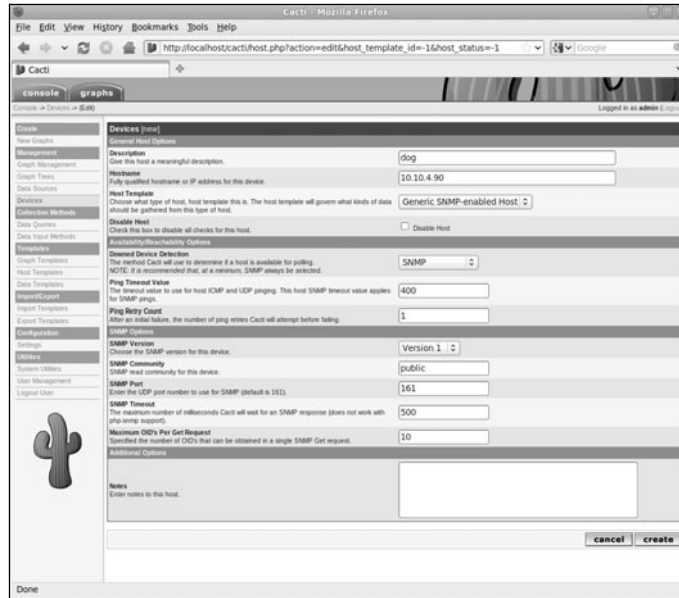


Figure 17-12 Adding a new device

## SETTING UP A REMOTE DATA SOURCE

You can set up any device that runs SNMP as a data source that Cacti can monitor and report on. This section explains how to set up a remote system on the local network as a data source and how to set up Cacti to monitor that source. Setting up a local data source is similar to setting up a remote data source.

### PREREQUISITES

Install the following packages on the remote system that Cacti will monitor:

- **net-snmp**
- **net-snmp-utils** (optional; includes `snmpwalk`)

**snmpd.conf** The `/etc/snmp/snmpd.conf` file controls the `snmpd` daemon. Save the installed `snmpd.conf` file so you can refer to it later. Set up the following `snmpd.conf` file, which sets the SNMP community to **public** and allows queries from **localhost** and **10.10.4.98** (the system running Cacti):

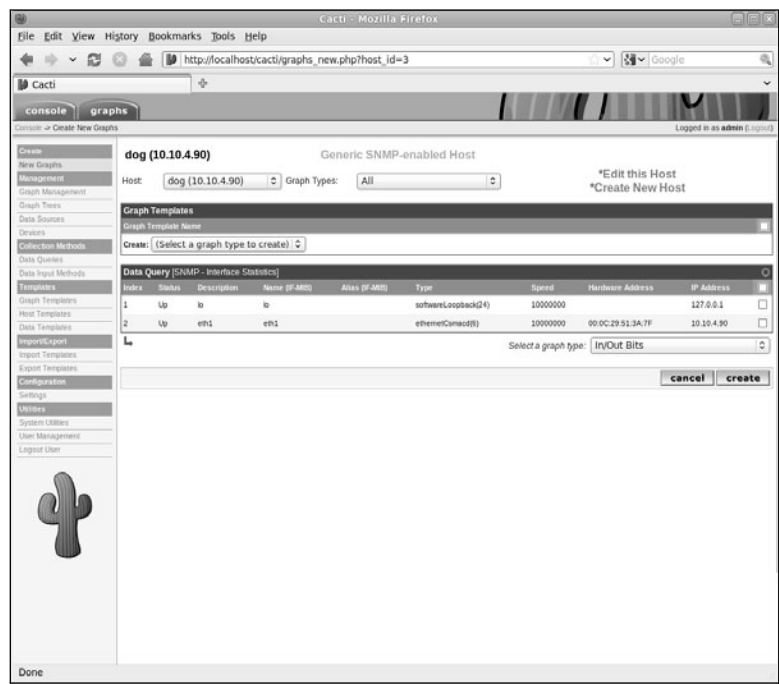
```
$ cat /etc/snmp/snmpd.conf
rocommunity public localhost
rocommunity public 10.10.4.98
```

Run `chkconfig` to cause `snmpd` to start when the system enters multiuser mode:

```
# /sbin/chkconfig snmpd on
```

**snmpd** init script Start the `snmpd` daemon:





**Figure 17-14** A list of queries/data sources for the new device

- Creating a graph Click **Create Graphs for this Host**. Cacti asks you to select colors for the graph. Click **Create**. Cacti displays a list of queries/data sources that it can graph (Figure 17-14). Put a tick in the check box at the right end of each line that holds a data source you want to create a graph for. Click **Create**. Cacti displays a message at the top of the screen that tells you which graphs it created.
- Adding a node to the graph tree Select **Management⇒Graph Trees** and click **Add** to add a node to the graph tree. Enter a name for the new node (e.g., Servers) and click **Create**.
- Now click **Add** (on the right) to add a Tree Item, select Host from the drop-down list labeled **Tree Item Type**, select the host you just added, and click **Create**.
- Wait Take a break for 10 or 15 minutes to allow Cacti to poll the new device a few times.
- Displaying the graph Click the **Graphs** tab. The name for the new node appears in the device tree on the left side of the screen. When you click the plus sign (+), Cacti expands the tree and displays the node you just added. Click the node name to display the graphs for the device (Figure 17-15).
- You can now browse through the graphs that are being generated, choose time periods you are interested in, and learn more about the behavior of the devices and networks.

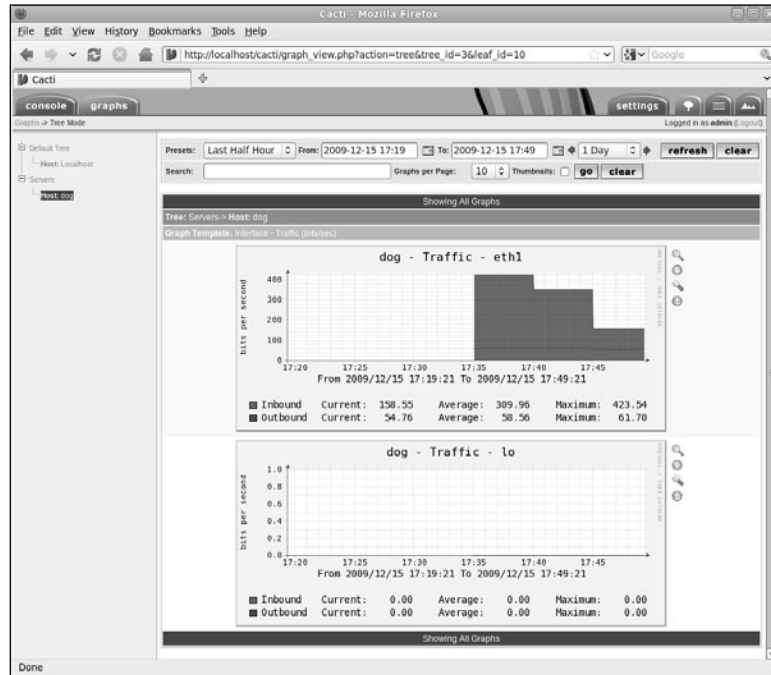


Figure 17-15 Cacti graphs for new devices

## MORE INFORMATION

Web SmoothWall Linux distribution: [www.smoothwall.org](http://www.smoothwall.org)  
 NdisWrapper: [ndiswrapper.sourceforge.net](http://ndiswrapper.sourceforge.net)  
 Hardware compatibility list: [hardware.redhat.com](http://hardware.redhat.com)  
 Cacti home page: [cacti.net](http://cacti.net)  
 RRDtool home page: [oss.oetiker.ch/rrdtool](http://oss.oetiker.ch/rrdtool)

HOWTOs *Linux Wireless Lan HOWTO*: [www.hpl.hp.com/personal/Jean\\_Tourrilhes/Linux/Wireless HOWTO](http://www.hpl.hp.com/personal/Jean_Tourrilhes/Linux/Wireless%20HOWTO)

## CHAPTER SUMMARY

A local area network (LAN) connects computers at one site and can allow the connected computers to share an Internet connection and a printer. Each system, or node, on a LAN must have a network interface card (NIC). NICs can be connected to the network via cables or radio waves (wireless).

An Ethernet-based LAN has a connection between each computer and a central hub. Two kinds of hubs exist: passive (sometimes just called a *hub*) and switching (faster, called a *switch*). A wireless access point (WAP) connects a wireless network to a wired one. If the LAN you are setting up is connected to another network, such as the Internet, you need a router (gateway) through which they can communicate. A router can perform several functions, the most common of which is allowing several systems to share a single Internet connection and IP address, called NAT.

You can configure the LAN to use NIS as a login server so that you do not have to set up accounts on each system. You can use NFS, which allows you to mount remote directory hierarchies, to set up a universal home directory. Samba is an important part of many LANs: It allows Linux systems to participate in a Windows network, sharing directories and printers, and accessing those shared by Windows systems.

Cacti is a network monitoring tool that graphs system and network information over time and provides a comprehensive Web interface for browsing and examining the ongoing performance of the devices on a network.

---

## EXERCISES

1. What advantage does a switch have over a passive hub?
2. Which server would you set up to allow users to log in with the same username and password on all computers on a LAN?
3. Name two servers that allow you to share directories between systems.
4. What is a WAP and what does it do?
5. What is a common function of a router? What is this function called?
6. What does a wireless bridge do?
7. What is NetworkManager? What does it do when you install a new NIC?
8. What is the private address space? When would you use a private address?

---

## ADVANCED EXERCISES

9. If you set a system's subnet mask to 255.255.255.0, how many computers can you put on the network without using a router?
10. Which file stores information about which DNS servers the system uses?

# **PART V**

---

## **USING CLIENTS AND SETTING UP SERVERS**

### **CHAPTER 18**

**OPENSSH: SECURE NETWORK COMMUNICATION 621**

### **CHAPTER 19**

**FTP: TRANSFERRING FILES ACROSS A NETWORK 643**

### **CHAPTER 20**

**sendmail: SETTING UP MAIL CLIENTS, SERVERS,  
AND MORE 669**

### **CHAPTER 21**

**NIS AND LDAP 695**

### **CHAPTER 22**

**NFS: SHARING FILESYSTEMS 727**

### **CHAPTER 23**

**SAMBA: INTEGRATING LINUX AND WINDOWS 749**

### **CHAPTER 24**

**DNS/BIND: TRACKING DOMAIN NAMES AND ADDRESSES 773**

### **CHAPTER 25**

**iptables: SETTING UP A FIREWALL 819**

### **CHAPTER 26**

**APACHE (httpd): SETTING UP A WEB SERVER 841**

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# OPENSASH: SECURE NETWORK COMMUNICATION

## IN THIS CHAPTER

About OpenSSH .....	622
OpenSSH Clients.....	625
JumpStart: Using ssh and scp ...	625
sshd: OpenSSH Server.....	633
JumpStart: Starting the sshd Daemon .....	633
Authorized Keys: Automatic Login.....	634
Troubleshooting .....	637
Tunneling/Port Forwarding.....	638

OpenSSH is a suite of secure network connectivity tools that replaces `telnet`, `rcp`, `rsh/rshd`, `rlogin/rlogind`, and `ftp/ftpd`. Unlike the tools it replaces, OpenSSH tools encrypt all traffic, including passwords. In this way they thwart malicious users who would eavesdrop, hijack connections, and steal passwords.

This chapter covers the following OpenSSH tools:

- `scp`—Copies files to/from another system
- `sftp`—Copies files to/from other systems (a secure replacement for `ftp`)
- `ssh`—Runs a command on or logs in on another system
- `sshd`—The OpenSSH daemon (runs on the server)
- `ssh-keygen`—Creates RSA or DSA host/user authentication keys

## INTRODUCTION

Using public key encryption (page 1045), OpenSSH provides two levels of authentication: server and client/user. First the client verifies that it is connected to the correct server. Then OpenSSH encrypts communication between the systems. Once a secure, encrypted connection has been established, OpenSSH makes sure that the user is authorized to log in on or copy files from/to the server. After verifying the system and user, OpenSSH allows different services to be passed through the connection. These services include interactive shell sessions (`ssh`), remote command execution (`ssh` and `scp`), X11 client/server connections, and TCP/IP port tunneling.

**SSH1 versus SSH2** SSH protocol version 2 (SSH2) is a complete rewrite of SSH protocol version 1 (SSH1) that offers improved security, performance, and portability. The two protocols are not compatible. Because SSH1 is being rapidly supplanted by SSH2 and because SSH1 is vulnerable to a man-in-the-middle attack (footnote 3 on page 1048), this chapter does not discuss SSH1. Because version 2 is floating-point intensive, version 1 does have a place on systems without FPUs (floating-point units or accelerators), such as old 486SX systems. As initially installed, the OpenSSH client supplied with Fedora/RHEL attempts to connect using version 2 and then version 1; the server supports version 2; see **Protocol** (page 637) if you want the server to support version 1.

**ssh** The `ssh` utility allows you to log in on a remote system over a network. You might choose to use a remote system to access a special-purpose application or to use a device that is available only on that system, or you might use a remote system because you know that it is faster or not as busy as the local computer. While traveling, many business-people use `ssh` on a laptop to log in on a system at company headquarters. From a GUI you can use several systems simultaneously by logging in on each from a different terminal emulator window.

**X11 forwarding** With X11 forwarding turned on, it is a simple matter to run an X11 program over an `ssh` connection: Run `ssh` from a terminal emulator running on a GUI and give an X11 command such as **gnome-calculator**; the graphical output appears on the local display. For more information refer to “Forwarding X11” on page 638.

---

## ABOUT OPENSASH

This section discusses configuration files used by OpenSSH clients and servers, describes how OpenSSH works, and highlights additional OpenSSH resources.

### FILES

OpenSSH clients and servers rely on many files. Global files are kept in `/etc/ssh` and user files in `~/.ssh`. In the description of each file, the first word indicates whether the client or the server uses the file.

## rhost authentication is a security risk

**caution** Although OpenSSH can get authentication information from `/etc/hosts.equiv`, `/etc/shosts.equiv`, `~/.rhosts`, and `~/.shosts`, this chapter does not cover the use of these files because they are security risks. The default settings in the `/etc/ssh/sshd_config` configuration file prevent their use.

## /etc/ssh: GLOBAL FILES

Global files listed in this section affect all users but can be overridden by files in a user's `~/.ssh` directory.

- moduli** (client and server) Contains key exchange information that OpenSSH uses to establish a secure connection. Do not modify this file.
- ssh\_config** (client) The global OpenSSH configuration file (page 631). Entries here can be overridden by entries in a user's `~/.ssh/config` file.
- sshd\_config** (server) The configuration file for `sshd` (page 636).
- ssh\_host\_dsa\_key,**  
**ssh\_host\_dsa\_key.pub**  
(server) SSH protocol version 2 DSA host keys. Both files should be owned by **root**. The `ssh_host_dsa_key.pub` public file should be readable by anyone but writable only by its owner (644 permissions). The `ssh_host_dsa_key` private file should not be readable or writable by anyone except its owner (600 permissions).
- ssh\_host\_rsa\_key,**  
**ssh\_host\_rsa\_key.pub**  
(server) SSH protocol version 2 RSA host keys. Both files should be owned by **root**. The `ssh_host_rsa_key.pub` public file should be readable by anyone but writable only by its owner (644 permissions). The `ssh_host_rsa_key` private file should not be readable or writable by anyone except its owner (600 permissions).
- ssh\_known\_hosts** (client) Contains public RSA (by default) keys of hosts that users on the local system can connect to. This file contains information similar to `~/.ssh/known_hosts`, except it is set up by the administrator and is available to all users. This file should be owned by **root** and should be readable by anyone but writable only by its owner (644 permissions).
- sshrcc** (server) Contains initialization routines. If `~/.ssh/rc` is not present, this script runs after `~/.ssh/environment` and before the user's shell starts.

## ~/.ssh: USER FILES

OpenSSH creates the `~/.ssh` directory and the `known_hosts` file therein automatically when you connect to a remote system.

- authorized\_keys** (server) Enables you to log in on or copy files from/to another system without supplying a password (page 634). No one except the owner should be able to write to this file.
- config** (client) A user's private OpenSSH configuration file (page 631). Entries here override those in `/etc/ssh/ssh_config`.

- environment** (server) Contains commands that are executed when a user logs in with `ssh`. Similar in function to `~/.bashrc` for a local `bash` shell.
- id\_dsa**, (client) User authentication DSA keys generated by `ssh-keygen` (page 634). Both files  
**id\_dsa.pub** should be owned by the user in whose home directory they appear. The **id\_dsa.pub** public file should be readable by anyone but writable only by its owner (644 permissions). The **id\_dsa** private file should not be readable or writable by anyone except its owner (600 permissions).
- id\_rsa**, (client) User authentication RSA keys generated by `ssh-keygen` (page 634). Both files  
**id\_rsa.pub** should be owned by the user in whose home directory they appear. The **id\_rsa.pub** public file should be readable by anyone but writable only by its owner (644 permissions). The **id\_rsa** private file should not be readable or writable by anyone except its owner (600 permissions).
- known\_hosts** (client) Contains public RSA keys (by default) of hosts that the user has connected to. OpenSSH automatically adds entries each time the user connects to a new server (page 626). Refer to “HostKeyAlgorithms” (page 632) for information on using DSA keys.
- rc** (server) Contains initialization routines. This script runs after **environment** and before the user’s shell starts. If this file is not present, OpenSSH runs `/etc/ssh/sshrd`; if that file does not exist, OpenSSH runs `xauth`.

## HOW OPENSASH WORKS

When OpenSSH starts, it first establishes an encrypted connection and then authenticates the user. Once these two tasks are completed, OpenSSH allows the two systems to send information back and forth.

OpenSSH uses two key pairs to negotiate an encrypted session: a *host key* pair and a *session key* pair. The host key pair is a set of public/private keys that is established the first time the server system runs `sshd` (page 633), typically the first time the system boots. The session key pair is a set of public/private keys that changes hourly.

The first time an OpenSSH client connects with an OpenSSH server, you are asked to verify that it is connected to the correct server (see “First-time authentication” on page 626). After verification, the client makes a copy of the server’s public host key. On subsequent connections, the client compares the key provided by the server with the key it stored. Although this test is not foolproof, the next one is quite secure.

The client then generates a random key, which it encrypts with both the server’s public host key and the session key. The client sends this encrypted key to the server. The server, in turn, uses its private keys to decrypt the encrypted key. This process creates a key that is known only to the client and server and is used to encrypt the rest of the session.

## MORE INFORMATION

Local man pages: `ssh`, `scp`, `ssh-keygen`, `ssh_config`, `sshd`, `sshd_config`, `ssh-copy-id`, `ssh-agent`, `ssh-add`



## SETUP

This section describes how to set up OpenSSH on the client side.

### RECOMMENDED SETTINGS

**X11 forwarding** The configuration files provided by Fedora/RHEL establish a mostly secure system and may or may not meet your needs. The important OpenSSH default value that the Fedora/RHEL configuration files override is `ForwardX11Trusted`, which is set to `yes` in the Fedora/RHEL `/etc/ssh/ssh_config` configuration file (page 637). See page 638 for more information on X11 forwarding.

### SERVER AUTHENTICATION/KNOWN HOSTS

**known\_hosts, ssh\_known\_hosts** Two files list the hosts the local system has connected to and positively identified: `~/.ssh/known_hosts` (user) and `/etc/ssh/ssh_known_hosts` (global). No one except the owner (`root` in the case of the second file) should be able to write to either of these files. No one except the owner should have any access to a `~/.ssh` directory.

**First-time authentication** When you connect to an OpenSSH server for the first time, the OpenSSH client prompts you to confirm that you are connected to the right system. This checking can help prevent a man-in-the-middle attack (footnote 3 on page 1048):

```
The authenticity of host 'grape (192.168.0.3)' can't be established.
RSA key fingerprint is c9:03:c1:9d:c2:91:55:50:e8:19:2b:f4:36:ef:73:78.
Are you sure you want to continue connecting (yes/no)? yes
Warning: Permanently added 'grape,192.168.0.3' (RSA) to the list of
known hosts.
```

Before you respond to the preceding query, make sure you are logging in on the correct system and not on an imposter. If you are not sure, a telephone call to someone who logs in on that system locally can help verify that you are on the intended system. When you answer `yes` (you must spell it out), the client appends the server's public host key (the single line in the `/etc/ssh/ssh_host_rsa_key.pub` or `/etc/ssh/ssh_host_dsa_key.pub` file on the server) to the user's `~/.ssh/known_hosts` file on the local client, creating the `~/.ssh` directory if necessary. So that it can keep track of which line in `known_hosts` applies to which server, OpenSSH prepends the name of the server and the server's IP address (by default) to the line.

When you subsequently use OpenSSH to connect to that server, the client verifies that it is connected to the correct server by comparing this key to the one the server supplies.

**known\_hosts file** The `known_hosts` file uses one very long line to identify each host it keeps track of. Each line starts with the hostname and IP address of the system the line corresponds to, followed by the type of encryption being used and the server's public host key. The following line (it is one logical line wrapped on to four physical lines) from `known_hosts` is used to connect to `grape` at 192.168.0.3 using `RSA` (page 1104) encryption:

```
$ cat ~/.ssh/known_hosts
grape,192.168.0.3 ssh-rsa AAAAB3NzaC1yc2EAAAABIwAAAIEAriPGsaLUtnSL4V7b
T51ksF7KoScsIk7wqm+2sJEC43rxVNS5+MO/064UXp5qQOHBmeLCCFCsIJg8xseuVkg9iwO
BKKOd1ZdBNVqFS7tnJdBQTFf+ofPIDDip8w6ftH0dM8hZ/diQq5gXqMH+Mpac31pQXAxXgY
SP8NYIgb3X18=
```

OpenSSH automatically stores keys from servers it has connected to in user-private files (`~/.ssh/known_hosts`). These files work only for the user whose directory they appear in. Working as **root** and using a text editor, you can copy lines from a user's private list of known hosts to the public list in `/etc/ssh/ssh_known_hosts` to make a server known globally on the local system. For more information, refer to the **ssh** man page and search for **KNOWN**.

If, after a remote system's public key is stored in one of the known hosts files, the remote system supplies a different fingerprint when the systems connect, OpenSSH displays the following message and does not complete the connection:

```
@@
@  WARNING: REMOTE HOST IDENTIFICATION HAS CHANGED!  @
@@
IT IS POSSIBLE THAT SOMEONE IS DOING SOMETHING NASTY!
Someone could be eavesdropping on you right now (man-in-the-middle attack)!
It is also possible that the RSA host key has just been changed.
The fingerprint for the RSA key sent by the remote host is
f1:6f:ea:87:bb:1b:df:cd:e3:45:24:60:d3:25:b1:0a.
Please contact your system administrator.
Add correct host key in /home/sam/.ssh/known_hosts to get rid of this message.
Offending key in /home/sam/.ssh/known_hosts:1
RSA host key for grape has changed and you have requested strict checking.
Host key verification failed.
```

If you see this message, you may be the subject of a man-in-the-middle attack. It is more likely, however, that something on the remote system has changed, causing it to supply a new fingerprint. Check with the remote system's administrator. If all is well, remove the offending key from the specified file (the third line from the bottom in the preceding example points to the line you need to remove) and try connecting again. You will see the first-time authentication (page 626) again as OpenSSH verifies that you are connecting to the correct system. Follow the same steps as when you initially connected to the remote host.

## ssh: CONNECTS TO OR EXECUTES COMMANDS ON A REMOTE SYSTEM

The format of an **ssh** command line is

```
ssh [options] [user@]host [command]
```

where **host**, the name of the OpenSSH server you want to connect to, is the only required argument. The **host** can be a local system name, an FQDN of a system on the Internet, or an IP address. Give the command **ssh host** to log in on the remote

system *host* with the same username that you are using on the local system. Include *user@* when you want to log in with a username other than the one you are using on the local system. Depending on how things are set up, you may need to supply your password.

Opening a remote shell Without *command*, ssh logs you in on *host*. The remote system displays a shell prompt and you can run commands on *host*. Give the command *exit* to close the connection to *host* and return to the local system's prompt:

```
[bravo]$ ssh speedy
alex@speedy's password:
Last login: Sat Sep 16 06:51:59 from bravo
Have a lot of fun...
You have new mail.
[speedy]$
...
[speedy]$ exit
Connection to speedy closed.
[bravo]$
```

Running a remote command When you include *command*, ssh logs in on *host*, executes *command*, closes the connection to *host*, and returns control to the local system. The remote system never displays a prompt.

The following example runs *ls* in the *memos* directory on the remote system *speedy*. The example assumes that the user running the command (Alex) has a login on *speedy* and that the *memos* directory is in Alex's home directory on *speedy*:

```
[bravo]$ ssh speedy ls memos
alex@speedy's password:
memo.0921
memo.draft
[bravo]$
```

For the next example, assume a file named *memo.new* is in the working directory on the local system (*bravo*). You cannot remember whether this file contains certain changes or whether you made these changes to the file named *memo.draft* on *speedy*. You could copy *memo.draft* to the local system and run *diff* (page 157) on the two files, but then you would have three similar copies of the file spread across two systems. If you are not careful about removing the old copies when you are done, you may just become confused again in a few days. Instead of copying the file, you can use ssh:

```
[bravo]$ ssh speedy cat memos/memo.draft | diff memos.new -
```

When you run *ssh*, standard output of the command run on the remote system is passed to the local shell as though the command had been run in place on the local system. As with all shell commands, you must quote special characters that you do not want the local system to interpret. In the preceding example, the output of the *cat* command on *speedy* is sent through a pipe on *bravo* to *diff* (running on *bravo*), which compares the local file *memos.new* to standard input (*-*). The following command line has the same effect but causes *diff* to run on the remote system:



```
[bravo]$ cat memos.new | ssh speedy diff - memos/memo.draft
```

Standard output from `diff` on the remote system is sent to the local shell, which displays it on the screen (because it is not redirected).

## OPTIONS

This section describes some of the options you can use with `ssh`.

- C (**compression**) Enables compression. (In the commercial version of `ssh`, –C disables compression and +C enables compression.)
- f (**not foreground**) Sends `ssh` to the background after asking for a password and before executing the *command*. Useful when you want to run the *command* in the background but must supply a password. Implies –n.
- L Forwards a port on the local client to a remote system. For more information refer to “Tunneling/Port Forwarding” on page 638.
- l *user* (**login**) Attempts to log in as *user*.
  - n (**null**) Redirects standard input to `ssh` to come from `/dev/null`. Required when running `ssh` in the background.
- o *option* (**option**) Specifies *option* in the format used in configuration files (page 631).
  - p (**port**) Specifies the port on the remote host that the connection is made to. Using the **host** declaration (page 632) in the configuration file, you can specify a different port for each system you connect to.
  - R Forwards a port on the remote system to the local client. For more information refer to “Tunneling/Port Forwarding” on page 638.
  - t (**tty**) Allocates a pseudo-tty to the `ssh` process on the remote system. Without this option, when you run a command on a remote system, `ssh` does not allocate a tty (terminal) to the process. Instead, `ssh` attaches standard input and standard output of the remote process to the `ssh` session—that is normally, but not always, what you want. This option forces `ssh` to allocate a tty on the remote system so programs that require a tty will work.
  - v (**verbose**) Displays debugging messages about the connection and transfer. Useful if things are not going as expected.
  - X (**X11**) Turns on nontrusted X11 forwarding. This option is not necessary if you turn on X11 nontrusted forwarding in the configuration file. For more information refer to “Forwarding X11” on page 638.
  - x (**X11**) Turns off X11 forwarding.
  - Y (**X11trusted**) Turns on trusted X11 forwarding. This option is not necessary if you turn on trusted X11 forwarding in the configuration file. For more information refer to “Forwarding X11” on page 638.

## scp: COPIES FILES FROM/TO A REMOTE SYSTEM

The `scp` (secure copy) utility copies an ordinary or directory file from one system to another on a network. This utility uses `ssh` to transfer files and employs the same authentication mechanism as `ssh`; thus it provides the same security as `ssh`. The `scp` utility asks you for a password when one is required. The format of an `scp` command is

```
scp [[user@]from-host:]source-file [[user@]to-host:][destination-file]
```

where *from-host* is the name of the system you are copying files from and *to-host* is the system you are copying to. The *from-host* and *to-host* arguments can be local system names, *FQDNs* (page 1083) of systems on the Internet, or IP addresses. When you do not specify a host, `scp` assumes the local system. The *user* on either system defaults to the user on the local system who is giving the command; you can specify a different user with *user@*. The `scp` utility can copy between two remote systems.

The *source-file* is the file you are copying, and the *destination-file* is the resulting copy. Make sure that you have read permission for the file you are copying and write permission for the directory you are copying it into. You can specify plain or directory files as relative or absolute pathnames. (A relative pathname is relative to the specified or implicit user's home directory.) When the *source-file* is a directory, you must use the `-r` option to copy its contents. When the *destination-file* is a directory, each of the source files maintains its simple filename. When the *destination-file* is missing, `scp` assumes the user's home directory.

Sam has an alternate username, `sls`, on `grape`. In the following example, Sam uses `scp` to copy `memo.txt` from the home directory of his `sls` account on `grape` to the `allmemos` directory in the working directory on the local system. If `allmemos` was not the name of a directory, `memo.txt` would be copied to a file named `allmemos` in the working directory.

```
$ scp sls@grape:memo.txt allmemos
sls@grape's password:
memo.txt          100% |*****| 14664      00:00
```

As the transfer progresses, the percent and number of bytes transferred increase and the time remaining decreases. The asterisks provide a visual representation of the progress of the transfer.

In the next example, Sam, while working from `peach`, copies the same file as in the previous example to the directory named `old` in Sam's home directory on `speedy`. For this example to work, Sam must be able to use `ssh` to log in on `speedy` from `grape` without using a password. For more information refer to "Authorized Keys: Automatic Login" on page 634.

```
$ [sam@peach] scp sls@grape:memo.txt speedy:old
sam@grape's password:
```

## OPTIONS

This section describes some of the options you can use with `scp`.

- `-C` (**compression**) Enables compression.
- `-o option` (**option**) Specifies *option* in the format used in configuration files (discussed shortly).
- `-P port` (**port**) Connects to port *port* on the remote host.
- `-p` (**preserve**) Preserves the modification and access times as well as the modes of the original file.
- `-q` (**quiet**) Does not display the progress meter.
- `-r` (**recursive**) Recursively copies a directory hierarchy.
- `-v` (**verbose**) Displays debugging messages about the connection and transfer. Useful if things are not going as expected.

## sftp: A SECURE FTP CLIENT

As part of OpenSSH, Fedora/RHEL provides `sftp`, a secure alternative to `ftp` (page 643). Functionally the same as `ftp`, `sftp` maps `ftp` commands into OpenSSH commands. You can replace `ftp` with `sftp` when you are logging in on a server that is running the OpenSSH daemon, `sshd`. Once you are connected to a system with `sftp`, give the command `?` to display a list of commands. For secure communication, use `sftp` or `scp` to perform all file transfers requiring authentication. Refer to the `sftp` man page for more information.

## ~/.ssh/config AND /etc/ssh/ssh\_config CONFIGURATION FILES

It is rarely necessary to modify OpenSSH client configuration files. For a given user there may be two configuration files: `~/.ssh/config` (user) and `/etc/ssh/ssh_config` (global). These files are read in this order and, for a given parameter, the first one found is the one that is used. A user can override a global parameter setting by setting the same parameter in his user configuration file. Parameters given on the `ssh` or `scp` command line take precedence over parameters set in either of these files.

A user's `~/.ssh/config` file must be owned by the user (the owner of the `~/` directory) and must not be writable by anyone except the owner; if it is, the client will exit with an error message. This file is typically set to mode 600 as there is no reason for anyone except its owner to be able to read it.

Lines in the configuration files contain declarations that start with a keyword, which is not case sensitive, followed by whitespace, and end with case-sensitive arguments.

You can use the **Host** keyword to cause declarations to apply to a specific system. A Host declaration applies to all the lines between it and the next Host declaration. You can use `*` and `?` wildcards within a hostname.

**Host *hostnames*** Specifies that the following declarations, until the next Host declaration, apply to *hostnames* only. The *hostnames* should be in the same form you would use on a command line and can contain ? and \* wildcards. A single \* specifies all hosts.

**CheckHostIP** yes | no

Uses an IP address in addition to a hostname to identify a system in the **known\_hosts** file when set to **yes** (default). Set to **no** to use a hostname only.

**ForwardX11** yes | no

When set to **yes**, automatically forwards X11 connections over a secure channel in nontrusted mode and sets the **DISPLAY** shell variable. Alternatively, you can use **-X** on the command line to redirect X11 connections in nontrusted mode. The default value for this parameter is **no**. For X11 forwarding to work, **X11Forwarding** must also be set to **yes** in the **/etc/sshd\_config** file on the server (page 637). For more information refer to “Forwarding X11” on page 638.

**ForwardX11Trusted** yes | no

When set to **yes**, automatically forwards X11 connections over a secure channel in trusted mode and sets the **DISPLAY** shell variable. Alternatively, you can use **-Y** on the command line to redirect X11 connections in trusted mode. The default value for this parameter is **no** but Fedora/RHEL sets it to **yes**. For X11 forwarding to work, **ForwardX11** must also be set to **yes** on the client (above) and **X11Forwarding** must be set to **yes** in the **/etc/sshd\_config** file on the server (page 637). For more information refer to “Forwarding X11” on page 638.

**HostbasedAuthentication** yes | no

Tries **rhhosts** authentication when set to **yes**. For a more secure system, set to **no** (default).

**HostKeyAlgorithms** *algorithms*

The *algorithms* is a comma-separated list of algorithms that the client uses in order of preference. Choose *algorithms* from **ssh-rsa** or **ssh-dss** (default is **ssh-rsa,ssh-dss**).

**StrictHostKeyChecking** yes | no | ask

Determines whether and how OpenSSH adds host keys to a user’s **known\_hosts** file. Set to **ask** (default) to ask whether to add a host key when connecting to a new system, set to **no** to add a host key automatically, and set to **yes** to require that host keys be added manually. The **yes** and **ask** arguments cause OpenSSH to refuse to connect to a system whose host key has changed. For a more secure system, set to **yes** or **ask**.

**TCPKeepAlive** yes | no

Periodically checks whether a connection is alive when set to **yes** (default). This checking causes the **ssh** or **scp** connection to be dropped when the server crashes or the connection dies for another reason, even if it is only temporary. Setting this parameter to **no** causes the client not to check whether the connection is alive.

This declaration uses the TCP **keepalive** option, which is not encrypted and is susceptible to *IP spoofing* (page 1089). Refer to “ClientAliveInterval” on page 636 for a server-based nonspoofable alternative.

- User *name*** Specifies a username to use when logging in on a system. Specify systems with the Host declaration. This option means that you do not have to enter a username on the command line when you are using a username that differs from your username on the local system.
- VisualHostKey *yes* | *no*** Displays an ASCII art representation of the key of the remote system in addition to displaying the hexadecimal representation of the key when set to **yes**. See *ssh-keygen* on page 634 for an example. When set to **no** (default), this declaration displays the hexadecimal key only.

---

## sshd: OPENSsh SERVER

This section discusses how to set up an OpenSSH server.

### PREREQUISITES

Install the following packages:

- openssh
- openssh-server

Run *chkconfig* to cause **sshd** to start when the system enters multiuser mode:

```
# /sbin/chkconfig sshd on
```

See “Starting **sshd** for the First Time” (page 634) for information on starting the server for the first time.

### NOTES

- Firewall** An OpenSSH server normally uses TCP port 22. If the OpenSSH server system is running a firewall, you need to open this port. Using the Firewall Configuration window Trusted Services tab (page 824), put a check in the box labeled **SSH** to open this port. For more general information see Chapter 25, which details *iptables*.
- SELinux** When SELinux is set to use a targeted policy, **sshd** is protected by SELinux. You can disable this protection if necessary. For more information refer to “Setting the Targeted Policy with *system-config-selinux*” on page 416.

### JUMPSTART: STARTING THE sshd DAEMON

Install the requisite packages and start the **sshd** daemon as described following. Look in */var/log/secure* to make sure everything is working properly.

## RECOMMENDED SETTINGS

The configuration files provided by Fedora/RHEL establish a mostly secure system and may or may not meet your needs. The Fedora/RHEL `/etc/ssh/sshd_config` file turns on X11 forwarding (page 638). For a more secure system, you can set `PermitRootLogin` to `no`, thereby removing a known-name, privileged account that is exposed to the outside world with only password protection.

## STARTING sshd FOR THE FIRST TIME

When you start the `sshd` OpenSSH daemon for the first time, generally when you first boot the system after installation, it automatically creates host key files (page 623) in `/etc/ssh`:

```
# /sbin/service sshd start
Generating SSH1 RSA host key:      [ OK ]
Generating SSH2 RSA host key:      [ OK ]
Generating SSH2 DSA host key:      [ OK ]
Starting sshd:                     [ OK ]
```

OpenSSH uses the files it creates to identify the server.

## AUTHORIZED KEYS: AUTOMATIC LOGIN

You can configure OpenSSH so you do not have to enter a password each time you connect to a remote system. To set things up, you need to generate a personal authentication key, place the public part of the key on the remote server, and keep the private part of the key on the local client. When you connect, the remote system issues a challenge based on the public part of the key. The private part of the key is required to respond properly to the challenge. If the local system provides the appropriate response, the remote system logs you in.

The first step in setting up an automatic login is to generate your personal authentication keys. Check whether these authentication keys already exist: Look in `~/.ssh` for either `id_dsa` and `id_dsa.pub` or `id_rsa` and `id_rsa.pub`. If one of these pairs of files is present, skip the next step (do not create a new key).

On the client, the `ssh-keygen` utility creates the public and private parts of an RSA key. The key's randomart image is a visual representation of the public key; it is designed to be easy to recall. Display of the randomart image by a client is controlled by the `VisualHostKey` declaration (page 633) in the `ssh_config` file.

```
ssh-keygen $ ssh-keygen -t rsa
Generating public/private rsa key pair.
Enter file in which to save the key (/home/sam/.ssh/id_rsa): RETURN
Created directory '/home/sam/.ssh'.
Enter passphrase (empty for no passphrase): RETURN
Enter same passphrase again: RETURN
Your identification has been saved in /home/sam/.ssh/id_rsa.
Your public key has been saved in /home/sam/.ssh/id_rsa.pub.
The key fingerprint is:
f2:eb:c8:fe:ed:fd:32:98:e8:24:5a:76:1d:0e:fd:1d sam@peach
```

The key's randomart image is:

```

+--[ RSA 2048 ]-----+
|      .. o o..o |
|      .o + .+. |
|      o o .. o |
|      o.   .E |
|      S    . . |
|              = o |
|              = +. |
|              = o . |
|              ..+ |
+-----+

```

Replace **rsa** with **dsa** to generate DSA keys. In this example, the user pressed RETURN in response to each query. You have the option of specifying a passphrase (10–30 characters is a good length) to encrypt the private part of the key. There is no way to recover a lost passphrase. See the following security tip for more information about the passphrase.

The **ssh-keygen** utility generates two keys: a private key or identification in **~/.ssh/id\_rsa** and a public key in **~/.ssh/id\_rsa.pub**. No one except the owner should be able to write to either of these files. Only the owner should be able to read from the private key file.

**authorized\_keys** To enable you to log in on or copy files from/to another system without supplying a password, first create a **~/.ssh** directory with permissions set to 700 on the remote system. Next copy **~/.ssh/id\_rsa.pub** on the local system to a file named **~/.ssh/authorized\_keys** on the remote system. No one except the owner should be able to read from or write to this file. Now when you run **ssh** or **scp** to access the remote system, you do not have to supply a password. To make the system even more secure, you can disable password authentication by setting **PasswordAuthentication** to **no** in **/etc/ssh/config**.

### When you encrypt your personal key

**security** The private part of the key is kept in a file that only you can read. If a malicious user compromises either your account or the **root** account on the local system, that user then has access to your account on the remote system because she can read the private part of your personal key.

Encrypting the private part of your personal key protects the key and, therefore, restricts access to the remote system should someone compromise your local account. Fedora/RHEL default to having **ssh-agent** running when a user logs in under GNOME. After logging in under RHEL, a user can use **ssh-add** to store a passphrase for a private key. On Fedora, GNOME prompts for the passphrase the first time it is used and adds it to **ssh-agent**. Each additional use of the key during that session obtains the passphrase from **ssh-agent** without prompting the user. When the user logs out, the passphrase is removed from memory and the first use of the next session requires the user to enter the passphrase again. If there is not a GUI with **ssh-agent** already running, a user can run **ssh-agent** manually.

## COMMAND-LINE OPTIONS

Command-line options override declarations in the configuration files. Following are descriptions of some of the more useful **sshd** options.

- d (debug)** Sets debug mode wherein **sshd** sends debugging messages to the system log and the server stays in the foreground. You can specify this option up to three times to increase the verbosity of the output. See also **-e**. (The **ssh** client uses **-v** for debugging; see page 629.)
- e (error)** Sends output to standard error, not to the system log. Useful with **-d**.
- f file (file)** Specifies the file with the pathname *file* as the default configuration file instead of **/etc/ssh/sshd\_config**.
- t (test)** Checks the configuration file syntax and the sanity of the key files.
- D (noDetach)** Keeps **sshd** in the foreground. Useful for debugging; implied by **-d**.

## /etc/ssh/sshd\_config CONFIGURATION FILE

The **/etc/ssh/sshd\_config** configuration file contains one-line declarations that start with a keyword, which is not case sensitive, followed by whitespace, and end with case-sensitive arguments.

### AllowUsers *userlist*

The *userlist* is a SPACE-separated list of usernames that specifies users who are allowed to log in using **sshd**. This list can include **\*** and **?** wildcards. You can specify a user as *user* or *user@host*. If you use the second format, make sure that you specify the host as returned by **hostname**. Without this declaration, any user who can log in locally can log in using an OpenSSH client.

### ClientAliveCountMax *n*

The *n* specifies the number of client-alive messages that can be sent without receiving a response before **sshd** disconnects from the client. See **ClientAliveInterval**. Default is 3.

### ClientAliveInterval *n*

Sends a message through the encrypted channel after *n* seconds of not receiving a message from the client. See **ClientAliveCountMax**. Default is 0, meaning that no messages are sent.

This declaration passes messages over the encrypted channel and is not susceptible to *IP spoofing* (page 1089). It differs from **TCPKeepAlive**, which uses the **TCP keepalive** option and is susceptible to IP spoofing.

### HostbasedAuthentication yes | no

Tries **rhosts** authentication when set to **yes**. For a more secure system, set to **no** (default).

### IgnoreRhosts yes | no

Ignores **.rhosts** and **.shosts** files for authentication. Does not affect the use of **/etc/hosts.equiv** and **/etc/ssh/shosts.equiv** files for authentication. For a more secure system, set to **yes** (default).



**LoginGraceTime *n***

Waits *n* seconds for a user to log in on the server before disconnecting. A value of 0 means there is no time limit. The default is 120.

**LogLevel *val*** Specifies how detailed the log messages are. Choose *val* from QUIET, FATAL, ERROR, INFO, and VERBOSE. The default is INFO.

**PasswordAuthentication**

Permits a user to use a password for authentication. Default is **yes**.

**PermitEmptyPasswords**

Permits a user to log in on an account that has an empty password. Default is **no**.

**Protocol** Specifies which protocols the server accepts, 1 and/or 2. Separate 1 and 2 with a comma if you want to specify both protocols. The default is 2. For more information refer to “SSH1 versus SSH2” on page 622.

**PermitRootLogin** Permits **root** to log in using an OpenSSH client. For a more secure system, set to **no**. The default is **yes**.

**StrictModes yes | no**

Checks modes and ownership of user’s home directory and files. Login fails if the directories and/or files can be written to by anyone. For security, set to **yes** (default).

**TCPKeepAlive yes | no**

Periodically checks whether a connection is alive when set to **yes** (default). Checking causes the **ssh** or **scp** connection to be dropped when the client crashes or the connection dies for another reason, even if it is only temporary. Setting this parameter to **no** causes the server not to check whether the connection is alive.

This declaration uses the TCP **keepalive** option, which is not encrypted and is susceptible to *IP spoofing* (page 1089). Refer to **ClientAliveInterval** (page 636) for a nonspoofable alternative.

**X11Forwarding yes | no**

Allows X11 forwarding when set to **yes**. The default is **no**, but Fedora/RHEL sets **X11Forwarding** to **yes**. For X11 forwarding to work, the **ForwardX11** declaration or the **ForwardX11Trusted** declaration must also be set to **yes** in either the `~/.ssh/config` or `/etc/ssh/ssh_config` client configuration file (page 632). For more information refer to “Forwarding X11” on page 638.

---

## TROUBLESHOOTING

**Log files** There are several places to look for clues when you have a problem connecting with **ssh** or **scp**. First look for **sshd** entries in `/var/log/secure` and `/var/log/messages` on the server. Following are messages you may see when you are using an **AllowUsers** declaration but have not included the user who is trying to log in (page 636):

```
# grep sshd /var/log/secure
grape sshd[16]: User sam not allowed because not listed in AllowUsers
grape sshd[16]: Failed password for illegal user sam from 192.168.0.6 port 59276 ssh2
```

The next messages originate with PAM (page 458) and indicate that the user is not known to the system:

```
# grep sshd /var/log/messages
grape sshd(pam_unix)[2817]: check pass; user unknown
grape sshd(pam_unix)[2817]: authentication failure; logname= uid=0
euid=0 tty=NODEVssh ruser= rhost=peach.sobell.com
```

**Debug the client** If entries in these files do not help solve the problem, try connecting with the `-v` option (either `ssh` or `scp`—the results should be the same). OpenSSH displays a lot of messages and one of them may help you figure out what the problem is.

```
$ ssh -v grape
OpenSSH_5.2p1, OpenSSL 1.0.0-fips-beta4 10 Nov 2009
debug1: Reading configuration data /etc/ssh/ssh_config
debug1: Applying options for *
debug1: Connecting to grape [192.168.0.3] port 22.
debug1: Connection established.
debug1: identity file /home/sam/.ssh/identity type -1
debug1: identity file /home/sam/.ssh/id_rsa type 1
...
debug1: Host 'grape' is known and matches the RSA host key.
debug1: Found key in /home/sam/.ssh/known_hosts:2
debug1: ssh_rsa_verify: signature correct
...
debug1: Authentications that can continue: publickey,password,keyboard-interactive
debug1: Trying private key: /home/sam/.ssh/id_dsa
debug1: Next authentication method: keyboard-interactive
debug1: Authentications that can continue: publickey,password,keyboard-interactive
debug1: Next authentication method: password
sam@grape's password:
```

**Debug the server** You can debug from the server side by running `sshd` with the `-de` options. The server will run in the foreground and its display may help you solve the problem.

---

## TUNNELING/PORT FORWARDING

The `ssh` utility allows you to forward a port (*port forwarding*, page 1099) through the encrypted connection it establishes. Because the data sent across the forwarded port uses the encrypted `ssh` connection as its data link layer (page 365), the term *tunneling* (page 1112) is applied to this type of connection: “The connection is tunneled through `ssh`.” You can secure protocols—including POP, X, IMAP, and WWW—by tunneling them through `ssh`.

**Forwarding X11** The `ssh` utility makes it easy to tunnel the X11 protocol. For X11 tunneling to work, you must enable it on both the server and the client. On the server, you enable X11 forwarding by setting the `X11Forwarding` declaration to `yes` in the `/etc/ssh/sshd_config` file (page 637).

**Trusted clients** In the past there was only one way for a client to enable X11 forwarding; today there are two ways. Previously, when you enabled X11 forwarding (by setting

ForwardX11 to **yes** in a configuration file or by using the **-X** option on the **ssh** command line) on a client, the client connected as a trusted client, which meant that the client trusted the server, and was given full access to the X11 display. With full access to the X11 display, in some situations a client may be able to modify other clients of the X display. Make a secure connection only when you trust the remote system. (You do not want someone tampering with your client.) If this concept is confusing, see the tip “The roles of X client and server may be counterintuitive” on page 257.

**Nontrusted clients** As of Fedora Core 3 and RHEL version 4 (OpenSSH 3.8 and later), an **ssh** client can connect to an **ssh** server as a trusted client or as a nontrusted client. A nontrusted client is given limited access to the X11 display and cannot modify other clients of the X display.

Few clients work properly when they are run in nontrusted mode. If you are running an X client in nontrusted mode and you encounter problems, try running in trusted mode (assuming you trust the remote system). Fedora/RHEL sets up **ssh** clients to run in trusted mode by default.

**Running ssh** When you start an **ssh** client, you can use the **-Y** option (page 629) on the command line to start the client in trusted mode. This option performs the same function as the **-X** option did in earlier versions of **ssh**. Or you can set the **ForwardX11trusted** declaration to **yes** in a user’s **~/.ssh/config** configuration file (page 632) or, working as **root**, you can set **ForwardX11trusted** to **yes** in the global **/etc/ssh/ssh\_config** file (page 632) to enable trusted X11 tunneling.

To use nontrusted tunneling you can use the **-X** option (page 629) or set the **ForwardX11** declaration to **yes** in one of the configuration files (page 632).

With X11 forwarding turned on, **ssh** tunnels the X11 protocol, setting the **DISPLAY** environment variable on the system it connects to and forwarding the required port. You must have the **DISPLAY** variable set. Typically you will be running from a GUI, which usually means that you are using **ssh** on a terminal emulator to connect to a remote system. When you give an X11 command from an **ssh** prompt, OpenSSH creates a new secure channel that carries the X11 data. The graphical output from the X11 program appears on your screen.

```
[peach] $ ssh speedy
[speedy] $ echo $DISPLAY
localhost:10.0
```

By default, **ssh** uses X Window System display numbers 10 and higher (port numbers 6010 and higher) for forwarded X sessions. Once you connect to a remote system using **ssh**, you can give a command to run an X application. The application will then run on the remote system with its display appearing on the local system, so that it appears to run locally.

**Port forwarding** You can forward arbitrary ports using the **-L** and **-R** options. The **-L** option forwards a local port to a remote system, so that a program that tries to connect to the forwarded port on the local system transparently connects to the remote system. The **-R** option does the reverse: It forwards remote ports to the local system. The **-N**

option, which prevents ssh from executing remote commands, is generally used with **-L** and **-R**. When you specify **-N**, ssh works only as a private network to forward ports. An ssh command line using one of these options has the following format:

```
$ ssh -N -L | -R local-port:remote-host:remote-port target
```

where *local-port* is the number of the local port that is being forwarded to or from *remote-host*, *remote-host* is the name or IP address of the system that *local-port* gets forwarded to or from, *remote-port* is the number of the port on *remote-host* that is being forwarded from or to the local system, and *target* is the name or IP address of the system ssh connects to.

As an example, assume that there is a POP mail client on the local system and that the POP server is on a remote network, on a system named **pophost**. POP is not a secure protocol; passwords are sent in cleartext each time the client connects to the server. You can make it more secure by tunneling POP through ssh (POP-3 connects on port 110; port 1550 is an arbitrary port on the local system):

```
$ ssh -N -L 1550:pophost:110 pophost
```

After giving the preceding command, you can point the POP client at **localhost:1550**, and the connection between the client and the server will be encrypted. (When you set up an account on the POP client, specify the location of the server as **localhost**, **port 1550**; details vary with different mail clients.) In this example, *remote-host* and *target* are the same system.

**Firewalls** The system specified for port forwarding (*remote-host*) does not have to be the same as the destination of the ssh connection (*target*). As an example, assume the POP server is behind a firewall and you cannot connect to it via ssh. If you can connect to the firewall via the Internet using ssh, you can encrypt the part of the connection over the Internet:

```
$ ssh -N -L 1550:pophost:110 firewall
```

Here *remote-host*, the system receiving the port forwarding, is **pophost**, and *target*, the system that ssh connects to, is **firewall**.

You can also use ssh when you are behind a firewall (that is running **sshd**) and want to forward a port into your system without modifying the firewall settings:

```
$ ssh -R 1678:localhost:80 firewall
```

The preceding command forwards connections from the outside to port 1678 on the firewall to the local Web server. Forwarding connections in this manner allows you to use a Web browser to connect to port 1678 on the firewall in order to connect to the Web server on the local system. This setup would be useful if you ran a Webmail program (page 686) on the local system because it would allow you to check your mail from anywhere using an Internet connection.

**Compression** Compression, which is enabled with the `-C` option, can speed up communication over a low-bandwidth connection. This option is commonly used with port forwarding. Compression can increase latency to an extent that may not be desirable for an X session forwarded over a high-bandwidth connection.

---

## CHAPTER SUMMARY

OpenSSH is a suite of secure network connectivity tools that encrypts all traffic, including passwords, thereby thwarting malicious users who might otherwise eavesdrop, hijack connections, and steal passwords. The components discussed in this chapter are `sshd` (the server daemon), `ssh` (runs a command on or logs in on another system), `scp` (copies files to/from another system), `sftp` (securely replaces `ftp`), and `ssh-keygen` (creates authentication keys).

To ensure secure communications, when an OpenSSH client opens a connection, it first verifies that it is connected to the correct server. Then OpenSSH encrypts communication between the systems. Finally OpenSSH makes sure that the user is authorized to log in on or copy files from/to the server.

OpenSSH also enables secure X11 forwarding. With this feature, you can run securely a graphical program on a remote system and have the display appear on the local system.

---

## EXERCISES

1. What is the difference between the `scp` and `sftp` utilities?
2. How can you use `ssh` to find out who is logged in on a remote system?
3. How would you use `scp` to copy your `~/.bashrc` file from **bravo** to the local system?
4. How would you use `ssh` to run `xterm` on **bravo** and show the display on the local system?
5. What problem can enabling compression present when using `ssh` to run remote X11 applications on a local display?
6. When you try to connect to another system using an OpenSSH client and you see a message warning you that the remote host identification has changed, what has happened? What should you do?

## ADVANCED EXERCISES

7. Which `scp` command would you use to copy your home directory from **bravo** to the local system?
8. Which single command could you give to log in as **root** on the remote system named **bravo**, if **bravo** has remote **root** logins disabled?
9. How could you use `ssh` to compare the contents of the `~/memos` directories on **bravo** and the local system?

# 19

## FTP: TRANSFERRING FILES ACROSS A NETWORK

### IN THIS CHAPTER

FTP Client. ....	645
JumpStart: Downloading Files Using ftp. ....	646
Anonymous FTP .....	649
Automatic Login .....	649
Binary Versus ASCII Transfer Mode .....	650
FTP Server (vsftpd) .....	654
JumpStart: Starting a vsftpd Server .....	655
vsftpd.conf: The vsftpd Configuration File .....	656

File Transfer Protocol is a method of downloading files from and uploading files to another system using TCP/IP over a network. File Transfer Protocol is the name of a client/server protocol (FTP) and a client utility (`ftp`) that invokes the protocol. In addition to the original `ftp` utility, there are many textual and graphical FTP client programs, including most browsers, that run under many different operating systems. There are also many FTP server programs.

## INTRODUCTION

First implemented under 4.2BSD, FTP has played an essential role in the propagation of Linux; this protocol/program is frequently used to distribute free software. The term *FTP site* refers to an FTP server that is connected to a network, usually the Internet. FTP sites can be public, allowing anonymous users to log in and download software and documentation. In contrast, private FTP sites require you to log in with a username and password. Some sites allow you to upload programs.

**ftp and vsftpd** Although most FTP clients are similar, the servers differ quite a bit. This chapter describes the **ftp** client with references to **sftp**, a secure FTP client. It also covers the FTP server that Red Hat uses internally and offers as part of its distribution, **vsftpd** (very secure FTP).

**Security** FTP is not a secure protocol. All usernames and passwords exchanged in setting up an FTP connection are sent in cleartext, data exchanged over an FTP connection is not encrypted, and the connection is subject to hijacking. FTP is best used for downloading public files. In most cases, the OpenSSH clients, **ssh** (page 627), **scp** (page 630), and **sftp** (page 631), offer secure alternatives to FTP.

---

### Use FTP only to download public information

---

**security** FTP is not secure. You can use **scp** for almost all FTP functions other than allowing anonymous users to download information. Because **scp** uses an encrypted connection, user passwords and data cannot be sniffed. See page 630 for more information on **scp**.

---

The **vsftpd** server does *not* make usernames, passwords, data, and connections more secure. The **vsftpd** server is secure in that a malicious user finds it more difficult to compromise directly the system running it, even if **vsftpd** is poorly implemented. One feature that makes **vsftpd** more secure than **ftpd** is that it does not run with **root** privileges. See also “Security” on page 655.

**ftp utility** The **ftp** utility is a user interface to File Transfer Protocol (FTP), the standard protocol used to transfer files between systems that can communicate over a network.

**sftp utility** Part of the OpenSSH suite, **sftp** is a secure alternative to **ftp**. See page 631 for more information.

**FTP connections** FTP uses two connections: one for control (you establish this connection when you log in on an FTP server) and one for data transfer (FTP sets up this connection when you ask it to transfer a file). An FTP server listens for incoming connections on port 21 by default and handles user authentication and file exchange.

**Passive versus active connections** A client can ask an FTP server to establish either a PASV (passive—the default) or a PORT (active) connection for data transfer. Some servers are limited to only one type of connection. The difference between a passive and an active FTP connection lies in whether the client or server initiates the data connection. In passive mode, the client initiates the connection to the server (on port 20 by default); in active mode, the server initiates the connection (there is no default port; see “Connection Parameters” on page 664 for the parameters that determine which ports are used). Neither is inherently more secure than the other. Passive connections are more common



because a client behind a NAT (page 820) can connect to a passive server and it is simpler to program a scalable passive server.

The parameters that control the type of connection that a **vsftpd** server allows are discussed under “Connection Parameters” on page 664.

## MORE INFORMATION

- Local Type **help** or **?** at an **ftp>** prompt to display a list of commands. Follow the **?** with a SPACE and an **ftp** command to display information about that command.  
Files: **/usr/share/doc/vsftpd\***  
man pages: **ftp**, **netrc**, **vsftpd.conf**
- Web **vsftpd** home page: [vsftpd.beasts.org](http://vsftpd.beasts.org)
- HOWTO *FTP mini-HOWTO*

## FTP CLIENT

- ftp** Fedora/RHEL supplies several FTP clients, including **ftp** (an older version of the BSD **ftp** utility). This section discusses **ftp** because most other FTP clients provide a super-set of **ftp** commands.
- sftp** Part of the OpenSSH suite, **sftp** is a secure alternative to **ftp**. See page 631 for more information.
- gftp** The **gftp** utility (**gftp** package) is a graphical client that works with FTP, SSH, and HTTP servers. This client has many useful features, including the ability to resume an interrupted file transfer. See the **gftp** man page for more information.
- ncftp** The **ncftp** utility (**ncftp** package) is a textual client that offers many more features than **ftp**, including filename completion and command-line editing. See the **ncftp** man page for details.

## PREREQUISITES

The **ftp** and **sftp** utilities are installed on most Fedora/RHEL systems. You can check for their presence by giving either of these utilities’ names as commands:

```
$ ftp
ftp> quit

$ sftp
usage: sftp [-lCv] [-B buffer_size] [-b batchfile] [-F ssh_config]
          [-o ssh_option] [-P sftp_server_path] [-R num_requests]
          [-S program] [-s subsystem | sftp_server] host
sftp [[user@]host[:file [file]]]
sftp [[user@]host[:dir[/]]]
sftp -b batchfile [user@]host
```

Install the **ftp** or **openssh-clients** (contains **sftp**) package if needed.

## JUMPSTART: DOWNLOADING FILES USING ftp

This JumpStart section is broken into two parts: a description of the basic commands and a tutorial session that shows a user working with ftp.

### BASIC COMMANDS

Give the command

```
$ ftp hostname
```

where *hostname* is the name of the FTP server you want to connect to. If you have an account on the server, log in with your username and password. If it is a public system, log in as the user **anonymous** (or **ftp**) and give your email address as your password. Use the **ls** and **cd** ftp commands on the server as you would use the corresponding utilities from a shell. The command **get** *file* copies *file* from the server to the local system, **put** *file* copies *file* from the local system to the server, **status** displays information about the FTP connection, and **help** displays a list of commands.

The preceding instructions, except for **status**, also work from **sftp** and **ncftp**.

### TUTORIAL SESSION

Following are two ftp sessions wherein Alex transfers files from and to a vsftpd server named **bravo**. When Alex gives the command **ftp bravo**, the local ftp client connects to the server, which asks for a username and password. Because he is logged in on his local system as **alex**, ftp suggests that Alex log in on **bravo** as **alex**. To log in as **alex**, he could just press RETURN. Because his username on **bravo** is **watson**, however, he types **watson** in response to the **Name (bravo:alex):** prompt. Alex responds to the **Password:** prompt with his normal system password, and the vsftpd server greets him and informs him that it is **Using binary mode to transfer files**. With ftp in binary mode, Alex can transfer ASCII and binary files (page 650).

Connect and log in

```
$ ftp bravo
Connected to bravo.
220 (vsFTPd 2.2.0)
530 Please login with USER and PASS.
530 Please login with USER and PASS.
KERBEROS_V4 rejected as an authentication type
Name (bravo:alex): watson
331 Please specify the password.
Password:
230 Login successful.
Remote system type is UNIX.
Using binary mode to transfer files.
ftp>
```

After logging in, Alex uses the ftp **ls** command to see what is in his remote working directory, which is his home directory on **bravo**. Then he cds to the **memos** directory and displays the files there.

ls and cd

```
ftp> ls
227 Entering Passive Mode (192,168,0,6,79,105)
150 Here comes the directory listing.
drwxr-xr-x    2 500        500          4096 Oct 10 23:52 expenses
```

```
drwxr-xr-x    2 500      500      4096 Oct 10 23:59 memos
drwxrwxr-x   22 500      500      4096 Oct 10 23:32 tech
226 Directory send OK.
```

```
ftp> cd memos
250 Directory successfully changed.
```

```
ftp> ls
227 Entering Passive Mode (192,168,0,6,114,210)
150 Here comes the directory listing.
-rw-r--r--    1 500      500      4770 Oct 10 23:58 memo.0514
-rw-r--r--    1 500      500      7134 Oct 10 23:58 memo.0628
-rw-r--r--    1 500      500      9453 Oct 10 23:58 memo.0905
-rw-r--r--    1 500      500      3466 Oct 10 23:59 memo.0921
-rw-r--r--    1 500      500      1945 Oct 10 23:59 memo.1102
226 Directory send OK.
```

Next Alex uses the **ftp get** command to copy **memo.1102** from the server to the local system. Binary mode ensures that he will get a good copy of the file regardless of whether it is binary or ASCII. The server confirms that this file was copied successfully and reports on the size of the file and how long it took to copy. Alex then copies the local file **memo.1114** to the remote system. The file is copied into his remote working directory, **memos**.

```
get and put    ftp> get memo.1102
                local: memo.1102 remote: memo.1102
                227 Entering Passive Mode (192,168,0,6,194,214)
                150 Opening BINARY mode data connection for memo.1102 (1945 bytes).
                226 File send OK.
                1945 bytes received in 7.1e-05 secs (2.7e+04 Kbytes/sec)

                ftp> put memo.1114
                local: memo.1114 remote: memo.1114
                227 Entering Passive Mode (192,168,0,6,174,97)
                150 Ok to send data.
                226 File receive OK.
                1945 bytes sent in 2.8e-05 secs (6.8e+04 Kbytes/sec)
```

Now Alex decides he wants to copy all the files in the **memo** directory on **bravo** to a new directory on his local system. He gives an **ls** command to make sure he will copy the right files, but **ftp** has timed out. Instead of exiting from **ftp** and giving another **ftp** command from the shell, he gives **ftp** an **open bravo** command to reconnect to the server. After logging in, he uses the **ftp cd** command to change directories to **memos** on the server.

```
Timeout and open ftp> ls
                No control connection for command: Bad file descriptor
                Passive mode refused. Turning off passive mode.
                No control connection for command: Bad file descriptor
                ftp> open bravo
                Connected to bravo (192.168.0.6).
                220 (vsFTPd 2.2.0)
                ...
                ftp> cd memos
                250 Directory successfully changed.
```

Local cd (**lcd**) At this point, Alex realizes he has not created the new directory to hold the files he wants to download. Giving an **ftp mkdir** command would create a new directory on the server, but Alex wants a new directory on his local system. He uses an exclamation point (!) followed by a **mkdir memos.hold** command to invoke a shell and run **mkdir** on the local system, creating a directory named **memos.hold** in his working directory on the local system. (You can display the name of your working directory on the local system with **!pwd**.) Next, because Alex wants to copy files from the server to the **memos.hold** directory on his local system, he has to change his working directory on the local system. Giving the command **!cd memos.hold** will not accomplish what Alex wants to do because the exclamation point will spawn a new shell on the local system and the **cd** command would be effective only in the new shell, which is not the shell that **ftp** is running under. For this situation, **ftp** provides the **lcd** (local cd) command, which changes the working directory for **ftp** and reports on the new local working directory:

```
ftp> !mkdir memos.hold

ftp> lcd memos.hold
Local directory now /home/alex/memos.hold
```

Alex uses the **ftp mget** (multiple get) command followed by the asterisk (\*) wildcard to copy all files from the remote **memos** directory to the **memos.hold** directory on the local system. When **ftp** prompts him for the first file, Alex realizes that he forgot to turn off prompts, so he responds with **n** and presses **CONTROL-C** to stop copying files in response to the second prompt. The server checks whether he wants to continue with his **mget** command.

Next Alex gives the **ftp prompt** command, which toggles the prompt action (turns it off if it is on and turns it on if it is off). Now when he gives a **mget \*** command, **ftp** copies all the files without prompting him. After getting the desired files, Alex gives a **quit** command to close the connection with the server, exit from **ftp**, and return to the local shell prompt.

```
mget and prompt    ftp> mget *
                   mget memo.0514? n
                   mget memo.0628? CONTROL-C
                   Continue with mget? n

                   ftp> prompt
                   Interactive mode off.

                   ftp> mget *
                   local: memo.0514 remote: memo.0514
                   227 Entering Passive Mode (192,168,0,6,53,55)
                   150 Opening BINARY mode data connection for memo.0514 (4770 bytes).
                   226 File send OK.
                   4770 bytes received in 8.8e-05 secs (5.3e+04 Kbytes/sec)
                   local: memo.0628 remote: memo.0628
                   227 Entering Passive Mode (192,168,0,6,65,102)
                   150 Opening BINARY mode data connection for memo.0628 (7134 bytes).
                   226 File send OK.
```

```
...
150 Opening BINARY mode data connection for memo.1114 (1945 bytes).
226 File send OK.
1945 bytes received in 3.9e-05 secs (4.9e+04 Kbytes/sec)
ftp> quit
221 Goodbye.
```

## NOTES

A Linux system running `ftp` can exchange files with any of the many operating systems that support FTP. Many sites offer archives of free information on an FTP server, although for many it is just an alternative to an easier-to-access Web site (see, for example, <ftp://ftp.ibiblio.org/pub/Linux> and <http://www.ibiblio.org/pub/Linux>). Most browsers can connect to and download files from FTP servers.

The `ftp` utility makes no assumptions about filesystem naming or structure because you can use `ftp` to exchange files with non-UNIX/Linux systems (which may use different filenames conventions).

## ANONYMOUS FTP

Many systems—most notably those from which you can download free software—allow you to log in as **anonymous**. Most systems that support anonymous logins accept the name `ftp` as an easier-to-spell and quicker-to-enter synonym for **anonymous**. An anonymous user is usually restricted to a portion of a filesystem set aside to hold files that are to be shared with remote users. When you log in as an anonymous user, the server prompts you to enter a password. Although any password may be accepted, by convention you are expected to supply your email address. Many systems that permit anonymous access store interesting files in the `pub` directory. Most browsers, such as Firefox, log in on an anonymous FTP site and transfer a file when you click on the filename.

## AUTOMATIC LOGIN

You can store server-specific FTP username and password information so that you do not have to enter it each time you visit an FTP site. Each line of `~/.netrc` identifies a server. When you connect to an FTP server, `ftp` reads the `~/.netrc` file to determine whether you have an automatic login set up for that server. The format of a line in `~/.netrc` is

*machine server login username password passwd*

where *server* is the name of the server, *username* is your username, and *passwd* is your password on *server*. Replace *machine* with *default* on the last line of the file to specify a username and password for systems not listed in `~/.netrc`. The *default* line is useful for logging in on anonymous servers. A sample `~/.netrc` file follows:

```
$ cat ~/.netrc
machine bravo login alex password mypassword
default login anonymous password alex@tcorp.com
```

To protect the account information in `.netrc`, make it readable by only the user whose home directory it appears in. Refer to the `netrc` man page for more information.

## BINARY VERSUS ASCII TRANSFER MODE

The `vsftpd` FTP server can—but does not always—provide two modes to transfer files. Binary mode transfers always copy an exact, byte-for-byte image of a file and never change line endings. Transfer all binary files using binary mode. Unless you need to convert line endings, use binary mode to transfer ASCII files as well.

ASCII files, such as text or program source code, when created under Linux with a text editor such as `vi`, use a single `NEWLINE` character (`CONTROL-J`, written as `\n`) to mark the end of each line. Other operating systems mark the ends of lines differently. Windows marks the end of each such line with a `RETURN` (`CONTROL-M`, written as `\r`) followed by a `NEWLINE` (two characters). Macintosh uses a `RETURN` by itself. These descriptions do not apply to files created by word processors such as Word or OpenOffice because those programs generate binary files.

The `vsftpd` FTP server can map Linux line endings to Windows line endings as you upload files and Windows line endings to Linux line endings as you download files. Although you could argue that these features should be on the client and not the server, they are incorporated in `vsftpd`, where the ASCII download feature can be a security risk.

To use ASCII mode on an FTP server that allows it, give an `ascii` command (page 652) after you log in and set `cr` to `ON` (the default, page 652). If the server does not allow you to change line endings as you transfer a file, you can use the `unix2dos` (page 161) or `dos2unix` (page 161) utility before or after you transfer a file in binary mode.

**Security** When run against a very large file, the `ftp size` command, which displays the size of a file, consumes a lot of server resources and can be used to initiate a *DoS attack* (page 1080). To enhance security, by default `vsftpd` transfers every file in binary mode, even when it appears to be using ASCII mode. On the server side, you can enable *real* ASCII mode transfers by setting the `ascii_upload_enable` and `ascii_download_enable` parameters (page 661) to `YES`. With the server set to allow ASCII transfers, the client controls whether line endings are mapped by using the `ascii`, `binary`, and `cr` commands (page 652).

## ftp SPECIFICS

This section covers the details of using `ftp`.

### FORMAT

An `ftp` command line has the following format:

```
ftp [options] [ftp-server]
```

where *options* is one or more options from the list in the next section and *ftp-server* is the name or network address of the FTP server that you want to exchange files with. If you do not specify an *ftp-server*, you will need to use the **ftp open** command to connect to a server once **ftp** is running.

## COMMAND-LINE OPTIONS

- g (**globbing**) Turns off globbing. See **glob** (page 652).
- i (**interactive**) Turns off prompts during file transfers with **mget** (page 652) and **mput** (page 652). See also **prompt** (page 653).
- n (**no automatic login**) Disables automatic logins (page 649).
- v (**verbose**) Tells you more about how **ftp** is working. Responses from the remote computer are displayed, and **ftp** reports information on how quickly files are transferred. See also **verbose** (page 654).

## ftp COMMANDS

The **ftp** utility is interactive: After you start **ftp**, it prompts you to enter commands to set parameters or transfer files. You can abbreviate commands as long as the abbreviations are unique. Enter a question mark (?) in response to the **ftp>** prompt to display a list of commands. Follow the question mark by a SPACE and a command to display a brief description of what the command does:

```
ftp> ? mget
mget          get multiple files
```

## SHELL COMMAND

!*[command]* Without *command*, escapes to (spawns) a shell on the local system. Use **CONTROL-D** or **exit** to return to **ftp** when you are finished using the local shell. Follow the exclamation point with *command* to execute that command only; **ftp** displays an **ftp>** prompt when execution of the command finishes. Because the shell that **ftp** spawns with this command is a child of the shell that is running **ftp**, no changes you make in this shell are preserved when you return to **ftp**. Specifically, when you want to copy files to a local directory other than the directory that you started **ftp** from, you need to use the **ftp lcd** command to change your local working directory: Issuing a **cd** command in the spawned shell will not make the change you desire. See “Local cd (lcd)” on page 648 for an example.

## TRANSFER FILES

In the following descriptions, *remote-file* and *local-file* can be pathnames.

**append** *local-file* [*remote-file*]

Appends *local-file* to the file of the same name on the remote system or to *remote-file* if specified.

**get** *remote-file* [*local-file*]

Copies *remote-file* to the local system under the name *local-file*. Without *local-file*, **ftp** uses *remote-file* as the filename on the local system.

**mget *remote-file-list***

(**multiple get**) Copies several files to the local system, each maintaining its original filename. You can name the remote files literally or use wildcards (see **glob**). Use **prompt** (page 653) to turn off prompts during transfers.

**mput *local-file-list***

(**multiple put**) Copies several files to the server, each maintaining its original filename. You can name the local files literally or use wildcards (see **glob**). Use **prompt** (page 653) to turn off prompts during transfers.

**newer *remote-file* [*local-file*]**

If the modification time of *remote-file* is more recent than that of *local-file* or if *local-file* does not exist, copies *remote-file* to the local system under the name *local-file*. Without *local-file*, ftp uses *remote-file* as the filename on the local system. Similar to **get**, but does not overwrite a newer file with an older one.

**put *local-file* [*remote-file*]**

Copies *local-file* to the remote system under the name *remote-file*. Without *remote-file*, ftp uses *local-file* as the filename on the remote system.

**reget *remote-file* [*local-file*]**

If *local-file* exists and is smaller than *remote-file*, assumes that a previous **get** of *local-file* was interrupted and continues from where the previous **get** left off. This command can save time when a **get** of a large file fails partway through the transfer.

**STATUS**

- ascii** Sets the file transfer type to ASCII. The **cr** command must be ON for **ascii** to work (page 650).
- binary** Sets the file transfer type to binary (page 650).
- bye** Closes the connection to the server and terminates ftp. Same as **quit**.
- case** Toggles and displays case mapping status. Default is OFF. When ON, for **get** and **mget** commands, maps filenames that are all uppercase on the server to all lowercase on the local system.
- close** Closes the connection to the server without exiting from ftp.
  - cr** (**carriage RETURN**) Toggles and displays (**carriage**) RETURN stripping status. Effective only when the file transfer type is **ascii**. Set **cr** to ON (default) to remove RETURN characters from RETURN/LINEFEED line termination sequences used by Windows, yielding the standard Linux line termination of LINEFEED. Set **cr** to OFF to leave line endings unmapped (page 650).
- debug [*n*]** Toggles/sets and displays debugging status/level, where *n* is the debugging level. OFF or 0 (zero) is the default. When *n* > 0, displays each command ftp sends to the server.
- glob** Toggles and displays filename expansion (page 243) status for **mdelete** (page 653), **mget** (page 652), and **mput** (page 652) commands.



- hash** Toggles and displays pound sign (#, also called a hash mark) display status. When ON, ftp displays one pound sign for each 1024-byte data block it transfers.
- open** [*hostname*] Specifies *hostname* as the name of the server to connect to. Without *hostname*, prompts for the name of the server. Useful when a connection times out or otherwise fails.
- passive** Toggles between active (PORT—the default) and passive (PASV) transfer modes and displays the transfer mode. For more information refer to “Passive versus active connections” on page 644.
- prompt** Toggles and displays the prompt status. When ON (default), **mdelete** (page 653), **mget** (page 652), and **mput** (page 652) ask for verification before transferring each file. Set to OFF to turn off these prompts.
- quit** Closes the connection to the server and terminates ftp. Same as **bye**.
- umask** [*nnn*] Changes the umask (page 440) applied to files created on the server to *nnn*. Without *nnn*, displays the umask.
- user** [*username*] [*password*] Prompts for or accepts the *username* and *password* that enable you to log in on the server. When you call it with the **-n** option, ftp prompts you for a username and password automatically. For more information refer to “Automatic Login” on page 649.

## DIRECTORIES

- cd** *remote-directory* Changes the working directory on the server to *remote-directory*.
- cdup** Changes the working directory on the server to the parent of the working directory.
- lcd** [*local\_directory*] (**local change directory**) Changes the working directory on the local system to *local\_directory*. Without an argument, this command changes the working directory on the local system to your home directory (just as the cd shell builtin does without an argument). See “Local cd (lcd)” on page 648 for an example.

## FILES

- chmod** *mode remote-file* Changes the access permissions of *remote-file* on the server to *mode*. See chmod on page 204 for more information on how to specify the *mode*.
- delete** *remote-file* Removes *remote-file* from the server.
- mdelete** *remote-file-list* (**multiple delete**) Deletes the files specified by *remote-file-list* from the server.

### DISPLAY INFORMATION

**dir** [*remote-directory*] [*file*]

Displays a listing of *remote-directory* from the server. When you do not specify *remote-directory*, displays the working directory. When you specify *file*, the listing is saved on the local system in a file named *file*.

**help** [*command*] Displays information about *command*. Without *command*, displays a list of local ftp commands.

**ls** [*remote-directory*] [*file*]

Similar to **dir** but produces a more concise listing from some servers. When you specify *file*, the listing is saved on the local system in a file named *file*.

**pwd** Displays the pathname of the working directory on the server. Use **!pwd** to display the pathname of the local working directory.

**status** Displays ftp connection and status information.

**verbose** Toggles and displays verbose mode, which displays responses from the server and reports on how quickly files are transferred. Same as specifying the **-v** option on the command line.

---

## FTP SERVER (vsftpd)

This section discusses the **vsftpd** server as supplied by Fedora/RHEL.

### PREREQUISITES

Install the following package:

- **vsftpd**

Run **chkconfig** to cause **vsftpd** to start when the system enters multiuser mode.

```
# /sbin/chkconfig vsftpd on
```

Start **vsftpd**:

```
# /sbin/service vsftpd start
```

If you change the **vsftpd.conf** configuration file, you need to restart **vsftpd**.

### NOTES

The **vsftpd** server can run in normal mode (the **xinetd** daemon [page 445] calls **vsftpd** each time a client tries to make a connection) or it can run in stand-alone mode (**vsftpd** runs as a daemon and handles connections directly).

**Stand-alone mode** Although by default **vsftpd** runs in normal mode, Fedora/RHEL sets it up to run in stand-alone mode by setting the **listen** parameter (page 657) to YES in the **vsftpd.conf** file. Under Fedora/RHEL, with **vsftpd** running in stand-alone mode, you start and stop the server using **service** and the **vsftpd** init script.

**Normal mode** You must install the **xinetd** software package and an **xinetd** control file (page 445) if you want to run **vsftpd** in normal mode. A sample file can be found at

`/usr/share/doc/vsftpd*/vsftpd.xinetd`. Copy the sample file to the `/etc/xinetd.d` directory, rename it `vsftpd`, and edit the file to change the `disable` parameter to `no`. With the `listen` parameter in `vsftpd.conf` set to `NO`, `xinetd` will take care of starting `vsftpd` as needed.

- Security The safest policy is not to allow users to authenticate against FTP: Use FTP for anonymous access only. If you do allow local users to authenticate and upload files to the server, be sure to put local users in a `chroot` jail (page 658). Because FTP sends usernames and passwords in cleartext, a malicious user can easily *sniff* (page 1107) them. With a username and password, the same user can impersonate a local user, upload a *Trojan horse* (page 1112), and compromise the system.
- Firewall An FTP server normally uses TCP port 21. If the FTP server system is running a firewall, you need to open this port. Using the Firewall Configuration window Trusted Services tab (page 824), put a check in the box labeled **FTP** to open this port 631. For more general information see Chapter 25, which details `iptables`.
- SELinux When SELinux is set to use a targeted policy, FTP is protected by SELinux. You can disable this protection if necessary. For more information refer to “Setting the Targeted Policy with `system-config-selinux`” on page 416.

## JUMPSTART: STARTING A vsftpd SERVER

By default, under Fedora/RHEL `vsftpd` allows anonymous users to log in on the server and does not set up a guest account. RHEL allows local users to log in. Fedora requires you to set `local_enable` (page 658) to `YES` to allow local users to log in. When someone logs in as an anonymous user, that person is working in the `/var/ftp` directory. You do not have to configure anything.

## TESTING THE SETUP

Make sure `vsftpd` is working by logging in from the system running the server. You can refer to the server as `localhost` or by using its hostname on the command line. Log in as `anonymous`; use any password.

```
$ ftp localhost
Trying ::1...
ftp: connect to address ::1: Connection refused
Trying 127.0.0.1...
Connected to localhost (127.0.0.1).
220 (vsFTPd 2.2.0)
Name (localhost:mark): anonymous
331 Please specify the password.
Password:
230 Login successful.
Remote system type is UNIX.
Using binary mode to transfer files.
ftp> quit
221 Goodbye.
```

If you are not able to connect to the server, first make sure the server is running:

```
$ /sbin/service vsftpd status
vsftpd (pid 3091) is running...
```

Next check that permissions on `/var/ftp`, or the home directory of `ftp` as specified in `/etc/passwd`, are set to 755. If the `ftp` user can write to `/var/ftp`, connections will fail.

```
# ls -ld /var/ftp
drwxr-xr-x. 3 root root 4096 Oct  7 15:10 /var/ftp
```

Once you are able to log in from the local system, log in from another system—either one on the LAN or another system with access to the server. On the command line, use the hostname from within the LAN or the *FQDN* (page 1083) from outside the LAN. The dialog should appear the same as in the previous example. If you cannot log in from a system that is not on your LAN, use `ping` (page 379) to test the connection and make sure the firewall is set up to allow FTP access. See “FTP connections” on page 644 for a discussion of active and passive modes and the ports that each mode uses.

## vsftpd.conf: THE vsftpd CONFIGURATION FILE

The configuration file for `vsftpd`, `/etc/vsftpd/vsftpd.conf`, lists Boolean, numeric, and string name-value pairs of configuration parameters, called directives. Each name-value pair is joined by an equal sign with no SPACES on either side. Fedora/RHEL provides a well-commented `/etc/vsftpd/vsftpd.conf` file that changes many of the compiled-in defaults. This section covers most of the options, noting their default values and their values as specified in the `vsftpd.conf` file supplied with Fedora/RHEL.

Set Boolean options to YES or NO and numeric options to a nonnegative integer. Octal numbers, which are useful for setting `umask` options, must have a leading 0 (zero). Numbers without a leading zero are treated as base 10 numbers. Following are examples from `vsftpd.conf` of setting each type of option:

```
anonymous_enable=YES
local_umask=022
xferlog_file=/var/log/vsftpd.log
```

Descriptions of the directives are broken into the following groups:

- Stand-alone mode (page 657)
- Logging in (page 657)
- Working directory and the `chroot` jail (page 658)
- Downloading and uploading files (page 660)
- Messages (page 662)
- Display (page 662)
- Logs (page 663)
- Connection parameters (page 664)

## STAND-ALONE MODE

Refer to “Notes” on page 649 for a discussion of normal and stand-alone modes. This section describes the parameters that affect stand-alone mode.

- listen** YES runs **vsftpd** in stand-alone mode; NO runs it in normal mode.  
 Default: NO  
 Fedora/RHEL: YES
- listen\_address** In stand-alone mode, specifies the IP address of the local interface that **vsftpd** listens on for incoming connections. When not set, **vsftpd** uses the default network interface.  
 Default: none
- listen\_port** In stand-alone mode, specifies the port that **vsftpd** listens on for incoming connections.  
 Default: 21
- max\_clients** In stand-alone mode, specifies the maximum number of clients. Zero (0) indicates unlimited clients.  
 Default: 0
- max\_per\_ip** In stand-alone mode, specifies the maximum number of clients from the same IP address. Zero (0) indicates unlimited clients from the same IP address.  
 Default: 0

## LOGGING IN

Three classes of users can log in on a **vsftpd** server: anonymous, local, and guest. The guest user is rarely used and is not covered in this chapter. Local users log in with their system username and password. Anonymous users log in with **anonymous** or **ftp**, using their email address as a password. You can control whether each of these classes of users can log in on the server and what they can do once they log in. You can also specify what a local user can do on a per-user basis; refer to **user\_config\_dir** on page 666.

## LOCAL USERS

- userlist\_enable** The **/etc/vsftpd/user\_list** file (page 666), or another file specified by **userlist\_file**, contains a list of zero or more users. YES consults this list and takes action based on **userlist\_deny**, either granting or denying users in the list permission to log in on the server. To prevent the transmission of cleartext passwords, access is denied immediately after the user enters her username. NO does not consult the list. For a more secure system, set to NO.  
 Default: NO  
 Fedora/RHEL: YES
- userlist\_deny** YES prevents users listed in **/etc/vsftpd/user\_list** (page 666) from logging in on the server. NO allows *only* users listed in **/etc/vsftpd/user\_list** to log in on the server.

Use **userlist\_file** to change the name of the file that this parameter consults. This parameter is checked only when **userlist\_enable** is set to YES.

Default: YES

**userlist\_file** The name of the file consulted when **userlist\_enable** is set to YES.

Default: **/etc/vsftpd/user\_list**

**local\_enable** YES permits local users (users listed in **/etc/passwd**) to log in on the server.

Default: NO

Fedora/RHEL: YES

### **ANONYMOUS USERS**

**anonymous\_enable**

YES allows anonymous logins.

Default: YES

**no\_anon\_password**

YES skips asking anonymous users for passwords.

Default: NO

**deny\_email\_enable**

YES checks whether the password (email address) that an anonymous user enters is listed in **/etc/vsftpd/banned\_emails** or other file specified by **banned\_email\_file**. If it is, the user is not allowed to log in on the system. NO does not perform this check. Using **iptables** (page 819) to block specific hosts is generally more productive than using this parameter.

Default: NO

**banned\_email\_file**

The name of the file consulted when **deny\_email\_enable** is set to YES.

Default: **/etc/vsftpd/banned\_emails**

### **WORKING DIRECTORY AND THE chroot JAIL**

When a user logs in on a **vsftpd** server, standard filesystem access permissions control which directories and files the user can access and how the user can access them. Three basic parameters control a user who is logged in on a **vsftpd** server:

- User ID (UID)
- Initial working directory
- Root directory

By default, the **vsftpd** server sets the user ID of a local user to that user's username and sets the user ID of an anonymous user to **ftp**. A local user starts in her home directory and an anonymous user starts in **/var/ftp**.

By default, anonymous users are placed in a chroot jail for security; local users are not. For example, when an anonymous user logs in on a **vsftpd** server, his home directory is **/var/ftp**. All that user sees, however, is that his home directory is **/**. The user sees the directory at **/var/ftp/upload** as **/upload**. The user cannot see, or work with, for example, the **/home**, **/usr/local**, or **/tmp** directories. The user is in a chroot jail. For more information refer to “Setting Up a chroot Jail” on page 448.

You can use the **chroot\_local\_user** option to put each local user in a chroot jail whose root is the user’s home directory. You can use **chroot\_list\_enable** to put selected local users in chroot jails.

#### **chroot\_list\_enable**

Upon login, YES checks whether a local user is listed in **/etc/vsftpd/chroot\_list** (page 666) or another file specified by **chroot\_list\_file**.

When a user is in the list and **chroot\_local\_user** is set to NO, the user is put in a chroot jail in his home directory. Only users listed in **/etc/vsftpd/chroot\_list** are put in chroot jails.

When a user is in the list and **chroot\_local\_user** is set to YES, that user is not put in a chroot jail. Users not listed in **/etc/vsftpd/chroot\_list** are put in chroot jails.

Default: NO

#### **chroot\_local\_user**

See **chroot\_list\_enable**. Set to NO for a more open system, but remember to add new users to the **chroot\_list\_file** as needed when you add users to the system. Set to YES for a more secure system. New users are automatically restricted unless you add them to **chroot\_list\_file**.

Default: NO

**chroot\_list\_file** The name of the file consulted when **chroot\_list\_enable** is set to YES.

Default: **/etc/vsftpd/chroot\_list**

#### **passwd\_chroot\_enable**

YES enables you to change the location of the chroot jail that the **chroot\_list\_enable** and **chroot\_local\_user** settings impose on a local user.

The location of the chroot jail can be moved up the directory structure by including a **./** within the home directory string for that user in **/etc/passwd**. This change has no effect on the standard system login, just as a **cd .** command has no effect on the working directory.

For example, changing the home directory field in **/etc/passwd** (page 475) for Sam from **/home/sam** to **/home/./sam** allows Sam to **cd** to **/home** after logging in using **vsftpd**. Given the proper permissions, Sam can now view files and possibly collaborate with another user.

Default: NO

**secure\_chroot\_dir** The name of an empty directory that is not writable by the user **ftp**. The **vsftpd** server uses this directory as a secure chroot jail when the user does not need access to the filesystem.

Default: `/usr/share/empty`

**local\_root** After a local user logs in on the server, this directory becomes the user's working directory. No error results if the specified directory does not exist.

Default: none

## DOWNLOADING AND UPLOADING FILES

By default, any user—whether local or anonymous—can download files from the **vsftpd** server, assuming proper filesystem access and permissions. You must change **write\_enable** from NO (default) to YES to permit local users to upload files. By default, **local\_umask** is set to 022, giving uploaded files 644 permissions (page 202).

**Security** Refer to “Security” on page 655 for information on the security hole that is created when you allow local users to upload files.

The following actions set up **vsftpd** to allow anonymous users to upload files:

1. Set **write\_enable** (page 661) to YES.
2. Create a directory under `/var/ftp` that an anonymous user can write to but not read from (mode 333). You do not want a malicious user to be able to see, download, modify, and upload a file that another user originally uploaded. The following commands create a `/var/ftp/uploads` directory that anyone can write to but no one can read from:

```
# mkdir /var/ftp/uploads
# chmod 333 /var/ftp/uploads
```

Because of the security risk, **vsftpd** prevents anonymous connections when an anonymous user (**ftp**) can write to `/var/ftp`.

3. Set **anon\_upload\_enable** (page 661) to YES.
4. See the other options in this section.

## DOWNLOAD/UPLOAD FOR LOCAL USERS

**local\_umask** The umask (page 440) setting for local users.

Default: 077

Fedora/RHEL: 022

**file\_open\_mode** Uploaded file permissions for local users. The umask (page 440) is applied to this value. Change to 0777 to make uploaded files executable.

Default: 0666



**write\_enable** YES permits users to create and delete files and directories (assuming appropriate filesystem permissions). NO prevents users from making changes to the filesystem.

Default: NO

Fedora/RHEL: YES

### ANONYMOUS USERS

**anon\_mkdir\_write\_enable**

YES permits an anonymous user to create new directories when **write\_enable**=YES and the anonymous user has permission to write to the parent directory.

Default: NO

**anon\_other\_write\_enable**

YES grants an anonymous user write permission in addition to the permissions granted by **anon\_mkdir\_write\_enable** and **anon\_upload\_enable**. For example, YES allows an anonymous user to delete and rename files, assuming permission to write to the parent directory. Not recommended for secure sites.

Default: NO

**anon\_root** After an anonymous user logs in on the server, this directory becomes the user's working directory. No error results if the specified directory does not exist.

Default: none

**anon\_umask** The umask (page 440) setting for anonymous users. The default setting gives only anonymous users access to files uploaded by anonymous users; set to 022 to give everyone read access to these files.

Default: 077

**anon\_upload\_enable**

YES allows anonymous users to upload files when **write\_enable**=YES and the anonymous user has permission to write to the directory.

Default: NO

**anon\_world\_readable\_only**

YES limits the files that a user can download to those that are readable by the owner of the file, members of the group the file is associated with, and others. It may not be desirable to allow one anonymous user to download a file that another anonymous user uploaded. Setting this parameter to YES can avoid this scenario.

Default: YES

**ascii\_download\_enable**

YES allows a user to download files using ASCII mode. Setting this parameter to YES can create a security risk (page 650).

Default: NO

**ascii\_upload\_enable**

YES allows a user to upload files using ASCII mode (page 650).

Default: NO

**chown\_uploads** YES causes files uploaded by anonymous users to be owned by **root** (or another user specified by **chown\_username**).

Default: NO

**chown\_username** See **chown\_uploads**.

Default: **root**

**ftp\_username** The username of anonymous users.

Default: **ftp**

**nopriv\_user** The name of the user with minimal privileges, as used by **vsftpd**. To enhance security, because other programs use **nobody**, replace **nobody** with the name of a dedicated user such as **ftp**.

Default: **nobody**

## MESSAGES

You can replace the standard greeting banner that **vsftpd** displays when a user logs in on the system (**banner\_file** and **ftpd\_banner**). You can also display a message each time a user enters a directory (**dirmessage\_enable** and **message\_file**). When you set **dirmessage\_enable**=YES, each time a user enters a directory using **cd**, **vsftpd** displays the contents of the file in that directory named **.message** (or other file specified by **message\_file**).

**dirmessage\_enable**

YES displays **.message** or another file specified by **message\_file** as an **ftp** user enters a new directory by giving a **cd** command.

Default: NO

Fedora/RHEL: YES

**message\_file** See **dirmessage\_enable**.

Default: **.message**

**banner\_file** The absolute pathname of the file that is displayed when a user connects to the server. Overrides **ftpd\_banner**.

Default: none

**ftpd\_banner** This string overrides the standard **vsftpd** greeting banner displayed when a user connects to the server.

Default: none; uses standard **vsftpd** banner

## DISPLAY

This section describes parameters that can improve security and performance by controlling how **vsftpd** displays information.

- hide\_ids** YES lists all users and groups in directory listings as **ftp**. NO lists the real owners.  
Default: NO
- setproctitle\_enable**  
NO causes **ps** to display the process running **vsftpd** as **vsftpd**. YES causes **ps** to display what **vsftpd** is currently doing (uploading and so on). Set to NO to provide a more secure system.  
Default: NO
- text\_userdb\_names**  
NO improves performance by displaying numeric UIDs and GIDs in directory listings. YES displays names.  
Default: NO
- use\_localtime** NO causes **ls**, **mls**, and **modtime** FTP commands to display *UTC* (page 1114); YES causes these commands to display the local time.  
Default: NO
- ls\_recurse\_enable** YES permits users to give **ls -R** commands. Setting this parameter to YES may pose a security risk because giving an **ls -R** command at the top of a large directory hierarchy can consume a lot of system resources.  
Default: NO

## LOGS

By default, logging is turned off. However, the **vsftpd.conf** file distributed with Fedora/RHEL turns it on. This section describes parameters that control the details and locations of logs.

- log\_ftp\_protocol** YES logs FTP requests and responses, provided that **xferlog\_std\_format** is set to NO.  
Default: NO
- xferlog\_enable** YES maintains a transfer log in **/var/log/vsftpd.log** (or another file specified by **xferlog\_file**). NO does not create a log.  
Default: NO  
Fedora/RHEL: YES
- xferlog\_std\_format**  
YES causes a transfer log (not covering connections) to be written in standard **xferlog** format, as used by **wu-ftp**, as long as **xferlog\_file** is explicitly set. The default **vsftpd** log format is more readable than **xferlog** format, but it cannot be processed by programs that generate statistical summaries of **xferlog** files. Search for **xferlog** on the Internet for more information.  
Default: NO  
Fedora/RHEL: YES
- xferlog\_file** See **xferlog\_enable** and **xferlog\_std\_format**.  
Default: **/var/log/vsftpd.log**

## CONNECTION PARAMETERS

You can allow clients to establish passive and/or active connections (page 644). Setting timeouts and maximum transfer rates can improve server security and performance. This section describes parameters that control the types of connections that a client can establish, the length of time **vsftpd** will wait while establishing a connection, and the speeds of connections for different types of users.

### PASSIVE (PASV) CONNECTIONS

**pasv\_enable** NO prevents the use of PASV connections.

Default: YES

**pasv\_promiscuous**

NO causes PASV to perform a security check that ensures that the data and control connections originate from a single IP address. YES disables this check; it is not recommended for a secure system.

Default: NO

**pasv\_max\_port** The highest port number that **vsftpd** will allocate for a PASV data connection; useful in setting up a firewall.

Default: 0 (use any port)

**pasv\_min\_port** The lowest port number that **vsftpd** will allocate for a PASV data connection; useful in setting up a firewall.

Default: 0 (use any port)

**pasv\_address** Specifies an IP address other than the one used by the client to contact the server.

Default: none; the address is the one used by the client

### ACTIVE (PORT) CONNECTIONS

**port\_enable** NO prevents the use of PORT connections.

Default: YES

**port\_promiscuous**

NO causes PORT to perform a security check that ensures that outgoing data connections connect only to the client. YES disables this check; it is not recommended for a secure system.

Default: NO

**connect\_from\_port\_20**

YES specifies port 20 (**ftp-data**, a privileged port) on the server for PORT connections, as required by some clients. NO allows **vsftpd** to run with fewer privileges (on a nonprivileged port).

Default: NO

Fedora/RHEL: YES

**ftp\_data\_port** With **connect\_from\_port\_20** set to NO, specifies the port that **vsftpd** uses for PORT connections.

Default: 20

### **TIMEOUTS**

**accept\_timeout** The number of seconds the server waits for a client to establish a PASV data connection.

Default: 60

**connect\_timeout** The number of seconds the server waits for a client to respond to a PORT data connection.

Default: 60

**data\_connection\_timeout**

The number of seconds the server waits for a stalled data transfer to resume before disconnecting.

Default: 300

**idle\_session\_timeout**

The number of seconds the server waits between FTP commands before disconnecting.

Default: 300

**local\_max\_rate** For local users, the maximum data transfer rate in bytes per second. Zero (0) indicates no limit.

Default: 0

**anon\_max\_rate** For anonymous users, the maximum data transfer rate in bytes per second. Zero indicates no limit.

Default: 0

**one\_process\_model**

YES establishes one process per connection, which improves performance but degrades security. NO allows multiple processes per connection. NO is recommended for a more secure system.

Default: NO

### **MISCELLANEOUS**

This section describes parameters not discussed elsewhere.

**pam\_service\_name**

The name of the PAM service used by **vsftpd**.

Default: **ftp**

Fedora/RHEL: **vsftpd**

**tcp\_wrappers** YES causes incoming connections to use **tcp\_wrappers** (page 447) if **vsftpd** was compiled with **tcp\_wrappers** support. When **tcp\_wrappers** sets the environment

variable **VSFTPD\_LOAD\_CONF**, **vsftpd** loads the configuration file specified by this variable, allowing per-IP configuration.

Default: NO

Fedora/RHEL: YES

**user\_config\_dir** Specifies a directory that contains files named for local users. Each of these files, which mimic **vsftpd.conf**, contains parameters that override, on a per-user basis, default parameters and parameters specified in **vsftpd.conf**. For example, assume that **user\_config\_dir** is set to **/etc/vsftpd/user\_conf**. If the default configuration file, **/etc/vsftpd/vsftpd.conf**, sets **idle\_session\_timeout=300** and Sam's individual configuration file, **/etc/vsftpd/user\_conf/sam**, sets **idle\_session\_timeout=1200**, all users' sessions, except for Sam's, will time out after 300 seconds of inactivity. Sam's sessions will time out after 1,200 seconds.

Default: none

## FILES

In addition to **/etc/vsftpd/vsftpd.conf**, the following files control the functioning of **vsftpd**. The directory hierarchy that **user\_config\_dir** points to is not included in this list as it has no default name.

**/etc/vsftpd/ftpusers**

Lists users, one per line, who are never allowed to log in on the FTP server, regardless of how **userlist\_enable** (page 657) is set and regardless of the users listed in the **user\_list** file. The default file lists **root**, **bin**, **daemon**, and others.

**/etc/vsftpd/user\_list**

Lists either the only users who can log in on the server or the users who are not allowed to log in on the server. The **userlist\_enable** (page 657) option must be set to YES for **vsftpd** to examine the list of users in this file. Setting **userlist\_enable** to YES and **userlist\_deny** (page 657) to YES (or not setting it) prevents listed users from logging in on the server. Setting **userlist\_enable** to YES and **userlist\_deny** to NO permits only the listed users to log in on the server.

**/etc/vsftpd/chroot\_list**

Depending on the **chroot\_list\_enable** (page 659) and **chroot\_local\_user** (page 659) settings, this file lists either users who are forced into a chroot jail in their home directories or users who are not placed in a chroot jail.

**/var/log/vsftpd.log**

Log file. For more information refer to “Logs” on page 663.

---

## CHAPTER SUMMARY

FTP is a protocol for downloading files from and uploading files to another system over a network. FTP is the name of both a client/server protocol (FTP) and a client

utility (`ftp`) that invokes this protocol. Because FTP is not a secure protocol, it should be used only to download public information. You can run the `vsftpd` FTP server in the restricted environment of a `chroot` jail to make it significantly less likely that a malicious user can compromise the system.

Many servers and clients implement the FTP protocol. The `ftp` utility is the original client implementation; `sftp` is a secure implementation that uses OpenSSH facilities to encrypt the connection. The `vsftpd` daemon is a secure FTP server; it better protects the server from malicious users than do other FTP servers.

Public FTP servers allow you to log in as **anonymous** or **ftp**. By convention, you supply your email address as a password when you log in as an anonymous user. Public servers frequently have interesting files in the **pub** directory.

FTP provides two modes of transferring files: binary and ASCII. It is safe to use binary mode to transfer all types of files, including ASCII files. If you transfer a binary file using ASCII mode, the transfer will fail.

---

## EXERCISES

1. What changes does FTP make to an ASCII file when you download it in ASCII mode to a Windows machine from a Linux server? What changes are made when you download the file to a Mac?
2. What happens if you transfer an executable program file in ASCII mode?
3. When would `ftp` be a better choice than `sftp`?
4. How would you prevent local users from logging in on a `vsftpd` server using their system username and password?
5. What advantage does `sftp` have over `ftp`?
6. What is the difference between `cd` and `lcd` in `ftp`?

---

## ADVANCED EXERCISES

7. Why might you have problems connecting to an FTP server in PORT mode?
8. Why is it advantageous to run `vsftpd` in a `chroot` jail?
9. After downloading a file, you find that it does not match the MD5 checksum provided. Downloading the file again gives the same incorrect checksum. What have you done wrong and how would you fix it?
10. How would you configure `vsftpd` to run through `xinetd`, and what would be the main advantage of this approach?

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# sendmail: SETTING UP MAIL CLIENTS, SERVERS, AND MORE

## IN THIS CHAPTER

JumpStart I: Configuring sendmail on a Client .....	672
JumpStart II: Configuring sendmail on a Server .....	673
How sendmail Works .....	674
Configuring sendmail .....	677
SpamAssassin.....	682
Webmail .....	686
Mailing Lists .....	688
Setting Up an IMAP or POP3 Server.....	689
Authenticated Relaying .....	689

Sending and receiving email require three pieces of software. At each end, there is a client, called an MUA (Mail User Agent), which is a bridge between a user and the mail system. Common MUAs are mutt, KMail, Thunderbird, and Outlook. When you send an email, the MUA hands it to an MTA (a Mail Transfer Agent such as **sendmail**), which transfers it to the destination server. At the destination, an MDA (a Mail Delivery Agent such as **procmail**) puts the mail in the recipient's mailbox file. On Linux systems, the MUA on the receiving system either reads the mailbox file or retrieves mail from a remote MUA or MTA, such as an ISP's SMTP (mail) server, using POP (Post Office Protocol) or IMAP (Internet Message Access Protocol).

Most Linux MUAs expect a local copy of **sendmail** to deliver outgoing email. On some systems, including those with a dial-up connection to the Internet, **sendmail** relays email to an ISP's mail server. Because **sendmail** uses SMTP (Simple Mail Transfer Protocol) to deliver email, **sendmail** is often referred to as an SMTP server.

In the default Fedora/RHEL setup, the **sendmail** MTA uses **procmail** as the local MDA. In turn, **procmail** writes email to the end of the recipient's mailbox file. You can also use **procmail** to sort email according to a set of rules, either on a per-user basis or globally. The global filtering function is useful for systemwide filtering to detect spam and for other tasks, but the per-user feature is largely superfluous on a modern system. Traditional UNIX MUAs were simple programs that could not filter mail and thus delegated this function to MDAs such as **procmail**. Modern MUAs, by contrast, incorporate this functionality.

### You do not need to set up sendmail to send and receive email

---

**tip** Most MUAs can use POP or IMAP for receiving email. These protocols do not require an MTA such as **sendmail**. As a consequence, you do not need to install or configure **sendmail** (or another MTA) to receive email. You still need SMTP to send email. However, the SMTP server can be at a remote location, such as your ISP, so you do not need to concern yourself with it.

---

---

## INTRODUCTION

When the network that was to evolve into the Internet was first set up, it connected a few computers, each serving a large number of users and running several services. Each computer was capable of sending and receiving email and had a unique hostname, which was used as a destination for email.

Today the Internet has a large number of transient clients. Because these clients do not have fixed IP addresses or hostnames, they cannot receive email directly. Users on these systems usually maintain an account on an email server run by their employer or an ISP, and they collect email from this account using POP or IMAP. Unless you own a domain that you want to receive email at, you will not need to set up **sendmail** as an incoming SMTP server.

You can set up **sendmail** on a client system so that it simply relays outbound mail to an SMTP server. This configuration is required by organizations that use firewalls to prevent email from being sent out on the Internet from any system other than the company's official mail servers. As a partial defense against spreading viruses, some ISPs block outbound port 25 to prevent their customers from sending email directly to a remote computer. This configuration is required by these ISPs.

You can also set up **sendmail** as an outbound server that does not use an ISP as a relay. In this configuration, **sendmail** connects directly to the SMTP servers for the domains receiving the email. An ISP set up as a relay is configured this way.

You can set up **sendmail** to accept email for a registered domain name as specified in the domain's DNS MX record (page 780). However, most mail clients (MUAs) do not interact directly with **sendmail** to receive email. Instead, they use POP or IMAP—protocols that include features for managing mail folders, leaving messages on the server, and reading only the subject of an email without downloading the entire message. If you want to collect your email from a system other than the one running the incoming mail server, you may need to set up a POP or IMAP server, as discussed on page 689.

## PREREQUISITES

Install the following packages:

- **sendmail** (required)
- **sendmail-cf** (required to configure **sendmail**)
- **squirrelmail** (optional; provides Webmail, page 686)
- **spamassassin** (optional; provides spam filtering, page 682)
- **mailman** (optional; provides mailing list support, page 688)
- **dovecot** (optional; provides IMAP and POP incoming mail server daemons)

Run **chkconfig** to cause **sendmail** to start when the system goes multiuser (by default, **sendmail** does not run in single-user mode):

```
# /sbin/chkconfig sendmail on
```

Start **sendmail**. Because **sendmail** is normally running, you need to restart it to cause **sendmail** to reread its configuration files. The following restart command works even when **sendmail** is not running—it just fails to shut down **sendmail**:

```
# /sbin/service sendmail restart
Shutting down sm-client:      [ OK ]
Shutting down sendmail:      [ OK ]
Starting sendmail:           [ OK ]
Starting sm-client:           [ OK ]
```

Run **chkconfig** to cause the SpamAssassin daemon, **spamd**, to start when the system enters multiuser mode (SpamAssassin is normally installed in this configuration):

```
# /sbin/chkconfig spamassassin on
```

As with **sendmail**, SpamAssassin is normally running. Restart it to cause **spamd** to reread its configuration files:

```
# /sbin/service spamassassin restart
Stopping spamd:               [ OK ]
Starting spamd:               [ OK ]
```

The IMAP and POP protocols are implemented as several daemons. See page 689 for information on these daemons and how to start them.

## NOTES

- Firewall** An SMTP server normally uses TCP port 25. If the SMTP server system is running a firewall, you need to open this port. Using the Firewall Configuration window Trusted Services tab (page 824), put a check in the box labeled **Mail (SMTP)** to open this port. For more general information see Chapter 25, which details **iptables**.
- cyrus** This chapter covers the IMAP and POP3 servers included in the **dovecot** package. Fedora/RHEL also provides IMAP and POP3 servers in the **cyrus-imapd** package.

## MORE INFORMATION

Web **sendmail**: [www.sendmail.org](http://www.sendmail.org)  
 IMAP: [www.imap.org](http://www.imap.org)  
 IMAP and POP3: [www.dovecot.org](http://www.dovecot.org)  
 IMAP and POP3: [cyrusimap.web.cmu.edu](http://cyrusimap.web.cmu.edu)  
 SquirrelMail: [www.squirrelmail.org](http://www.squirrelmail.org)  
 Postfix: [www.postfix.org/docs.html](http://www.postfix.org/docs.html) (alternative MTA, page 691)  
 Qmail: [qmail.area.com](http://qmail.area.com)  
 Mailman: [www.list.org](http://www.list.org)  
**procmail**: [www.procmail.org](http://www.procmail.org)  
 SpamAssassin: [spamassassin.org](http://spamassassin.org)  
 Spam database: [razor.sourceforge.net](http://razor.sourceforge.net)

## JUMPSTART I: CONFIGURING sendmail ON A CLIENT

### You may not need to configure sendmail to send email

**tip** With **sendmail** running, give the command described under “Test” on page 673. As long as **sendmail** can connect to port 25 outbound, you should not need to set up **sendmail** to use an SMTP relay as described in this section. If you receive the mail sent by the test, you can skip this section.

This JumpStart configures an outbound **sendmail** server. This server

- Uses a remote SMTP server—typically an ISP—to relay outbound email to its destination (an SMTP relay).
- Sends to the SMTP server email originating from the local system only. It does not forward email originating from other systems.
- Does not handle inbound email. As is frequently the case, you need to use POP or IMAP to receive email.

To set up this server, you must edit `/etc/mail/sendmail.mc` and restart **sendmail**.

**Change** The **dn1** at the start of the following line in **sendmail.mc** indicates that this line is a comment:

```
dn1 define(`SMART_HOST', `smtp.your.provider')dn1
```

You can ignore the **dn1** at the end of the line. To specify a remote SMTP server, you must open **sendmail.mc** in an editor and change the preceding line, deleting **dn1** from the beginning of the line and replacing **smtp.your.provider** with the FQDN of your ISP’s SMTP server (obtain this name from your ISP). Be careful not to alter the back ticks ( ``` ) and the single quotation marks ( `'` ) in this line. If your ISP’s SMTP server is at **smtp.myisp.com**, you would change the line to

```
define(`SMART_HOST', `smtp.myisp.com')
```

**Do not alter the back ticks ( ` ) or the single quotation marks ( ' )**

**tip** Be careful not to alter the back ticks ( ` ) or the single quotation marks ( ' ) in any line in **sendmail.mc**. These symbols control the way the m4 preprocessor converts **sendmail.mc** to **sendmail.cf**; **sendmail** will not work properly if you do not preserve these symbols.

Restart sendmail When you restart it, **sendmail** regenerates the **sendmail.cf** file from the **sendmail.mc** file you edited:

```
# /sbin/service sendmail restart
```

Test Test **sendmail** with the following command:

```
$ echo "my sendmail test" | /usr/sbin/sendmail user@remote.host
```

Replace *user@remote.host* with an email address on *another system* where you receive email. You need to send email to a remote system to make sure that **sendmail** is relaying your email.

---

## JUMPSTART II: CONFIGURING sendmail ON A SERVER

If you want to receive inbound email sent to a registered domain that you own, you need to set up **sendmail** as an incoming mail server. This JumpStart describes how to set up such a server. This server

- Accepts outbound email from the local system only.
- Delivers outbound email directly to the recipient's system, without using a relay.
- Accepts inbound email from any system.

This server does not relay outbound email originating on other systems. Refer to “access: Sets Up a Relay Host” on page 680 if you want the local system to act as a relay. For this configuration to work, you must be able to make outbound connections from and receive inbound connections to port 25.

The line in **sendmail.mc** that limits **sendmail** to accepting inbound email from the local system only is

```
DAEMON_OPTIONS( ` Port=smtp,Addr=127.0.0.1, Name=MTA' )dn1
```

To allow **sendmail** to accept inbound email from other systems, remove the parameter **Addr=127.0.0.1**, from the preceding line:

```
DAEMON_OPTIONS( ` Port=smtp, Name=MTA' )dn1
```

By default, **sendmail** does not use a remote SMTP server to relay email, so there is nothing to change to cause **sendmail** to send email directly to recipients' systems. (JumpStart I set up a **SMART\_HOST** to relay email.)

Once you have restarted **sendmail**, it will accept mail addressed to the local system, as long as a DNS MX record (page 780) points at the local system. If you are not running a DNS server, you must ask your ISP to set up an MX record.

## How sendmail WORKS

**Outbound email** When you send email, the MUA passes the email to **sendmail**, which creates in the `/var/spool/mqueue` (mail queue) directory two files that hold the message while **sendmail** processes it. To create a unique filename for a particular piece of email, **sendmail** generates a random string and uses that string in filenames pertaining to the email. The **sendmail** daemon stores the body of the message in a file named **df** (data file) followed by the generated string. It stores the headers and other information in a file named **qf** (queue file) followed by the generated string.

If a delivery error occurs, **sendmail** creates a temporary copy of the message that it stores in a file whose name starts with **tf** (temporary file) and logs errors in a file whose name starts with **xf**. Once an email has been sent successfully, **sendmail** removes all files pertaining to that email from `/var/spool/mqueue`.

**Incoming email** By default, the MDA stores incoming messages in users' files in the mail spool directory, `/var/spool/mail`, in **mbox** format. Within this directory, each user has a mail file named with the user's username. Mail remains in these files until it is collected, typically by an MUA. Once an MUA collects the mail from the mail spool, the MUA stores the mail as directed by the user, usually in the user's home directory hierarchy.

**mbox versus maildir** The **mbox** format stores all messages for a user in a single file. To prevent corruption, the file must be locked while a process is adding messages to or deleting messages from the file; you cannot delete a message at the same time the MTA is adding messages. A competing format, **maildir**, stores each message in a separate file. This format does not use locks, allowing an MUA to read and delete messages at the same time as new mail is delivered. In addition, the **maildir** format is better able to handle larger mailboxes. The downside is that the **maildir** format adds overhead when you are using a protocol such as IMAP to check messages. The **dovecot** package supports both **mbox** and **maildir** formats. Qmail (page 691), a **sendmail** alternative, uses **maildir**-format mailboxes.

## MAIL LOGS

The **sendmail** daemon stores log messages in `/var/log/maillog`. Other mail servers, such as the **dovecot** **imap-login** and **pop3-login** daemons, may also log information to this file. Following is a sample log entry:

```
/var/log/maillog      # cat /var/log/maillog
...
Mar  3 16:25:33 MACHINENAME sendmail[7225]: i23GPXvm007224:
to=<user@localhost.localdomain>, ctldaddr=<root@localhost.localdomain>
(0/0), delay=00:00:00, xdelay=00:00:00, mailer=local, pri=30514,
dsn=2.0.0, stat=Sent
```

Each log entry starts with a timestamp, the name of the system sending the email, the name of the mail server (**sendmail**), and a unique identification number. The address of the recipient follows the **to=** label and the address of the sender follows **ctldaddr=**. Additional fields provide the name of the mailer and the time it took to send the message. If a message is sent correctly, the **stat=** label is followed by **Sent**.

A message is marked **Sent** when **sendmail** sends it; **Sent** does not indicate that the message has been delivered. If a message is not delivered because an error occurred farther down the line, the sender usually receives an email saying that it was not delivered and giving a reason why.

If you send and receive a lot of email, the **maillog** file can grow quite large. The **rsyslog** logrotate (page 579) entry is set up to archive and rotate the **maillog** files regularly.

## ALIASES AND FORWARDING

Three files can forward email: **.forward** (page 676), **aliases** (discussed next), and **virtusertable** (page 682). Table 20-1 on page 682 compares the three files.

**/etc/aliases** Most of the time when you send email, it goes to a specific person; the recipient, **user@system**, maps to a specific, real user on the specified system. Sometimes you may want email to go to a class of users and not to a specific recipient. Examples of classes of users include **postmaster**, **webmaster**, **root**, and **tech\_support**. Different users may receive this email at different times or the email may be answered by a group of users. You can use the **/etc/aliases** file to map inbound addresses to local users, files, commands, and remote addresses.

Each line in **/etc/aliases** contains the name of a local pseudouser, followed by a colon, whitespace, and a comma-separated list of destinations. The default installation includes a number of aliases that redirect messages for certain pseudousers to **root**. These have the form

```
system:      root
```

Sending messages to the **root** account is a good way of making them easy to review. However, because **root**'s email is rarely checked, you may want to send copies to a real user. The following line forwards mail sent to **abuse** on the local system to **root** and **alex**:

```
abuse:      root, alex
```

You can create simple mailing lists with this type of alias. For example, the following alias sends copies of all email sent to **admin** on the local system to several users, including Zach, who is on a different system:

```
admin:      sam, helen, mark, zach@tcorp.com
```

You can direct email to a file by specifying an absolute pathname in place of a destination address. The following alias, which is quite popular among less conscientious system administrators, redirects email sent to **complaints** to **/dev/null** (page 469), where they disappear:

```
complaints: /dev/null
```

You can also send email to standard input of a command by preceding the command with a pipe character (`|`). This technique is commonly used with mailing list software such as Mailman (page 688). For each list it maintains, Mailman has entries, such as the following entry for **mylist**, in the **aliases** file:

```
mylist:                "|/usr/lib/mailman/mail/mailman post mylist"
```

**newaliases** After you edit **/etc/aliases**, you must either run **newaliases** as **root** or restart **sendmail** to re-create the **aliases.db** file that **sendmail** reads.

**praliases** You can use **praliases** to list aliases currently loaded by **sendmail**:

```
# /usr/sbin/praliases | tail -5
vcsa:root
webalizer:root
wnn:root
www:webmaster
xfs:root
```

**~/forward** Systemwide aliases are useful in many cases, but **nonroot** users cannot make or change them. Sometimes you may want to forward your own mail: Maybe you want mail from several systems to go to one address or perhaps you just want to forward your mail while you are working at another office for a week. The **~/forward** file allows ordinary users to forward their email.

Lines in a **.forward** file are the same as the right column of the **aliases** file explained previously: Destinations are listed one per line and can be a local user, a remote email address, a filename, or a command preceded by a pipe character (`|`).

Mail that you forward does not go to your local mailbox. If you want to forward mail and keep a copy in your local mailbox, you must specify your local username preceded by a backslash to prevent an infinite loop. The following example sends Sam's email to himself on the local system and on the system at **tcorp.com**:

```
$cat ~sam/.forward
sams@tcorp.com
\sam
```

## RELATED PROGRAMS

**sendmail** The **sendmail** package includes several programs. The primary program, **sendmail**, reads from standard input and sends an email to the recipient specified by its argument. You can use **sendmail** from the command line to check that the mail delivery system is working and to email the output of scripts. See page 673 for an example.

**mailq** or **sendmail -bp** The **mailq** utility (*RHEL*) displays the status of the outgoing mail queue and normally reports there are no messages in the queue. From *FEDORA*, **sendmail -bp** performs the same function. Messages in the queue usually indicate a problem with the local or remote **sendmail** configuration or a network problem.

```
# /usr/bin/mailq
/var/spool/mqueue is empty
Total requests: 0
```



**mailstats** The mailstats utility reports on the number and sizes of messages **sendmail** has sent and received since the date it displays on the first line:

```
# /usr/sbin/mailstats
Statistics from Fri Sep 11 12:01:04 2009
M  msgsftr  bytes_from  msgsto  bytes_to  msgsjrej  msgsdisc  msgsqur  Mailer
4      0      0K        1      1K        0        0        0  esmtp
9      5      5K        2      2K        0        0        0  local
=====
T      5      5K        3      3K        0        0        0
C      5              3              0
```

In the preceding output, each mailer is identified by the first column, which displays the mailer number, and by the last column, which displays the name of the mailer. The second through fifth columns display the number and total sizes of messages sent and received by the mailer. The sixth, seventh, and eighth columns display the number of messages rejected, discarded, and quarantined respectively. The row that starts with **T** lists the column totals, and the row that starts with **C** lists the number of TCP connections.

## CONFIGURING sendmail

The **sendmail** configuration files reside in **/etc/mail**, where the primary configuration file is **sendmail.cf**. This directory contains other text configuration files, such as **access**, **mailertable**, and **virtusertable**. The **sendmail** daemon does not read these files but instead reads the corresponding **\*.db** files in the same directory.

**makemap** You can use **makemap** or give the command **make** from the **/etc/mail** directory to generate the **\*.db** files, although this step is not usually necessary. The **sendmail** init script automatically generates these files when you start or restart **sendmail**:

```
# /sbin/service sendmail restart
```

## THE sendmail.mc AND sendmail.cf FILES

This **sendmail.cf** file is not intended to be edited by hand and contains a large warning to this effect:

```
$ cat /etc/mail/sendmail.cf
...
#####
##### DO NOT EDIT THIS FILE! Only edit the source .mc file.
#####
#####
...

```

## EDITING sendmail.mc AND GENERATING sendmail.cf

The **sendmail.cf** file is generated from **sendmail.mc** using the **m4** macro processor. It can be helpful to use a text editor that supports syntax highlighting, such as **vim**, to edit **sendmail.mc**.

**dnl** Many of the lines in **sendmail.mc** start with **dnl**, which stands for **delete to new line**; this token causes m4 to delete from the **dnl** to the end of the line (the next **NEWLINE** character). Because m4 ignores anything on a line after a **dnl** instruction, you can use **dnl** to introduce comments; it works the same way as **#** does in a shell script.

Many of the lines in **sendmail.mc** end with **dnl**. Because **NEWLINES** immediately follow these **dnl**s, these **dnl**s are superfluous; you can remove them if you like.

After you edit **sendmail.mc**, you need to regenerate **sendmail.cf** to make your changes take effect. When you restart **sendmail**, the **sendmail** init script regenerates **sendmail.cf**.

## ABOUT sendmail.mc

Lines near the beginning of **sendmail.mc** provide basic configuration information:

```
divert(-1)dnl
include(`/usr/share/sendmail-cf/m4/cf.m4')dnl
VERSIONID('setup for linux')dnl
OSTYPE('linux')dnl
```

The line that starts with **divert** tells m4 to discard extraneous output it may generate when processing this file.

The **include** statement tells m4 where to find the macro definition file that it will use to process the rest of this file; it points to the file named **cf.m4**. The **cf.m4** file contains other **include** statements that include parts of the **sendmail** configuration rule sets.

The **VERSIONID** statement defines a string that indicates the version of this configuration. You can change this string to include a brief comment about changes you have made to this file or other information. The value of this string is not significant to **sendmail**.

Do not change the **OSTYPE** statement unless you are migrating a **sendmail.mc** file from another operating system.

Other statements you may want to change are explained in the following sections and in the **sendmail** documentation.

## Quoting m4 strings

---

**tip** The m4 macro processor, which converts **sendmail.mc** to **sendmail.cf**, requires strings to be preceded by a back tick ( **`** ) and closed with a single quotation mark ( **'** ).

---

## MASQUERADING

Typically you want your email to appear to come from the user and the domain where you receive email; sometimes the outbound server is in a different domain than the inbound server. You can cause **sendmail** to alter outbound messages so that they appear to come from a user and/or domain other than the one they are sent from: In other words, you *masquerade* (page 1093) the message.

Several lines in **sendmail.mc** pertain to this type of masquerading. Each is commented out in the file that Fedora/RHEL distributes:

```
dn1 MASQUERADE_AS( 'mydomain.com')dn1
dn1 MASQUERADE_DOMAIN(localhost)dn1
dn1 FEATURE(masquerade_entire_domain)dn1
```

The **MASQUERADE\_AS** statement causes email that you send from the local system to appear to come from the specified domain (**mydomain.com** in the commented-out line in the distributed file). Remove the leading **dn1** and change **mydomain.com** to the domain name that you want mail to appear to come from.

The **MASQUERADE\_DOMAIN** statement causes email from the specified system or domain to be masqueraded, just as local email is. That is, email from the system specified in this statement is treated as though it came from the local system: It is changed so that it appears to come from the domain specified in the **MASQUERADE\_AS** statement. Remove the leading **dn1** and change **localhost** to the name of the system or domain that sends the email that you want to masquerade. If the name you specify has a leading period, it specifies a domain. If there is no leading period, the name specifies a system or host. The **sendmail.mc** file can include as many **MASQUERADE\_DOMAIN** statements as necessary.

The **masquerade\_entire\_domain** feature statement causes **sendmail** also to masquerade subdomains of the domain specified in the **MASQUERADE\_DOMAIN** statement. Remove the leading **dn1** to masquerade entire domains.

## ACCEPTING EMAIL FROM UNKNOWN HOSTS

As configured by Fedora/RHEL, **sendmail** accepts email from domains that it cannot resolve (and that may not exist). To turn this feature off and cut down the amount of spam you receive, add **dn1** to the beginning of the following line:

```
FEATURE( 'accept_unresolvable_domains')dn1
```

When this feature is off, **sendmail** uses DNS to look up the domains of all email it receives. If it cannot resolve the domain, it rejects the email.

## SETTING UP A BACKUP SERVER

You can set up a backup mail server to hold email when the primary mail server experiences problems. For maximum coverage, the backup server should be on a different connection to the Internet from the primary server.

Setting up a backup server is easy. Just remove the leading **dn1** from the following line in the *backup* mail server's **sendmail.mc** file:

```
dn1 FEATURE( 'relay_based_on_MX')dn1
```

DNS MX records (page 780) specify where email for a domain should be sent. You can have multiple MX records for a domain, each pointing to a different mail server. When a domain has multiple MX records, each record usually has a different

priority; the priority is specified by a two-digit number, where lower numbers specify higher priorities.

When attempting to deliver email, an MTA first tries to deliver email to the highest-priority server. If that delivery attempt fails, it tries to deliver to a lower-priority server. If you activate the **relay\_based\_on\_MX** feature and point a low-priority MX record at a secondary mail server, the mail server will accept email for the domain. The mail server will then forward email to the server identified by the highest-priority MX record for the domain when that server becomes available.

## OTHER FILES IN /etc/mail

The **/etc/mail** directory holds most of the files that control **sendmail**. This section discusses three of those files: **mailertable**, **access**, and **virtusertable**.

### mailertable: FORWARDS EMAIL FROM ONE DOMAIN TO ANOTHER

When you run a mail server, you may want to send mail destined for one domain to a different location. The **sendmail** daemon uses the **/etc/mail/mailertable** file for this purpose. Each line in **mailertable** holds the name of a domain and a destination mailer separated by whitespace; when **sendmail** receives email for the specified domain, it forwards it to the mailer specified on the same line. Fedora/RHEL enables this feature by default: Put an entry in the **mailertable** file and restart **sendmail** to use it.

The following line in **mailertable** forwards email sent to **tcorp.com** to the mailer at **bravo.com**:

```
$ cat /etc/mail/mailertable
tcorp.com      smtp:[bravo.com]
```

The square brackets in the example instruct **sendmail** not to use MX records but rather to send email directly to the SMTP server. Without the brackets, email could enter an infinite loop.

A period in front of a domain name acts as a wildcard and causes the name to match any domain that ends in the specified name. For example, **.tcorp.com** matches **sales.tcorp.com**, **mktg.tcorp.com**, and so on.

The **sendmail** init script regenerates **mailertable.db** from **mailertable** each time you run it, as when you restart **sendmail**.

### access: SETS UP A RELAY HOST

On a LAN, you may want to set up a single server to process outbound mail, keeping local mail inside the network. A system that processes outbound mail for other systems is called a *relay host*. The **/etc/mail/access** file specifies which systems the local server relays email for. As configured by Fedora/RHEL, this file lists only the local system:

```
$ cat /etc/mail/access
...
```

```
# by default we allow relaying from localhost...
Connect:localhost.localdomain      RELAY
Connect:localhost                  RELAY
Connect:127.0.0.1                  RELAY
```

You can add systems to the list in **access** by adding an IP address followed by white-space and the word **RELAY**. The following line adds the 192.168. subnet to the list of hosts that the local system relays mail for:

```
Connect:192.168.                  RELAY
```

The **sendmail** init script regenerates **access.db** from **access** each time you run it, as when you restart **sendmail**.

## virtusertable: SERVES EMAIL TO MULTIPLE DOMAINS

When the DNS MX records are set up properly, a single system can serve email to multiple domains. On a system that serves mail to many domains, you need a way to sort the incoming mail so that it goes to the right places. The **virtusertable** file can forward inbound email addressed to different domains (**aliases** cannot do this).

As **sendmail** is configured by Fedora/RHEL, **virtusertable** is enabled. You need to put forwarding instructions in the **/etc/mail/virtusertable** file and restart **sendmail** to serve the specified domains. The **virtusertable** file is similar to the **aliases** file (page 675), except the left column contains full email addresses, not just local ones. Each line in **virtusertable** starts with the address that the email was sent to, followed by whitespace and the address **sendmail** will forward the email to. As with **aliases**, the destination can be a local user, an email address, a file, or a pipe symbol (**|**), followed by a command.

The following line from **virtusertable** forwards mail addressed to **zach@tcorp.com** to **zcs**, a local user:

```
zach@tcorp.com      zcs
```

You can also forward email for a user to a remote email address:

```
sams@bravo.com      sams@tcorp.com
```

You can forward all email destined for a domain to another domain without specifying each user individually. To forward email for every user at **bravo.com** to **tcorp.com**, specify **@bravo.com** as the first address on the line. When **sendmail** forwards email, it replaces the **%1** in the destination address with the name of the recipient. The next line forwards all email addressed to **bravo.com** to **tcorp.com**, keeping the original recipients' names:

```
@bravo.com          %1@tcorp.com
```

Finally you can specify that email intended for a specific user should be rejected by using the **error** namespace in the destination. The next example bounces email addressed to **spam@tcorp.com** with the message **5.7.0:550 Invalid address**:

```
spam@tcorp.com      error:5.7.0:550 Invalid address
```

**.forward, aliases, and virtusertable** The **.forward** (page 676), **aliases** (page 675), and **virtusertable** files all do the same thing: They forward email addressed to one user to another user. They can also redirect email to a file or to serve as input to a program. The difference between them is scope and ownership; see Table 20-1.

**Table 20-1**    Comparison of forwarding techniques

	<b>.forward</b>	<b>aliases</b>	<b>virtusertable</b>
<b>Controlled by</b>	nonroot user	root	root
<b>Forwards email addressed to</b>	nonroot user	Any real or virtual user on the local system	Any real or virtual user on any domain recognized by <b>sendmail</b>
<b>Order of precedence</b>	Third	Second	First

# ADDITIONAL EMAIL TOOLS

This section covers SpamAssassin, Webmail, and mailing lists. In addition, it discusses how to set up IMAP and POP3 servers and a KMail client.

## SPAMASSASSIN

Spam—or more correctly, UCE (unsolicited commercial email)—accounts for more than three-quarters of all email. SpamAssassin evaluates each piece of incoming email and assigns it a number that indicates the likelihood that the email is spam. The higher the number, the more likely that the email is spam. You can filter email based on its rating. SpamAssassin is effective as installed, but you can modify its configuration files to make it better fit your needs.

How SpamAssassin works You can set up SpamAssassin (**spamassassin** package) on a mail server so that it rates all inbound email before it is sent to users. Alternatively, individual users can run it from their mail clients. Either way, you run the SpamAssassin **spamd** daemon and filter email through this daemon using the **spamc** client.

SpamAssassin uses several techniques to identify spam:

- **Header analysis**—Checks for tricks that people who send spam use to make you think email is legitimate
- **Text analysis**—Checks the body of an email for characteristics of spam
- **Blacklists**—Checks various lists to see if the sender is known for sending spam
- **Database**—Checks the signature of the message against Vipul’s Razor (razor.sourceforge.net), a spam-tracking database

With **spamd** running, you can see how **spamc** works by sending a simple string to it:

```
$ echo "hi there" | spamc
```

```
X-Spam-Checker-Version: SpamAssassin 3.3.0-alpha3-r816412 (2009-09-17) on F12Ad
```

```
X-Spam-Flag: YES
```

```
X-Spam-Level: *****
```

```
X-Spam-Status: Yes, score=6.0 required=5.0 tests=EMPTY_MESSAGE,MISSING_DATE,
MISSING_HB_SEP,MISSING_HEADERS,MISSING_MID,MISSING_SUBJECT,NO_HEADERS_MESSAGE,
NO_RECEIVED,NO_RELAYS autolearn=no version=3.3.0-alpha3-r816412
```

```
X-Spam-Report:
```

```
* -0.0 NO_RELAYS Informational: message was not relayed via SMTP
* 2.5 MISSING_HB_SEP Missing blank line between message header and body
* 1.6 MISSING_HEADERS Missing To: header
* 0.0 MISSING_MID Missing Message-Id: header
* 1.3 MISSING_SUBJECT Missing Subject: header
* 0.6 EMPTY_MESSAGE Message appears to have no textual parts and no
  Subject: text
* -0.0 NO_RECEIVED Informational: message has no Received headers
* 0.0 MISSING_DATE Missing Date: header
* 0.0 NO_HEADERS_MESSAGE Message appears to be missing most RFC-822
  headers
```

```
hi there
```

```
Subject: [SPAM]
```

```
X-Spam-Prev-Subject: (nonexistent)
```

Of course, SpamAssassin complains because the string you gave it did not contain standard email headers. The logical line that starts with X-Spam-Status contains the heart of the report on the string **hi there**. First it says **Yes** (it considers the message to be spam). SpamAssassin uses a rating system that assigns a number of hits to a piece of email. If the email receives more than the required number of hits (5.0 by default), SpamAssassin marks it as spam. The string failed for many reasons that are enumerated on this status line. The reasons are detailed in the following X-Spam-Report. The following listing is from a real piece of spam processed by SpamAssassin. It received 24.5 hits, indicating that it is almost certainly spam.

```
X-Spam-Status: Yes, hits=24.5 required=5.0
  tests=DATE_IN_FUTURE_06_12,INVALID_DATE_TZ_ABSURD,
  MSGID_OE_SPAM_4ZERO,MSGID_OUTLOOK_TIME,
  MSGID_SPAMSIGN_ZEROES,RCVD_IN_DSNL,RCVD_IN_NJABL,
  RCVD_IN_UNCONFIRMED_DSNL,REMOVE_PAGE,VACATION_SCAM,
  X_NJABL_OPEN_PROXY
  version=2.55
X-Spam-Level: *****
X-Spam-Checker-Version: SpamAssassin 2.55 (1.174.2.19-2003-05-19-exp)
X-Spam-Report: This mail is probably spam. The original message has been attached
  along with this report, so you can recognize or block similar unwanted
  mail in future. See http://spamassassin.org/tag/ for more details.
  Content preview: Paradise SEX Island Awaits! Tropical 1 week vacations
  where anything goes! We have lots of WOMEN, SEX, ALCOHOL, ETC! Every
  man's dream awaits on this island of pleasure. [...]
  Content analysis details: (24.50 points, 5 required)
  MSGID_SPAMSIGN_ZEROES (4.3 points) Message-Id generated by spam tool (zeroes variant)
  INVALID_DATE_TZ_ABSURD (4.3 points) Invalid Date: header (timezone does not exist)
  MSGID_OE_SPAM_4ZERO (3.5 points) Message-Id generated by spam tool (4-zeroes variant)
  VACATION_SCAM (1.9 points) BODY: Vacation Offers
  REMOVE_PAGE (0.3 points) URI: URL of page called "remove"
  MSGID_OUTLOOK_TIME (4.4 points) Message-Id is fake (in Outlook Express format)
  DATE_IN_FUTURE_06_12 (1.3 points) Date: is 6 to 12 hours after Received: date
  RCVD_IN_NJABL (0.9 points) RBL: Received via a relay in dnsbl.njabl.org
  [RBL check: found 94.99.190.200.dnsbl.njabl.org.]
  RCVD_IN_UNCONFIRMED_DSNL (0.5 points) RBL: Received via a relay in unconfirmed.dsnl.org
  [RBL check: found 94.99.190.200.unconfirmed.dsnl.org.]
  X_NJABL_OPEN_PROXY (0.5 points) RBL: NJABL: sender is proxy/relay/formmail/spam-source
  RCVD_IN_DSNL (2.6 points) RBL: Received via a relay in list.dsnl.org
  [RBL check: found 211.157.63.200.list.dsnl.org.]
X-Spam-Flag: YES
Subject: [SPAM] re: statement
```

Because SpamAssassin considered the preceding email to be spam, it modified the Subject line by adding [SPAM] at the beginning of the line.

**Configuration** Edit `/etc/mail/spamassassin/local.cf` to configure SpamAssassin globally. Users can override the global options and add their own options in `~/.spamassassin/user_prefs`. You can put the options discussed in this section in either of these files. Use `perldoc` (page 977) to display the configuration document that lists all the options:

**Documentation** `$ perldoc Mail::SpamAssassin::Conf`

As shown in the preceding example, SpamAssassin rewrites the Subject line of email that it rates as spam. The `rewrite_subject` keyword in the configuration files controls this behavior. A `1` following this keyword indicates that SpamAssassin will rewrite Subject lines. Change the `1` to a `0` (zero) to turn off this behavior:

```
rewrite_subject 0
```

The `required_hits` keyword specifies the minimum number of hits a piece of email must receive before SpamAssassin considers it to be spam. The default is `5.0`. With a higher number, SpamAssassin marks fewer pieces of email as spam.

```
required_hits 5.00
```

Sometimes mail from addresses that should be marked as spam is not, or mail from addresses that should not be marked as spam is. Use the `whitelist_from` keyword to specify addresses that should never be marked as spam and `blacklist_from` to specify addresses that should always be marked as spam:

```
whitelist_from sams@tcorp.com
blacklist_from spammer.net
```

You can specify multiple addresses, separated by SPACES, on the `whitelist_from` and `blacklist_from` lines. Each address can include wildcards. You can also use multiple lines.

**SELinux** When SELinux is set to use a targeted policy, the SpamAssassin daemon, `spamd`, is protected by SELinux. You can disable this protection if necessary. For more information refer to “Setting the Targeted Policy with `system-config-selinux`” on page 416.

## CONFIGURING SPAMASSASSIN

SpamAssassin looks in many locations for configuration files; for details, refer to the `spamassassin` man page. The easiest configuration file to work with is `/etc/mail/spamassassin/local.cf`. You can edit this file to configure SpamAssassin globally. Users can override these global options and add their own options in the `~/.spamassassin/user_prefs` file. You can put the options discussed in this section in either of these files. You can use `perldoc` (page 977) to display information on SpamAssassin options:

```
$ perldoc Mail::SpamAssassin::Conf
```



As shown in the preceding example, SpamAssassin rewrites the Subject line of email that it rates as spam. A **rewrite\_subject** keyword in the configuration files controls this behavior. A **1** following this keyword indicates that SpamAssassin will rewrite Subject lines. A **0** (zero) turns off this behavior.

SpamAssassin is set up to rewrite the Subject line of email that it rates as spam. The **rewrite\_header** keyword in the configuration files controls this behavior. The word **Subject** following this keyword tells SpamAssassin to rewrite Subject lines.

```
rewrite_header Subject [SPAM]
```

The **required\_hits** keyword specifies the minimum number of hits a piece of email must receive before SpamAssassin considers it to be spam. The default is 5.0. Set the value of this keyword to a higher number to cause SpamAssassin to mark fewer pieces of email as spam.

A **required\_score** keyword specifies the minimum score a piece of email must receive before SpamAssassin considers it to be spam. The default is 5.00. Set the value of this keyword to a higher number to cause SpamAssassin to mark fewer pieces of email as spam.

```
required_score 5.00
```

When set to 0 (zero), the **report\_safe** keyword causes SpamAssassin to modify the header of email it rates as spam.

Sometimes mail from addresses that should be marked as spam is not, or mail from addresses that should not be marked as spam is. Use the **whitelist\_from** keyword to specify addresses that should never be marked as spam and **blacklist\_from** to specify addresses that should always be marked as spam:

```
whitelist_from sams@example.com
blacklist_from *@spammer.net
```

You can specify multiple addresses, separated by SPACES, on the **whitelist\_from** and **blacklist\_from** lines. Each address can include wildcards. To whitelist everyone sending email from the example.com domain, use **whitelist\_from \*@example.com**. You can use multiple **whitelist\_from** and **blacklist\_from** lines.

## RUNNING SPAMASSASSIN ON A MAIL SERVER

This section explains how to set up SpamAssassin on a mail server so that it will process all email being delivered to local systems before it is sent to users. It shows how to use **procmail** as the MDA and have **procmail** send email through **spamc**.

First, make sure the MTA (**sendmail**) uses **procmail** as the MDA. The first of the following lines in **sendmail.mc** specifies the **procmail** command, its path, and flags. The MAILER line defines **procmail** as the mailer. You should not have to change either of these lines.

```
FEATURE(local_procmail,`, `procmail -t -Y -a $h -d $u')dn1
MAILER(procmail)dn1
```

Also make sure the **procmail** package is installed on the server system. Next, if the **/etc/procmailrc** configuration file does not exist, create it so that this file is owned by **root** and has 644 permissions and the following contents. If it does exist, append the last two lines from the following file to it:

```
$ cat /etc/procmailrc
DROPPRIVS=yes
:0 fw
| /usr/bin/spamc
```

The first line of this file ensures that **procmail** runs with the least possible privileges. The next two lines implement a rule that pipes each user's incoming email through **spamc**. The **:0** tells **procmail** that a rule follows. The **f** flag indicates a filter; the **w** flag causes **procmail** to wait for the filter to complete and check the exit code. The last line specifies that the **/usr/bin/spamc** utility will be used as the filter.

With this file in place, all email that the server system receives for local delivery passes through SpamAssassin, which rates it according to the options in the global configuration file. Users with accounts on the server system can override the global SpamAssassin configuration settings in their **~/spamassassin/user\_prefs** files.

When you run SpamAssassin on a server, you typically want to rate the email conservatively so that fewer pieces of good email are marked as spam. Setting **required\_hits** in the range of 6–10 is generally appropriate. Also, you do not want to remove any email automatically because you could prevent a user from getting a piece of nonspam email. When the server marks email as possibly being spam, users can manually or automatically filter the spam and decide what to do with it.

## WEBMAIL

Traditionally you read email using a dedicated email client such as KMail. Recently it has become more common to use a Web application to read email. If you have an email account with a commercial provider such as Gmail, HotMail, or Yahoo! Mail, you use a Web browser to read email. Email read in this manner is called *Webmail*. Unlike email you read on a dedicated client, you can read Webmail from anywhere you can open a browser on the Internet: You can check your email from an Internet cafe or a friend's computer, for example.

SquirrelMail (**squirrelmail** package) provides Webmail services; the SquirrelMail files reside in **/usr/share/squirrelmail**. If you want to run SquirrelMail, you must run IMAP (page 689) because SquirrelMail uses IMAP to receive and authenticate email. You must also run Apache (Chapter 26) so a user can use a browser to connect to SquirrelMail.

SquirrelMail is modular: You can easily add functionality using plugins. There are plugins that allow you to share a calendar and plugins that give you the ability to change passwords using the Webmail interface. See the plugins section of the SquirrelMail Web site for more information.

Create the following link to make SquirrelMail accessible from the Web:

```
# ln -s /usr/share/squirrelmail /var/www/html/mail
```

With this link in place, you can point a Web browser at <http://localhost/mail> to display the SquirrelMail login page (Figure 20-1).

Next use the `conf.pl` script in `/usr/share/squirrelmail/config` to configure SquirrelMail:

```
# cd /usr/share/squirrelmail/config
# ./conf.pl
SquirrelMail Configuration : Read: config_default.php (1.4.0)
-----
Main Menu --
1. Organization Preferences
2. Server Settings
3. Folder Defaults
4. General Options
5. Themes
6. Address Books
7. Message of the Day (MOTD)
8. Plugins
9. Database
10. Languages

D. Set pre-defined settings for specific IMAP servers

C Turn color on
S Save data
Q Quit

Command >>
```

The only item that you must set to get SquirrelMail to work is the server's domain name (from the Server Settings page). SquirrelMail provides several themes; if you do not like the way SquirrelMail looks, choose another theme from the Themes page.



**Figure 20-1** SquirrelMail login page

## MAILING LISTS

A mailing list can be an asset if you regularly send email to the same large group of people. A mailing list provides several advantages over listing numerous recipients in the To or Cc field of an email or sending the same email individually to many people:

- **Anonymity**—None of the recipients of the email can see the addresses of the other recipients.
- **Archiving**—Email sent to the list is stored in a central location where list members or the public, as specified by the list administrator, can browse through it.
- **Access control**—You can easily specify who can send email to the list.
- **Consistency**—When you send mail to a group of people using To or Cc, it is all too easy to leave people who want to be on the list off and to leave people who want to be off the list on.
- **Efficiency**—A mailing list application spreads email transmissions over time so it does not overload the mail server.

Mailman provides mailing list support. The bulk of Mailman resides in `/usr/lib/mailman`. The configuration file is `/etc/mailman/mm_cfg.py`, which is a link to `/usr/lib/mailman/Mailman/mm_cfg.py`. Before you can use Mailman, you need to replace `fqdn` in the two following lines in `mm_cfg.py` with the name of the local domain enclosed within single quotation marks:

```
DEFAULT_URL_HOST = fqdn
DEFAULT_EMAIL_HOST = fqdn
```

After making these changes, create a new mailing list with the `newlist` utility:

```
# /usr/lib/mailman/bin/newlist
```

Enter the name of the list: **painting\_class**

Enter the email of the person running the list: **helen@tcorp.com**

Initial painting\_class password:

To finish creating your mailing list, you must edit your `/etc/aliases` (or equivalent) file by adding the following lines, and possibly running the 'newaliases' program:

```
## painting_class mailing list
painting_class: "|/usr/lib/mailman/mail/mailman post painting_class"
painting_class-admin: "|/usr/lib/mailman/mail/mailman admin painting_class"
painting_class-bounces: "|/usr/lib/mailman/mail/mailman bounces painting_class"
painting_class-confirm: "|/usr/lib/mailman/mail/mailman confirm painting_class"
painting_class-join: "|/usr/lib/mailman/mail/mailman join painting_class"
painting_class-leave: "|/usr/lib/mailman/mail/mailman leave painting_class"
painting_class-owner: "|/usr/lib/mailman/mail/mailman owner painting_class"
painting_class-request: "|/usr/lib/mailman/mail/mailman request painting_class"
painting_class-subscribe: "|/usr/lib/mailman/mail/mailman subscribe painting_class"
painting_class-unsubscribe: "|/usr/lib/mailman/mail/mailman unsubscribe painting_class"
```

Hit enter to notify painting\_class owner...

Before the list can receive email, you need to copy the lines generated by `newlist` to the end of `/etc/aliases` (page 675) and run `newaliases`.

Mailman includes a Web configuration interface that you can enable by configuring a Web server to run the scripts in `/usr/lib/mailman/cgi-bin`. Refer to the file `/etc/httpd/conf.d/mailman.conf` for a sample entry that you can put in `/etc/httpd/conf/httpd.conf` (page 850) to set up this interface (pipemail is the archive manager that Mailman uses).

## SETTING UP AN IMAP OR POP3 SERVER

Two protocols allow users to retrieve email remotely: IMAP (Internet Message Access Protocol) and POP (Post Office Protocol). The `dovecot` package ([www.dovecot.org](http://www.dovecot.org)) includes the `imap-login` and `pop3-login` daemons that implement these protocols. Typically you do not have to modify the `dovecot` configuration file (`/etc/dovecot.conf`). See `/usr/share/doc/dovecot*` for more information.

The `dovecot` self-signed certificate

The rpm installation script creates the self-signed certificates that `dovecot` requires in `/etc/pki/dovecot/certs/dovecot.pem` and `/etc/pki/dovecot/private/dovecot.pem`.

Run `chkconfig` to cause the `dovecot` daemons to start when the system enters multi-user mode:

```
# /sbin/chkconfig dovecot on
```

Start the daemons with the following command:

```
# /sbin/service dovecot start
Starting Dovecot Imap:
```

[ OK ]

Despite `dovecot` reporting that it started the IMAP server only, it also starts the POP3 server.

---

## AUTHENTICATED RELAYING

If you travel with a portable computer such as a laptop, you may connect to the Internet through a different connection at each location where you work. Perhaps you travel for work, or maybe you just bring your laptop home at night.

This section does not apply if you always dial in to the network through your ISP. In that case, you are always connected to your ISP's network and it is as though you never moved your computer.

On a laptop you do not use a local instance of `sendmail` to send email. Instead you use SMTP to connect to an ISP or to a company's SMTP server, which relays the outgoing mail. To avoid relaying email for anyone, including malicious users who would send spam, SMTP servers restrict who they relay email for, based on IP address. By implementing authenticated relaying, you can cause the SMTP server to authenticate, based on user identification. In addition, SMTP can encrypt communication when you send mail from your email client and use the SMTP server.

An authenticated relay provides these advantages over a plain connection:

- You can send email from any Internet connection.
- The secure connection makes it more difficult to intercept email as it traverses the Internet.
- The outgoing mail server requires authentication, preventing it from being used for spam.

You set up authenticated relaying by creating an SSL certificate or using an existing one, enabling SSL in **sendmail**, and telling your email client to connect to the SMTP server using SSL. If you have an SSL certificate from a company such as Verisign, you can skip the next section, in which you create a self-signed certificate.

## CREATING A SELF-SIGNED CERTIFICATE FOR sendmail

*FEDORA* The default location for SSL certificates is `/etc/pki/tls/certs` (PKI stands for public key infrastructure). Working as **root**, use **mkdir** to create this directory if necessary and then use the **Makefile** in this directory to generate the required certificates. Apache uses a similar procedure for creating a certificate (page 878).

```
# cd /etc/pki/tls/certs
# make sendmail.pem
...
Generating a 2048 bit RSA private key
.....+++
.....+++
writing new private key to '/tmp/openssl.1TUEh3'
-----
You are about to be asked to enter information that will be incorporated
into your certificate request.
What you are about to enter is what is called a Distinguished Name or a DN.
There are quite a few fields but you can leave some blank
For some fields there will be a default value,
If you enter '.', the field will be left blank.
-----
Country Name (2 letter code) [XX]:US
State or Province Name (full name) []:California
Locality Name (eg, city) [Default City]:San Francisco
Organization Name (eg, company) [Default Company Ltd]:Sobell Associates Inc.
Organizational Unit Name (eg, section) []:
Common Name (eg, your name or your server's hostname) []:sobell.com
Email Address []:mgs@sobell.com
```

You can enter any information you wish in the certificate.

## ENABLING SSL IN sendmail

Once you have a certificate, instruct **sendmail** to use it by uncommenting the following lines in **sendmail.mc**:

```
TRUST_AUTH_MECH( `EXTERNAL DIGEST-MD5 CRAM-MD5 LOGIN PLAIN')
define( `confAUTH_MECHANISMS', `EXTERNAL GSSAPI DIGEST-MD5 CRAM-MD5 LOGIN PLAIN')
```

These lines specify the authentication mechanisms.

Next, uncomment the following lines in **sendmail.mc** to tell **sendmail** where the certificate is:

```
dn1 define(`confCACERT_PATH', `/etc/pki/tls/certs')dn1
dn1 define(`confCACERT', `/etc/pki/tls/certs/ca-bundle.crt')dn1
dn1 define(`confSERVER_CERT', `/etc/pki/tls/certs/sendmail.pem')dn1
dn1 define(`confSERVER_KEY', `/etc/pki/tls/certs/sendmail.pem')dn1
```

Encrypted connections are made in one of two ways: SSL (simpler) or TLS. SSL requires a dedicated port and has the client and the server negotiate a secure connection and continue the transaction as if the connection were not encrypted. TLS has the client connect to the server using an insecure connection and then issue a STARTTLS command to negotiate a secure connection. TLS runs over the same port as an unencrypted connection. Because many clients support only SSL, it is a good idea to instruct **sendmail** to listen on the SMTPS port. The final line you must uncomment in **sendmail.mc** instructs **sendmail** to listen on the SSL port:

```
DAEMON_OPTIONS( `Port=smtps, Name=TLSMTPA, M=s')
```

## ENABLING SSL IN THE MAIL CLIENT

Enabling SSL in a mail client is usually quite simple. For example, KMail provides **Settings⇒Configure KMail⇒Accounts⇒Receiving⇒Add/Modify⇒Extras** that allows you to choose the type of encryption you want to use: **None**, **SSL**, or **TLS**.

---

## ALTERNATIVES TO sendmail

Over the years, **sendmail** has grown to be enormously complex. Its complexity makes it challenging to configure if you want to set up something more than a simple mail server. Its size and complexity also add to its vulnerability. For optimal security, make sure you run the latest version of **sendmail** and always keep **sendmail** up-to-date. You might consider using one of the following alternatives.

- Postfix (postfix package) is an alternative MTA. Postfix attempts to be fast and easy to administer, while also being **sendmail** compatible enough to not upset **sendmail** users. Postfix has a good reputation for ease of use and security and is a drop-in replacement for **sendmail**. Documentation for Postfix can be found at [www.postfix.org/docs.html](http://www.postfix.org/docs.html).
- Qmail is a direct competitor of Postfix and has the same objectives. By default, Qmail stores email using the **maildir** format as opposed to the **mbox** format that other MTAs use (page 674). The Qmail Web site is [www.qmail.org](http://www.qmail.org).

## CHAPTER SUMMARY

The **sendmail** daemon is an MTA (Mail Transfer Agent). When you send a message, **sendmail** works with other software to get it to the proper recipients. You can set up **sendmail** to relay email to an SMTP server that sends the email on to its ultimate destination or you can have **sendmail** send email directly to the SMTP servers for the domains receiving the email. By default, **sendmail** stores incoming messages in the mail spool directory, **/var/spool/mail**.

The file that controls many aspects of how **sendmail** works is **sendmail.cf**. If you edit **sendmail.mc**, when you restart **sendmail**, the **sendmail** init script generates **sendmail.cf**. The system administrator can use the **/etc/aliases** file and ordinary users can use **~/forward** files to reroute email to one or more local or remote addresses, to files, or as input to programs.

You can use a program such as SpamAssassin to grade and mark email as to the likelihood of it being spam. You can then decide what to do with the marked email: You can look at each piece of potential spam and decide where to put it, or you can have your MUA automatically put potential spam in a special mailbox for spam.

Other programs that can help with email include SquirrelMail, which provides Webmail services, and Mailman, which provides mailing list support.

---

## EXERCISES

1. By default, email addressed to **system** goes to **root**. How would you also save a copy in **/var/logs/systemmail**?
2. How would Max store a copy of his email in **~/mbox** and send a copy to **max@bravo.com**?
3. If your firewall allowed only the machine with the IP address 192.168.1.1 to send email outside the network, how would you instruct your local copy of **sendmail** to use this server as a relay?
4. What does **dnl** stand for in the m4 macro language? What are **dnl** commands used for?
5. SpamAssassin is installed on your mail server, with the threshold set to an unusually low value of 3, resulting in a lot of false positives. What rule could you give to your mail client to allow it to identify spam with a score of 5 or higher?
6. Describe the software and protocols used when Max sends an email to Sam on a remote Linux system.



---

## ADVANCED EXERCISES

7. Your company's current mail server runs on a commercial UNIX server, and you are planning to migrate it to Linux. After copying the configuration files across to the Linux system, you find that it does not work. What might you have forgotten to change?
8. Assume you have a script that sends its output to standard output. How would you modify the script to send the output in an email to a user specified by the first argument on the command line? (You may assume that the data is stored in `$RESULT`.)
9. Give a simple way of reading your email that does not involve the use of an MUA.
10. If you accidentally delete the `/etc/aliases` file, how could you easily re-create it (assuming that you had not restarted `sendmail`)?

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## NIS AND LDAP

### IN THIS CHAPTER

How NIS Works .....	696
Setting Up an NIS Client .....	699
yppasswd: Changes NIS Passwords .....	702
Setting Up an NIS Server .....	703
yyppasswdd: The NIS Password Update Daemon .....	709
LDAP .....	710
Setting Up an LDAP Server .....	713

NIS (Network Information Service) simplifies the maintenance of common administrative files by keeping them in a central database and having clients contact the database server to retrieve information from the database. Developed by Sun Microsystems, NIS is an example of the client/server paradigm.

Just as DNS addresses the problem of keeping multiple copies of `/etc/hosts` files up-to-date, NIS deals with the issue of keeping system-independent configuration files (such as `/etc/passwd`) current. Most networks today are *heterogeneous* (page 1085); even though they run different varieties of UNIX or Linux, they have certain common attributes, such as a `passwd` file.

An LDAP (Lightweight Directory Access Protocol) directory can hold many types of information, including names and addresses, lists of network services, and authentication data. Another example of a client/server setup, LDAP is appropriate for any kind of relatively static, structured information where fast lookups are required. Many types of clients are set up to communicate with LDAP servers, including email clients, browsers, and authentication servers.

## INTRODUCTION TO NIS

A primary goal of a LAN administrator is to make the network transparent to users. One aspect of this transparency is presenting users with similar environments, including username and password, when they log in on different machines. From the administrator's perspective, the information that supports a user's environment should not be replicated but rather should be kept in a central location and distributed as requested. NIS simplifies this task.

As with DNS, users need not be aware that NIS is managing system configuration files. Setting up and maintaining NIS databases are tasks for the system administrator; individual users and users on single-user Linux systems rarely need to work directly with NIS.

**Yellow Pages** NIS used to be called the *Yellow Pages*, and some people still refer to it by this name. Sun renamed the service because another corporation holds the trademark to that name. The names of NIS utilities and files, however, are reminiscent of the old name: `ypcat` displays and `ypmatch` searches an NIS file, and the server daemon is named `ypserv`.

---

## How NIS Works

**NIS domain** NIS makes a common set of information available to systems on a network. The network, referred to as an *NIS domain*, is characterized by each system having the same *NIS domain name* (different than a (DNS) *domain name* [page 1080]). Technically, an NIS domain is a set of NIS maps, or database files.

**Master and slave servers** Each NIS domain must have exactly one master server; larger networks may have slave servers. Each slave server holds a copy of the NIS database from the master. The need for slave servers is based on the size of the NIS domain and the reliability of the systems and network. A system can belong to only one NIS domain at a time.

When a client determines that a server is down or is not responding fast enough, it selects another server, as specified in the configuration file. If it cannot reach a server, `ybind` terminates with an error.

**nsswitch.conf** Whether a system uses NIS, DNS, local files, or a combination as the source of certain information, and in what order, is determined by `/etc/nsswitch.conf` (page 455). When it needs information from the NIS database, a client requests the information from the NIS server. For example, when a user attempts to log in, the client system may authenticate the user with name and password information from the NIS server.

You can configure `nsswitch.conf` to cause `/etc/passwd` to override NIS password information for the local system. When you do not export the `root` account to NIS

(and you should not), this setup allows you to have a unique **root** password for each system.

**Source files** Under Fedora/RHEL, NIS derives the information it offers—such as usernames, passwords, and local system names and IP addresses—from local ASCII configuration files such as **/etc/passwd** and **/etc/hosts**. These files are called *source files* or *master files*. (Some administrators avoid confusion by using different files for local configuration and NIS source information.) An NIS server can include information from as many of the following source files as is appropriate:

<b>/etc/group</b>	Defines groups and their members
<b>/etc/gshadow</b>	Provides shadow passwords for groups
<b>/etc/hosts</b>	Maps local systems and IP addresses
<b>/etc/passwd</b>	Lists user information
<b>/etc/printcap</b>	Lists printer information
<b>/etc/rpc</b>	Maps RPC program names and numbers
<b>/etc/services</b>	Maps system service names and port numbers
<b>/etc/shadow</b>	Provides shadow passwords for users

The information that NIS offers is based on files that change from time to time; NIS is responsible for making this changing information available in a timely manner to all systems in the NIS domain.

**NIS maps** Before NIS can store the information contained in a source file, it must be converted to a *dbm* (page 1078) format file called a *map*. Each map is indexed on one field (column). Records (rows) from a map can be retrieved by specifying a value from the indexed field. Some files generate two maps, each indexed on a different field. For example, the **/etc/passwd** file generates two maps: one indexed by username, the other indexed by UID. These maps are named **passwd.byname** and **passwd.byuid**.

**optional** NIS maps correspond to C library functions. The **getpwnam()** and **getpwuid()** functions obtain username and UID information from **/etc/passwd** on non-NIS systems. On NIS systems, these functions place RPC calls to the NIS server in a process that is transparent to the application calling the function.

**Map names** The names of the maps that NIS uses correspond to the files located in the **/var/yp/nisdomainname** directory on the master server, where *nisdomainname* is the name of the NIS domain:

```
$ ls /var/yp/mgs
group.bygid  mail.aliases  protocols.byname  services.byname
group.byname netid.byname  protocols.bynumber services.byservicename
hosts.byaddr passwd.byname  rpc.byname        ypservers
hosts.byname passwd.byuid   rpc.bynumber
```

**Map nicknames** To make it easier to refer to NIS maps, you can assign nicknames to maps. The `/var/yp/nicknames` file contains a list of commonly used nicknames. View the `nicknames` file or give the command `ypcat -x` to display the list of nicknames:

```
$ cat /var/yp/nicknames
passwd          passwd.byname
group           group.byname
networks        networks.byaddr
hosts           hosts.byname
protocols       protocols.bynumber
services        services.byname
aliases         mail.aliases
ethers          ethers.byname
```

Each line in `nicknames` contains a nickname followed by whitespace and the name of the map the nickname refers to. You can add, remove, or modify nicknames by changing the `nicknames` file.

**Displaying maps** The `ypcat` and `ypmatch` utilities display information from the NIS maps. Using the nickname `passwd`, the following command displays the information contained in the `passwd.byname` map:

```
$ ypcat passwd
mark:$1$X4JAzD0.$c.64fRCLPvQNSmq9qrFYv/:500:500:Mark Sobell:/home/mark:/bin/bash
...
```

By default, NIS stores passwords only for users with UIDs less than 500 (see MINUID, on page 706). Thus `ypcat` does not display lines for `root`, `bin`, and other system entries. You can display password information for a single user with `ypmatch`:

```
$ ypmatch mark passwd
mark:$1$X4JAzD0.$c.64fRCLPvQNSmq9qrFYv/:500:500:Mark Sobell:/home/mark:/bin/bash
```

You can retrieve the same information by filtering the output of `ypcat` through `grep`, but `ypmatch` is more efficient because it searches the map directly, using a single process. The `ypmatch` utility works on the key for the map only. To match members of the group or other fields not in a map, such as the *GECOS* (page 1084) field in `passwd`, you need to use `ypcat` with `grep`:

```
$ ypcat passwd | grep -i sobell
mark:$1$X4JAzD0.$c.64fRCLP9qrFYv/:500:500:Mark Sobell:/home/mark:/bin/bash
```

**Terminology** This chapter uses the following definitions:

NIS source files	The ASCII files that NIS obtains information from
NIS maps	The dbm-format files created from NIS source files
NIS database	The collection of NIS maps

## MORE INFORMATION

Local man pages: `domainname`, `makedbm`, `netgroup`, `revnetgroup`, `ypbind`, `ypcat`, `ypinit`, `ypmatch`, `yppasswd`, `ypoll`, `yppush`, `ypset`, `ypserv`, `ypserv.conf`, `ypwhich`, `ypxfr`, `ypxfrd`

(Some of these are installed only when you install **ypserv**, which is needed when you run an NIS server [page 703].)

Web [www.linux-nis.org](http://www.linux-nis.org)

## SETTING UP AN NIS CLIENT

This section discusses how to set up an NIS client on the local system.

### PREREQUISITES

Install the following packages:

- **yp-tools**
- **ypbind**

Run **chkconfig** to cause **ypbind** to start when the system enters multiuser mode:

```
# /sbin/chkconfig ypbind on
```

After you have configured **ypbind**, start it with **service**:

```
# /sbin/service ypbind start
```

```
Starting NIS service:
```

```
[ OK ]
```

```
Binding NIS service:
```

```
[ OK ]
```

### NOTES

If there is no NIS server for the local system's NIS domain, you need to set one up (page 703). If there is an NIS server, you need to know the name of the NIS domain the system belongs to and (optionally) the name or IP address of one or more NIS servers for the NIS domain.

An NIS client can run on the same system as an NIS server.

**SELinux** When SELinux is set to use a targeted policy, NIS is protected by SELinux. You can disable this protection if necessary. For more information refer to “Setting the Targeted Policy with **system-config-selinux**” on page 416.

### STEP-BY-STEP SETUP

This section lists the steps involved in setting up and starting an NIS client.

#### SPECIFYING THE SYSTEM'S NIS DOMAIN NAME

Specify the system's NIS domain name in the **/etc/sysconfig/network** file by adding the following line:

```
NISDOMAIN=nisdomainname
```

where *nisdomainname* is the name of the NIS domain that the local system belongs to. The **ypbind** and **ypserv** init scripts execute the **network** file so that the name of the

system's NIS domain is set just before it is needed. You can use the `nisdomainname` utility to set or view the NIS domain name, but setting it in this manner does not maintain the name when the system is rebooted:

```
# nisdomainname
(none)
# nisdomainname mgs
# nisdomainname
mgs
```

---

### A DNS domain name is different from an NIS domain name

**tip** The DNS domain name is used throughout the Internet to refer to a group of systems. DNS maps these names to IP addresses to enable systems to communicate with one another.

The NIS domain name is used strictly to identify systems that share an NIS server and is normally not seen or used by users and other programs. Some administrators use one name as both a DNS domain name and an NIS domain name, although this practice can degrade security.

---

---

### To avoid confusion, use `nisdomainname`, not `domainname`

**caution** The `domainname` and `nisdomainname` utilities do the same thing: They display or set the system's NIS domain name. Use `nisdomainname` to avoid confusion when you are also working with DNS domain names.

---

---

### You must set the local system's NIS domain name

**caution** If you do not set the local system's NIS domain name, when you start `yppbind`, it sends a message to `rsyslogd` (page 582) and quits.

---

---

## EDIT /etc/yp.conf TO SPECIFY AN NIS SERVER

Edit `/etc/yp.conf` to specify one or more NIS servers (masters and/or slaves). As explained by comments in the file, you can use one of three formats to specify each server:

*domain nisdomain server server\_name*

*domain nisdomain broadcast (do not use)*

*ypserver server\_name*

where *nisdomain* is the name of the NIS domain that the local (client) system belongs to and *server\_name* is the hostname of the NIS server that the local system queries. The second format is less secure than the first and third formats because it exposes the system to rogue servers by broadcasting a request for a server to identify itself.

You can use multiple lines to specify multiple servers for one or more domains. Specifying multiple servers for a single domain allows the system to change to another server when its current server is slow or down.



When you specify more than one NIS domain, you must set the system's NIS domain name before starting **ypbind** so the client queries the proper server. Specifying the NIS domain name in `/etc/sysconfig/network` before running the **ypbind** init script takes care of this issue. See “Specifying the System's NIS Domain Name” on page 699.

## START ypbind

The Fedora/RHEL **ypbind** daemon is **ypbind-mt** renamed—that is, a newer, multi-threaded version of the older **ypbind** daemon. Use `chkconfig` to cause **ypbind** to start each time the system enters multiuser mode and `service` to start **ypbind** immediately. For more information refer to “Prerequisites” on page 699.

## TESTING THE SETUP

After starting **ypbind**, use `nisdomainname` to make sure the correct NIS domain name is set. Refer to “Specifying the System's NIS Domain Name” on page 699 if you need to set the NIS domain name. Next check that the system is set up to connect to the proper server. The name of the server is set in `/etc/yp.conf` (page 700).

```
$ ypwhich
localhost
```

Make sure the NIS server is up and running (replace *server* with the name of the server that `ypwhich` returned):

```
$ /usr/sbin/rpcinfo -u server ypserv
program 100004 version 1 ready and waiting
program 100004 version 2 ready and waiting
```

After starting **ypbind**, check that it has registered with **rpcbind** (*FEDORA*) or **portmap** (*RHEL*):

```
$ /usr/sbin/rpcinfo -u localhost ypbind
program 100007 version 1 ready and waiting
program 100007 version 2 ready and waiting
```

If `rpcinfo` does not report that **ypbind** is **ready and waiting**, check that **ypbind** is running:

```
$ /sbin/service ypbind status
ypbind (pid 28689) is running...
```

If NIS is still not working properly, use the init script to stop **ypbind**. Start it again with debugging turned on:

```
# /sbin/service ypbind stop
Shutting down NIS services: [ OK ]
# /sbin/ypbind -debug
...
```

The `-debug` option keeps **ypbind** in the foreground and causes it to send error messages and debugging output to standard error.

## yppasswd: CHANGES NIS PASSWORDS

The `yppasswd` utility—not to be confused with the `yppasswdd` daemon (two `d`'s; see page 709) that runs on the NIS server—replaces the functionality of `passwd` on clients when you are using NIS for passwords. Where `passwd` changes password information in the `/etc/shadow` file on the local system, `yppasswd` changes password information in the `/etc/shadow` file on the NIS master server *and* in the NIS `shadow.byname` map. Optionally, `yppasswd` can also change user information in the `/etc/passwd` file and `passwd.byname` map.

The `yppasswd` utility changes the way you log in on all systems in the NIS domain that use NIS to authenticate passwords. The `yppasswd` utility cannot change `root` and system passwords; by default, NIS does not store passwords of users with UIDs less than 500. You have to use `passwd` to change these users' passwords locally.

To use `yppasswd`, the `yppasswdd` daemon must be running on the NIS master server.

### passwd VERSUS yppasswd

When a user who is authenticated using NIS passwords runs `passwd` to change her password, all appears to work properly, yet the user's password is not changed: The user needs to use `yppasswd`. The `root` and system accounts, in contrast, must use `passwd` to change their passwords. A common solution to this problem is first to rename `passwd`, for example, to `rootpasswd`, and then to change its permissions so only `root` can execute it.<sup>1</sup> Second, create a link to `yppasswd` named `passwd`:

```
# ls -l /usr/bin/passwd
-r-s--x--x 1 root root 16336 Feb 13 2006 /usr/bin/passwd
# mv /usr/bin/passwd /usr/bin/rootpasswd
# chmod 700 /usr/bin/rootpasswd
# ln -s /usr/bin/yppasswd /usr/bin/passwd
# ls -l /usr/bin/{yppasswd,passwd,rootpasswd}
lrwxrwxrwx 1 root root      17 Oct  8 15:32 /usr/bin/passwd -> /usr/bin/yppasswd
-rwx----- 1 root root 16336 Feb 13 2006 /usr/bin/rootpasswd
-r-xr-xr-x 3 root root 18544 Jan 25 2006 /usr/bin/yppasswd
```

With this setup, a nonroot user changing his password using `passwd` will run `yppasswd`, which is appropriate. If `root` or a system account user runs `passwd` (really `yppasswd`), `yppasswd` displays an error that will ideally remind the administrator to run `rootpasswd`.

## MODIFYING USER INFORMATION

As long as `yppasswdd` is running on the NIS master server, a user can use `yppasswd` from an NIS client to change her NIS password and `root` can change any user's password (except that of `root` or a system account user). A user can also use `yppasswd` to

---

1. The `passwd` utility has `setuid` permission with execute permission for all users. If, after changing its name and permissions, you want to restore its original name and permissions, first change its name and then give the command `chmod 4511 /usr/bin/passwd`.

change his login shell and GECOS (page 1084) information if the **yppasswdd** daemon is set up to permit these changes. Refer to “**yppasswdd: The NIS Password Update Daemon**” on page 709 for information on how to configure **yppasswdd** to permit users to change these fields. Use the **-l** option with **yppasswd** to change the login shell. Use **-f** to change GECOS information:

```
$ yppasswd -f
Changing NIS account information for mark on localhost.
Please enter password:

Changing full name for mark on localhost.
To accept the default, simply press return. To enter an empty
field, type the word "none".
Name [MSobell]: Mark G Sobell
Location []: SF
Office Phone []:
Home Phone []:

The GECOS information has been changed on localhost.

$ ypmatch mark passwd
mark:$1$X49qrFYv/:500:500:Mark G Sobell,SF:/home/mark:/bin/bash
```

## ADDING AND REMOVING USERS

There are several ways to add and remove users from the NIS **passwd** map. The easiest approach is to keep the **/etc/passwd** file on the NIS master server synchronized with the **passwd** map. You can keep these files synchronized by making changes to the **passwd** file using standard tools such as **passwd** and running **ypinit** to update the map (page 708).

---

# SETTING UP AN NIS SERVER

This section discusses how to set up an NIS server.

## PREREQUISITES

Decide on an NIS domain name. Some sites use their DNS domain name as the NIS domain name. Choosing a different name is more secure.

Install the following package:

- **ypserv**

Run **chkconfig** to cause **ypserv** to start when the system enters multiuser mode:

```
# /sbin/chkconfig ypserv on
```

On the master server only, run **chkconfig** to cause the map server, **ypxfrd** (page 708), to start when the system enters multiuser mode:

```
# /sbin/chkconfig ypxfrd on
```

In addition, on the master server only, run `chkconfig` to cause the NIS password update daemon, `yppasswdd` (page 709), to start when the system enters multiuser mode:

```
# /sbin/chkconfig yppasswdd on
```

After configuring `ypserv`, start it with the `ypserv` init script:

```
# /sbin/service ypserv start
Starting YP server services: [ OK ]
```

Next start the `ypxfrd` daemon (page 708) on the system running the master server:

```
# /sbin/service ypxfrd start
Starting YP map server: [ OK ]
```

Now start the `yppasswdd` daemon (page 709) on the master server:

```
# /sbin/service yppasswdd start
Starting YP passwd service: [ OK ]
```

## NOTES

An NIS client can run on the same system as an NIS server.

There must be only one master server for each domain.

You can run multiple NIS domain servers (for different domains) on a single system.

An NIS server serves the NIS domains listed in `/var/yp`. For a more secure system, remove the maps directories from `/var/yp` when disabling an NIS server.

**SELinux** When SELinux is set to use a targeted policy, NIS is protected by SELinux. You can disable this protection if necessary. For more information refer to “Setting the Targeted Policy with `system-config-selinux`” on page 416.

## STEP-BY-STEP SETUP

This section lists the steps involved in setting up and starting an NIS server.

### SPECIFY THE SYSTEM’S NIS DOMAIN NAME

Specify the system’s NIS domain name by adding the following line to the `/etc/sysconfig/network` file:

```
NISDOMAIN=nisdomainname
```

where *nisdomainname* is the name of the NIS domain that the local system belongs to. For more information refer to “Specifying the System’s NIS Domain Name” on page 699.

### EDIT `/etc/ypserv.conf` TO CONFIGURE THE NIS SERVER

The `/etc/ypserv.conf` file, which holds NIS server configuration information, specifies options and access rules. Option rules specify server options and have the following format:

```
option: value
```

## OPTIONS

Following is a list of *options* and their default *values*:

- files** Specifies the maximum number of map files that **ypserv** caches. Set to 0 to turn off caching. Default is 30.
- trusted\_master** On a slave server, the name/IP address of the master server that new maps will be accepted from. Default is no master server, meaning no new maps are accepted.
- xfer\_check\_port** YES (default) requires the master server to run on a *privileged port* (page 1100). NO allows it to run on any port.

## ACCESS RULES

Access rules, which specify which hosts and domains can access which maps, have the following format:

*host:domain:map:security*

where *host* and *domain* specify the IP address and NIS domain this rule applies to; *map* is the name of the map that this rule applies to; and *security* is either **none** (always allow access), **port** (allow access from a privileged port), or **deny** (never allow access).

The following lines appear in the **ypserv.conf** file supplied with Fedora/RHEL:

```
$ cat /etc/ypserv.conf
...
# Not everybody should see the shadow passwords, not secure, since
# under MSDOS everybody is root and can access ports < 1024 !!!
* : * : shadow.byname : port
* : * : passwd.adjunct.byname : port
...
```

These lines restrict the **shadow.byname** and **passwd.adjunct.byname** (the **passwd** map with shadow [asterisk] entries) maps to access from ports numbered less than 1024. As the comment points out, however, anyone using a DOS or early Windows system on the network can read the maps because they can access ports numbered less than 1024.

The following example describes a LAN with some addresses that you want to grant NIS access from and some that you do not; perhaps you have a wireless segment or some public network connections that you do not want to expose to NIS. You can list the systems or an IP subnet that you want to grant access to in **ypserv.conf**. Anyone logging in on another IP address will then be denied NIS services. The following line from **ypserv.conf** grants access to anyone logging in from an IP address in the range of 192.168.0.1 to 192.168.0.255 (specified as 192.168.0.1 with a subnet mask [page 443] of /24):

```
$ cat /etc/ypserv.conf
...
192.168.0.1/24 : * : * : none
```

## CREATE /var/yp/securenets TO ENHANCE SECURITY

To enhance system security, create the `/var/yp/securenets` file, which prevents unauthorized systems from sending RPC requests to the NIS server and retrieving NIS maps. Notably `securenets` prevents unauthorized users from retrieving the `shadow` map, which contains encrypted passwords. When `securenets` does not exist or is empty, an NIS server accepts requests from any system.

Each line of `securenets` lists a netmask and IP address. NIS accepts requests from systems whose IP addresses are specified in `securenets` and ignores and logs requests from other addresses. You must include the (local) server system as `localhost` (127.0.0.1) in `securenets`. A simple `securenets` file follows:

```
$ cat /var/yp/securenets
# you must accept requests from localhost
255.255.255.255      127.0.0.1
#
# accept requests from IP addresses 192.168.0.1 - 192.168.0.62
255.255.255.192      192.168.0.0
#
# accept requests from IP addresses starting with 192.168.14
255.255.255.0         192.168.14.0
```

## EDIT /var/yp/Makefile TO SPECIFY MAPS

The `make` utility, controlled by `/var/yp/Makefile`, uses `makedbm` to create the NIS maps that hold the information that NIS distributes. When you run `ypinit` on the master server, `ypinit` calls `make`: You do not need to run `make` manually.

Edit `/var/yp/Makefile` to set options and specify which maps to create. The following sections discuss `/var/yp/Makefile` in more detail.

### VARIABLES

Following is a list of variables you can set in `/var/yp/Makefile`. The values following the words `Fedora/RHEL` are the values set in the file distributed by `Fedora/RHEL`.

- B** Do not change.  
Fedora/RHEL: not set
- NOPUSH** Specifies that `ypserv` is not to copy (push) maps to slave servers. Set to `TRUE` if you do not have any slave NIS servers; set to `FALSE` to cause NIS to copy maps to slave servers.  
Fedora/RHEL: `TRUE`
- MINUID,**  
**MINGID** Specifies the lowest UID and GID numbers to include in NIS maps. In the `/etc/passwd` and `/etc/group` files, lower ID numbers belong to `root` and system accounts and groups. To enhance security, NIS does not distribute password and group information about these users and groups. Set `MINUID` to the lowest UID number you want to include in the NIS maps and set `MINGID` to the lowest GID number you want to include.  
Fedora/RHEL: 500/500

**NFSNOBODYUID,  
NFSNOBODYGID**

Specifies the UID and GID of the user named **nfsnobody**. NIS does not export values for this user. Set to 0 to export maps for **nfsnobody**.

Fedora/RHEL: 65534/65534

**MERGE\_PASSWD,  
MERGE\_GROUP**

TRUE merges the **/etc/shadow** and **/etc/passwd** files and the **/etc/gshadow** and **/etc/group** files in the **passwd** and **group** maps, enabling shadow user passwords and group passwords.

Fedora/RHEL: TRUE/TRUE

**FILE LOCATIONS**

The next sections of **/var/yp/Makefile** specify the standard file locations; you do not normally need to change them. This part of the makefile is broken into the following groups:

<b>Commands</b>	Locates <b>gawk</b> and <b>make</b> and sets a value for <b>umask</b> (page 440)
<b>Source directories</b>	Locates directories that contain NIS source files
<b>NIS source files</b>	Locates NIS source files used to build the NIS database
<b>Servers</b>	Locates the file that lists NIS servers

**THE all: TARGET**

The **all:** target in **/var/yp/Makefile** specifies the maps that **make** is to build for NIS:

```
all: passwd group hosts rpc services netid protocols mail \
    # netgrp shadow publickey networks ethers bootparams printcap \
    # amd.home auto.master auto.home auto.local passwd.adjunct \
    # timezone locale netmasks
```

The first line of the **all:** target lists the maps that **make** builds by default. This line starts with the word **all**, followed by a colon (**:**) and a **TAB**. Because each of the first three lines of the **all:** target ends with a backslash, each of the four physical lines in the **all:** target is part of one long logical line. The last three physical lines are commented out. Uncomment lines and delete or move map names until the list matches your needs.

As your needs change, you can edit the **all:** target in **Makefile** and run **make** in the **/var/yp** directory to modify the list of maps that NIS distributes.

**START THE SERVERS**

Start the master server and then the slave servers after completing the preceding steps. Use **chkconfig** to cause **ypserv** to start each time the system enters multiuser mode and **service** to start **ypserv** immediately. For more information refer to “Pre-requisites” on page 703.

**ypxfrd:** the map server The **ypxfrd** daemon speeds up the process of copying large NIS databases from servers to slaves. It allows slaves to copy the maps, thereby avoiding the need for each slave to copy the raw data and then compile the maps. When an NIS slave receives a message from the server stating that there is a new map, it starts **ypxfr**, which reads the map from the server.

The **ypxfrd** daemon runs on the master server only; it is not necessary to run it on slave servers. Use **chkconfig** to cause **ypxfrd** to start each time the system enters multiuser mode and **service** to start **ypxfrd** immediately. For more information refer to “Prerequisites” on page 703.

## ypinit: BUILDS OR IMPORTS THE MAPS

The **ypinit** utility builds or imports and then installs the NIS database. On the master server, **ypinit** gathers information from the **passwd**, **group**, **hosts**, **networks**, **services**, **protocols**, **netgroup**, and **rpc** files in **/etc** and builds the database. On a slave server, **ypinit** copies the database from the master server.

You must run **ypinit** by giving its absolute pathname (**/usr/lib/yp/ypinit**). Use the **-m** option to create the domain subdirectory under **/var/yp** and build the maps that go in it on the master server; use the **-s master** option on slave servers to import maps from **master** (the master server). In the following example, **ypinit** asks for the names of each of the slave servers; it already has the name of the master server because this command is run on that system (**localhost** in the example). Terminate the list with **CONTROL-D** on a line by itself. After you respond to the query about the list of servers being correct, **ypinit** builds the **ypservers** map and calls **make** with **/var/yp/Makefile**, which builds the maps specified in **Makefile**.

```
# /usr/lib/yp/ypinit -m
```

At this point, we have to construct a list of the hosts which will run NIS servers. **localhost** is in the list of NIS server hosts. Please continue to add the names for the other hosts, one per line. When you are done with the list, type a **<control D>**.

```
next host to add: localhost
```

```
next host to add: speedy
```

```
next host to add: CONTROL-D
```

The current list of NIS servers looks like this:

```
localhost
```

```
speedy
```

```
Is this correct? [y/n: y] y
```

```
We need a few minutes to build the databases...
```

```
Building /var/yp/mgs/ypservers...
```

```
Running /var/yp/Makefile...
```

```
gmake[1]: Entering directory `/var/yp/mgs'
```

```
Updating passwd.byname...
```

```
Updating passwd.byuid...
```

```
Updating group.byname...
```

```
Updating group.bygid...
```



```

Updating hosts.byname...
Updating hosts.byaddr...
Updating rpc.byname...
Updating rpc.bynumber...
Updating services.byname...
Updating services.byservicename...
Updating netid.byname...
Updating protocols.bynumber...
Updating protocols.byname...
Updating mail.aliases...
gmake[1]: Leaving directory '/var/yp/mgs'

```

localhost has been set up as a NIS master server.

Now you can run `ypinit -s localhost` on all slave server.

## TESTING

From the server, check that `ypserv` is connected to `rpcbind` (*FEDORA*)/`portmap` (*RHEL*):

```

# rpcinfo -p | grep ypserv
100004 2 udp 717 ypserv
100004 1 udp 717 ypserv
100004 2 tcp 720 ypserv
100004 1 tcp 720 ypserv

```

Again from the server system, make sure the NIS server is up and running:

```

$ /usr/sbin/rpcinfo -u localhost ypserv
program 100004 version 1 ready and waiting
program 100004 version 2 ready and waiting

```

If the server is not working properly, use `service` to stop `ypserv`. Start it again with debugging turned on:

```

# /sbin/service ypserv stop
Stopping YP server services: [ OK ]
# /usr/sbin/ypserv --debug
...

```

The `--debug` option keeps `ypserv` in the foreground and causes it to send error messages and debugging output to standard error.

## ypasswdd: THE NIS PASSWORD UPDATE DAEMON

The NIS password update daemon, `ypasswdd`, runs only on the master server; it is not necessary to run it on slave servers. (If the master server is down and you try to change your password from a client, you get an error message.) When a user runs `ypasswd` (page 702) on a client, `ypasswd` exchanges information with the `ypasswdd` daemon to update the user's password (and optionally other) information in the NIS `shadow` (and optionally `passwd`) map and in the `/etc/shadow` (and optionally `/etc/passwd`) file on the NIS master server. Password change requests are sent to `rsyslogd` (page 582).

## START yppasswdd

Use `chkconfig` to cause `yppasswdd` to start each time the system enters multiuser mode and service to start `yppasswdd` immediately. For more information refer to “Prerequisites” on page 703.

## ALLOW GECOS AND LOGIN SHELL MODIFICATION

By default, `yppasswdd` does not allow users to change *GECOS* (page 1084) information or the login shell when they run `yppasswd`. You can allow users to change this information with options on the command line when you start `yppasswdd` or, more conveniently, by modifying the `/etc/sysconfig/yppasswdd` configuration file. The `-e chfn` option to `yppasswdd` allows users to change their GECOS information; `-e chsh` allows users to change their login shell. When you set the options in the `/etc/sysconfig/yppasswdd` file, they are set automatically each time the `yppasswdd` init file is run.

```
$ cat /etc/sysconfig/yppasswdd
...
YPPASSWDD_ARGS=" -e chfn -e chsh"
```

---

## LDAP

LDAP (Lightweight Directory Access Protocol) is an alternative to the older X.500 DAP (Directory Access Protocol). It runs over TCP/IP and is network aware, standards-based, and available on many platforms. A client queries an LDAP server, specifying the data it wants. For example, a query could ask for the first names and email addresses of all people with a last name of Smith who live in San Francisco.

**Directory** Because LDAP is designed to work with data that does not change frequently, the server holds a search and read optimized database, called a *directory*. LDAP clients query and update this directory.

In addition to name and address information, an LDAP directory can hold lists of network services. Or, other services can use it for authentication. LDAP is appropriate for any kind of relatively static structured information where fast lookups are required. Many types of clients are set up to communicate with LDAP servers, including LDAP-specific clients (page 720), email clients, and authentication servers.

**OpenLDAP** Fedora and RHEL provide the OpenLDAP ([www.openldap.org](http://www.openldap.org)) implementation of LDAP. OpenLDAP uses the Sleepycat Berkeley Database (Berkeley DB, now owned by Oracle), which meets the needs of an LDAP database. It supports distributed architecture, replication, and encryption. The Berkeley DB differs from a relational database (RDBMS): Instead of holding information in rows and columns, Berkeley DB implements an LDAP directory as a hierarchical data structure that groups information with similar attributes. This section describes OpenLDAP.

Fedora and Red Hat Directory Servers In addition to OpenLDAP, Fedora provides the 389 Directory Server ([directory.fedoraproject.org](http://directory.fedoraproject.org); **389-ds-base** package) and RHEL provides the Red Hat Directory Server, both of which are LDAP servers. For more information see the references on page 712.

Entries and attributes An *entry* (a node in the LDAP directory hierarchy, or a container) is the basic unit of information in an LDAP directory. Each entry holds one or more *attributes*. Each attribute has a name (an attribute type or description) and one or more values. Attribute names come from a standard schema that is held in files found in the `/etc/openldap/schema` directory. This schema is standard across many implementations of LDAP, enabling LDAP clients to obtain data from many LDAP servers. Although it is not usually necessary or advisable, you can augment or modify the standard schema.

DN A Distinguished Name (DN) uniquely identifies each entry in an LDAP directory. A DN comprises a Relative Distinguished Name (RDN), which is constructed from one or more attributes in the entry, followed by the DN of the parent entry. Because a DN can change (e.g., a woman may change her last name), and because a consistent, unique identifier is sometimes required, the server assigns a UUID (an unambiguous identifier) to each entry.

DSE and DC The DSE (DSA Specific Entry) is the root, or top-level, entry in an LDAP directory. (DSA stands for Directory System Agent.) The DSE specifies the domain name of the server and is defined in the `/etc/openldap/slapd.d/cn=config/olcDatabase={1}bdb.ldif` file. LDAP defines a domain name in terms of its component parts. The default `olcDatabase={1}bdb.ldif` file holds the following line, which defines the DSE comprising the Domain Component (DC) **my-domain** and the DC **com**:

```
olcSuffix: dc=my-domain,dc=com
```

LDIF and CN The LDAP directory specified by the default DSE could contain the following entry, which is specified in LDAP Data Interchange Format (LDIF; see the `ldif` man page for more information):

```
dn: cn=Samuel Smith,dc=my-domain,dc=com
cn: Samuel Smith
cn: Sam
cn: SLS
givenName: Smith
sn: Samuel
mail: sls@my-domain.com
objectClass: inetOrgPerson
objectClass: organizationalPerson
objectClass: person
objectClass: top
```

Each line except the first specifies an attribute. The word on each line preceding the colon is the attribute name. Following the colon and a SPACE is the attribute value. The first line in this example specifies the DN of the entry. The attribute value used in the RDN is a CN (Common Name) from the entry: **Samuel Smith**.

This second-level entry is a child of the top-level entry; thus the DN of the parent entry is the DN of the top-level entry (**dc=my-domain,dc=com**). You can uniquely identify this entry by its DN: **cn=Samuel Smith,dc=my-domain,dc=com**.

Because this entry defines three CNs, a search for **Samuel Smith**, **Sam**, or **SLS** will return this entry. This entry also defines a given name, a surname (**sn**), and an email address (**mail**).

**ObjectClass** attribute Entries inherit object class attributes from their parents. In addition, each entry must have at least one **objectClass** attribute (the preceding entry has four). Each **objectClass** value must be a class defined in the schema. The schema specifies both mandatory and optional (allowed) attributes for an object class. For example, the following entry in the schema defines the object class named **person**. The **MUST** and **MAY** lines specify which attributes the **person** object class requires (**sn** [surname] and **cn**; attribute names are separated by a dollar sign) and which attributes are optional (**userPassword**, **telephoneNumber**, **seeAlso**, and **description**).

```
$ cat /etc/openldap/slapd.d/cn=config/cn=schema/cn={1}core.ldif
...
olcObjectClasses: {4}( 2.5.6.6 NAME 'person'
    DESC 'RFC2256: a person'
    SUP top STRUCTURAL
    MUST ( sn $ cn )
    MAY ( userPassword $ telephoneNumber $ seeAlso $ description ) )
...
```

**Abbreviations** The following list summarizes the abbreviations discussed in this section.

CN	Common Name
DC	Domain Component
DN	Distinguished Name
DSE	DSA Specific Entry
LDIF	LDAP Data Interchange Format
RDN	Relative Distinguished Name

## MORE INFORMATION

**Local** man pages: **ldap.conf**, **ldapmodify**, **ldapsearch**, **ldif**, **slapd**, **slapd.conf**, **slappasswd**

**Web** LDAP home page: [www.openldap.org](http://www.openldap.org)  
 Administrator's Guide: [www.openldap.org/doc/admin24](http://www.openldap.org/doc/admin24)  
 OpenLDAP Faq-O-Matic: [www.openldap.org/faq](http://www.openldap.org/faq)  
 Book: [www.zytrax.com/books/ldap](http://www.zytrax.com/books/ldap)  
 gq: [sourceforge.net/projects/gqclient](http://sourceforge.net/projects/gqclient)  
 Fedora Directory Server home page: [directory.fedoraproject.org](http://directory.fedoraproject.org)  
 Red Hat Directory Server manuals: [www.redhat.com/docs/manuals/dir-server](http://www.redhat.com/docs/manuals/dir-server) (these manuals apply to both the Fedora and Red Hat Directory Servers)

**HOWTO** LDAP Linux HOWTO

---

# SETTING UP AN LDAP SERVER

This section explains the steps involved in setting up an LDAP server.

## PREREQUISITES

Install the following packages:

- **openldap-clients**
- **openldap-servers**

Under Fedora, run **chkconfig** to cause the LDAP daemon, **slapd** (stand-alone LDAP daemon—the abbreviation does not quite work), to start when the system enters multiuser mode. The **slapd** init script starts the **slapd** daemon. Do not confuse **ldap** and **slapd** in the names of utilities, daemons, and init scripts.

```
# /sbin/chkconfig slapd on
```

Under RHEL, the name of the script is **ldap**.

Under Fedora, give the following command to change ownership of some files to avoid errors when starting **slapd**:

```
# chown ldap /var/lib/ldap/*
```

Under Fedora, after configuring **slapd**, start it with the following command. RHEL uses **ldap**.

```
# /sbin/service slapd start
```

Replace **start** with **restart** when you need to restart the daemon, such as after changing the **slapd.conf** configuration file.

## NOTE

**Firewall** The **slapd** LDAP server normally listens on TCP port 389, which is not encrypted. If you are using LDAP for authentication, use LDAP over SSL on port 636. If the LDAP server system is running a firewall, you need to open one of these ports. Using the Firewall Configuration window, Other Ports tab (page 825), open TCP port 389 or 636. For more general information see Chapter 25, which details iptables.

## STEP-BY-STEP SETUP

This section lists the steps involved in setting up an LDAP server at the sobell.com domain. When you set up an LDAP server, substitute the domain name of the server you are setting up for **sobell.com** in the examples. The example in this section is quite simple, so you will probably need different entries in the directory you set up.

To experiment with and learn about LDAP, set up and run locally the example server described in this section. Although the example uses `sobell.com`, when working from the server system you can refer to the LDAP server as `localhost`.

## CONFIGURE THE SERVER (*FEDORA*)

1. Rename `ldap.conf` so it does not interfere with the server you are setting up:

```
# mv /etc/openldap/ldap.conf /etc/openldap/ldap.conf.0
```

2. The other files you need to change are in the `cn=config` directory; `cd` to that directory:

```
# cd /etc/openldap/slapd.d/cn=config
```

3. Make the following changes to the `olcDatabase={1}bdb.ldif` file:

- a. The `olcSuffix` line defines the DSE (page 711). Change the existing `olcSuffix` line as follows. The examples in this section use `sobell.com`:

```
olcSuffix: dc=sobell,dc=com
```

- b. The `olcRootDN` line establishes the user (the LDAP administrator) who can read any information from and write any information to the LDAP directory. The value on this line is the DN for this user. The RDN is the name of the LDAP administrator; the DN includes the DN of the parent node (the DSE as specified in step 3a).

In this example, the name of this user is `ldapadmin` and the password is `porcupine`. This user does not need to exist as a user on the system (i.e., the user does not need to be listed in `/etc/passwd`).

```
olcRootDN: cn=ldapadmin,dc=sobell,dc=com
```

- c. The `olcRootPW` line sets up a password for the LDAP administrator specified in step 3b. Add an `olcRootPW` line as shown next. This example sets up `porcupine` as a cleartext password.

```
olcRootPW: porcupine
```

If you will be administrating LDAP over a network, use an encrypted password. First use `slappasswd` to encrypt a password:

```
# slappasswd
New password:
Re-enter new password:
{SSHA}7h060/qgeUrXl/Tsqy801TbGYB0Xdc/+
```

Then copy the output of `slappasswd` a new `olcRootPW` line:

```
olcRootPW: {SSHA}7h060/qgeUrXl/Tsqy801TbGYB0Xdc/+
```

4. Make the following change to the `olcDatabase={2}monitor.ldif` file:

```
olcAccess: {0}to * by dn.base="cn=ldapadmin,dc=sobell,dc=com" read by * none
```

## CONFIGURE THE SERVER (RHEL)

First make the following changes to the `/etc/openldap/slapd.conf` file:

1. The `suffix` line defines the DSE (page 711). Put a pound sign at the left end of the existing `suffix` line to change it to a comment and add a new `suffix` line. The examples in this section use `sobell.com`:

```
#suffix      "dc=my-domain,dc=com"
suffix       "dc=sobell,dc=com"
```

2. The `rootdn` line establishes the user (the LDAP administrator) who can read any information from and write any information to the LDAP directory. The value on this line is the DN for this user. The RDN is the name of the LDAP administrator; the DN includes the DN of the parent node (the DSE as specified in step 1).

In this example, the name of this user is `ldapadmin` and the password is `porcupine`. This user does not need to exist as a user on the system (i.e., the user does not need to be listed in `/etc/passwd`). Comment out the existing `rootdn` line and add a new one.

```
#rootdn      "cn=Manager,dc=my-domain,dc=com"
rootdn       "cn=ldapadmin,dc=sobell,dc=com"
```

3. The `rootpw` line sets up a password for the LDAP administrator specified in step 2. Two example lines in the file are already commented out. Add a `rootpw` line as shown next. This example sets up `porcupine` as a cleartext password.

```
# rootpw      secret
# rootpw      {crypt}ijFYncSNctBYg
rootpw        porcupine
```

If you will be administrating LDAP over a network, use an encrypted password. First use `slappasswd` to encrypt a password:

```
# slappasswd
New password:
Re-enter new password:
{SSHA}7h060/qgeUrX1/Tsqy801TbGYBOXdc/+
```

Then copy the output of `slappasswd` to the `rootpw` line in `slapd.conf`:

```
rootpw        {SSHA}7h060/qgeUrX1/Tsqy801TbGYBOXdc/+
```

**DB\_CONFIG** As shipped, `/var/lib/ldap` does not hold a `DB_CONFIG` file. The `slapd` daemon does not require this file, but the `ldap` init script displays an error message when

it is missing. To avoid this message, copy the `DB_CONFIG.example` file to `/var/lib/ldap/DB_CONFIG`:

```
# cp /usr/share/doc/openldap-servers*/DB_CONFIG.example /var/lib/ldap/DB_CONFIG [FEDORA]
```

```
# cp /etc/openldap/DB_CONFIG.example /var/lib/ldap/DB_CONFIG [RHEL]
```

See the [www.openldap.org/faq/data/cache/1072.html](http://www.openldap.org/faq/data/cache/1072.html) Web page and the comments in the `/etc/openldap/DB_CONFIG.example` file for more information on this configuration file.

## START AND TEST THE SERVER

Start the `slapd` daemon as explained under “Prerequisites” on page 713. Then test the server with the following query:

```
# ldapsearch -x -s base namingContexts
# extended LDIF
#
# LDAPv3
# base <> (default) with scope baseObject
# filter: (objectclass=*)
# requesting: namingContexts
#
#
dn:
namingContexts: dc=sobell,dc=com

# search result
search: 2
result: 0 Success

# numResponses: 2
# numEntries: 1
```

The `-x` on the command line specifies simple authentication, `-s base` specifies the scope of the search as the base object, and `namingContexts` is the attribute you are searching for. The output of this command should look similar to that shown in the preceding example. The `namingContexts` returned by the search should be the same as the DSE you specified when you configured the server.

## ADD ENTRIES TO THE DIRECTORY

You can use many tools, both graphical and textual, to add information to and query an LDAP directory. This section explains how to use the `ldapmodify` command-line utility to set up an employee LDAP directory. See page 720 for descriptions of other tools.

When you specify the following file on an `ldapmodify` command line, `ldapmodify` adds a second-level entry (one below the DSE entry) to the directory:



```
$ cat sa1.ldif
dn: dc=sobell,dc=com
changetype: add
dc: sobell
objectClass: dcObject
objectClass: organization
organizationName: Sobell Associates Inc.
```

The first line of **sa1.ldif** specifies the root DN for the entry you are adding. The **changetype** instruction tells **ldapmodify** to add the entry to the directory. You can omit this instruction if you use the **-a** option on the **ldapmodify** command line or if you use the **ldapadd** utility in place of **ldapmodify**. The line that starts with **dc** specifies the DC (domain component). The **objectClass** lines specify the object classes this entry belongs to. The **organizationName** specifies the name of the organization this entry is part of.

The following command modifies the LDAP directory based on the **sa1.ldif** file. The **ldif** filename extension is commonly used but is not required for files holding LDIF entries.

```
$ ldapmodify -xD "cn=ldapadmin,dc=sobell,dc=com" -w porcupine -f sa1.ldif
adding new entry "dc=sobell,dc=com"
```

The **-x** option causes the server to use simple authentication. The argument following **-D** specifies the DN of the LDAP administrator of the directory the command is to work with (specified in step 2 on page 715). By specifying this user, this argument also specifies the DSE of the LDAP directory. (The DN of the parent of the LDAP administrator's entry specifies the DSE.) The argument following **-w** is the password for the LDAP administrator. For better security, you can use **-W** to cause **ldapmodify** to prompt for this password. The name of the input file follows the **-f** option. The **ldapmodify** utility reports the DN of the new entry.

The **slapcat** utility, which must be run as the **root** user of the system (not the administrator of the LDAP directory), displays all entries in the LDAP directory in LDIF format. After the executing the preceding command, there is one entry:

```
$ su -c /usr/sbin/slapcat
Password:
dn: dc=sobell,dc=com
dc: sobell
objectClass: dcObject
objectClass: organization
o: Sobell Associates Inc.
structuralObjectClass: organization
entryUUID: 13485538-7884-102e-9401-05a9d3fd842a
creatorsName: cn=ldapadmin,dc=sobell,dc=com
createTimestamp: 20091208202905Z
entryCSN: 20091208202905.821337Z#000000#000#000000
modifiersName: cn=ldapadmin,dc=sobell,dc=com
modifyTimestamp: 20091208202905Z
```

The **o** attribute name is an abbreviation for **organizationName**. The server adds additional information to the entry, including a UUID number that remains constant throughout the life of the entry, timestamps, and the names of the users who created and modified the entry. In this case they are the same person.

You can put as many entries in a file as you like, but each must be separated from the next by a blank line. For clarity, the examples in this section show one entry per file.

The next file adds to the LDAP directory the object class **organizationalUnit** named **employees** (**ou=employees**). The DN is **ou=employees** followed by the DSE:

```
$ cat sa2.ldif
dn: ou=employees,dc=sobell,dc=com
changetype: add
objectClass: organizationalUnit
ou: employees
```

```
$ ldapmodify -xD "cn=ldapadmin,dc=sobell,dc=com" -w porcupine -f sa2.ldif
adding new entry "ou=employees,dc=sobell,dc=com"
```

With this object class in place, you can add employees to the LDAP directory. You can use the following file to add an employee:

```
$ cat sa3a.ldif
dn: cn=Mark Sobell,ou=employees,dc=sobell,dc=com
changetype: add
cn: Mark Sobell
cn: sobell
objectClass: inetOrgPerson
mail: mgs@sobell.com
givenName: Mark
surname: Sobell
displayName: Mark G Sobell
telephoneNumber: 999 999 9999
homePhone: 000 000 0000
initials: MGS
```

```
$ ldapmodify -xD "cn=ldapadmin,dc=sobell,dc=com" -w porcupine -f sa3a.ldif
adding new entry "cn=Mark Sobell,ou=employees,dc=sobell,dc=com"
```

Now **slapcat** shows the employee you just added:

```
$ su -c /usr/sbin/slapcat
Password:
dn: dc=sobell,dc=com
dc: sobell
...
dn: cn=Mark Sobell,ou=employees,dc=sobell,dc=com
cn: Mark Sobell
cn: sobell
objectClass: inetOrgPerson
mail: mgs@sobell.com
```

```

givenName: Mark
sn: Sobell
displayName: Mark G Sobell
telephoneNumber: 999 999 9999
homePhone: 000 000 0000
initials: MGS
structuralObjectClass: inetOrgPerson
entryUUID: 74becfcc-7884-102e-9403-05a9d3fd842a
creatorsName: cn=ldapadmin,dc=sobell,dc=com
createTimestamp: 20091208203149Z
entryCSN: 20091208203149.336806Z#000000#000#000000
modifiersName: cn=ldapadmin,dc=sobell,dc=com
modifyTimestamp: 20091208203149Z

```

The DN shows that the new employee is at the third level of the directory structure: The first level is **dc=sobell,dc=com**; **ou=employees,dc=sobell,dc=com** is at the second level; and **cn=Mark Sobell,ou=employees,dc=sobell,dc=com**, the employee, is at the third level.

The following example adds another employee at the third level:

```

$ cat sa3b.ldif
dn: cn=Helen Simpson,ou=employees,dc=sobell,dc=com
changetype: add
cn: Helen Simpson
cn: simpson
objectClass: inetOrgPerson
mail: helen@sobell.com
givenName: Helen
surname: Simpson
displayName: Helen L Simpson
telephoneNumber: 888 888 8888
homePhone: 111 111 1111
initials: HLS

```

```

$ ldapmodify -xD "cn=ldapadmin,dc=sobell,dc=com" -w porcupine -f sa3b.ldif
adding new entry "cn=Helen Simpson,ou=employees,dc=sobell,dc=com"

```

The next example uses the `ldapmodify modify` instruction to replace the `mail` attribute value and add a `title` attribute for the employee named Helen Simpson. Because the file specifies Helen's DN, the server knows which entry to modify.

```

$ cat sa3bm.ldif
dn: cn=Helen Simpson,ou=employees,dc=sobell,dc=com
changetype: modify
replace: mail
mail: hls@sobell.com
-
add: title
title: CTO

```

```

$ ldapmodify -xD "cn=ldapadmin,dc=sobell,dc=com" -w porcupine -f sa3bm.ldif
modifying entry "cn=Helen Simpson,ou=employees,dc=sobell,dc=com"

```

You can use `slapcat` to verify the change. The final example deletes Helen from the LDAP directory:

```
$ cat sa3bd.ldif
```

```
dn: cn=Helen Simpson,ou=employees,dc=sobell,dc=com
changetype: delete
```

```
$ ldapmodify -xD "cn=ldapadmin,dc=sobell,dc=com" -w porcupine -f sa3bd.ldif
deleting entry "cn=Helen Simpson,ou=employees,dc=sobell,dc=com"
```

## OTHER TOOLS FOR WORKING WITH LDAP

You can use a variety of tools to work with LDAP. For example, most email clients are able to retrieve data from an LDAP database.

## EVOLUTION MAIL

This section explains how to use Evolution (Mail) to retrieve data from the example LDAP database created earlier. It assumes you have configured Evolution on the local system. If you are running KDE, you can use KAddressBook, which is integrated into many KDE tools, including Kontact.

Open the Mail-Evolution window by selecting **Main menu: Applications⇒Internet⇒Evolution Mail** or by giving the command `evolution` from a terminal emulator or Run Application window (ALT-F2). To query an LDAP database, select **File⇒New⇒Address Book** from the menubar. Evolution displays the General tab of the New Address Book window (Figure 21-1).

**General tab** Select **On LDAP Servers** from the drop-down list labeled **Type**. Enter the name Evolution Mail will use to refer to this LDAP directory in the text box labeled **Name**;



**Figure 21-1** The New Address Book window, General tab

the example uses **employees**. Enter the FQDN of the LDAP server in the text box labeled **Server**. If you are experimenting on the local system, enter **localhost** in this box. If appropriate, change the value in the text box labeled **Port**. To follow the example in this chapter, select **No encryption** from the drop-down list labeled **Use secure connection**.

In the section labeled **Authentication**, select **Using distinguished name (DN)** from the drop-down list labeled **Login method**. Enter the DN of the LDAP administrator in the text box labeled **Login** (the example uses **cn=ldapadmin,dc=sobell,dc=com**).

**Details tab** Next click the tab labeled **Details** (Figure 21-2). Click **Find Possible Search Bases**. If all is working properly, Evolution will display the Supported Search Bases window. Highlight the DN of the directory you want to use and click **OK**. Evolution displays the selected DN in the text box labeled **Search base**. Select **Sub** from the drop-down list labeled **Search scope** to enable searches at all levels of the directory. Click **OK**.

Next click the **Contacts** button at the lower-left corner of the Mail-Evolution window. **On this computer** and **On LDAP servers** appear at the left side of the window. If the name of the address book you specified (**employees** in the example) does not appear below **On LDAP servers**, click the triangle to the left of this label. Then click the name of the address book you want to work with. Evolution prompts for the LDAP administrator password. Enter the password and click **OK**. Evolution highlights the name of the address book; you can now search the LDAP database.

Enter the name of an entry in the **Search** text box at the upper-right corner of the window and press RETURN. Evolution displays the entry. Figure 21-3 on the next page shows the result of following the example in this chapter and entering **Mark** in the **Search** text box.



**Figure 21-2** The New Address Book window, Details tab

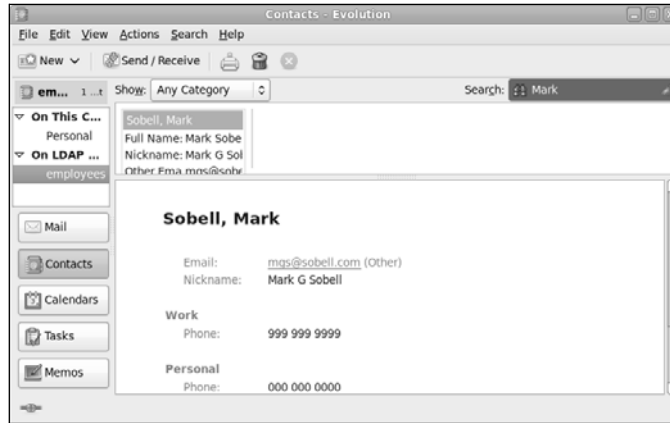


Figure 21-3 Contacts - Evolution window

## KONQUEROR

If you are running KDE, you can use Konqueror to examine the contents of an LDAP directory. Enter the following string in the Konqueror location bar and press RETURN:

*ldap://server-name/DN*

where *server-name* is the name or IP address of the LDAP server (or **localhost** if you are running Konqueror on the server system) and *DN* is the DN of the entry you want to view. Konqueror displays all entries below the DN you specify. Double-click an entry to display it. For example, to work with the LDAP directory created earlier, enter **ldap://localhost/ou=employee,dc=sobell,dc=com** in the location bar. In response, Konqueror will display the entries with this RDN. You can then click one of these entries to display that entry in its entirety.

## gq: AN LDAP CLIENT

The **gq** utility ([gq-project.org](http://gq-project.org)) is a graphical (GTK+-based) LDAP client you can use to display, edit, and delete entries. It is part of the **gq** package. Before you can work with **gq**, you must specify the DN for the administrator. Select **menubar: File⇒Preferences**, click the Servers tab, highlight the server (**localhost** in the example), click **Edit**, click the Connections tab, and set Bind DN to the DN for the administrator (**cn=ldapadmin,dc=sobell,dc=com** in the example). Figure 21-4 shows **gq** displaying an entry from the example LDAP directory.

You can also use **gq** for browsing the schema: Click the Schema tab and select the server from the left side of the window (**localhost** in Figure 21-5). Select **object-Classes** and then an object class to view information about that object class, including a list of required and optional attributes.

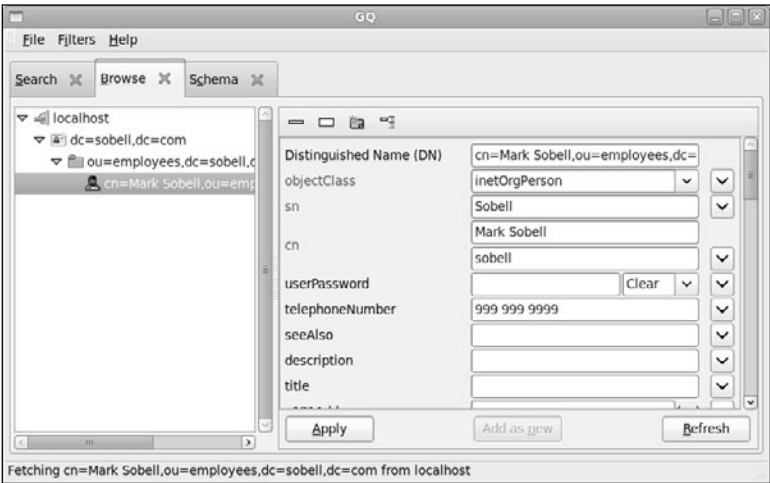


Figure 21-4 Using gq to browse an LDAP directory

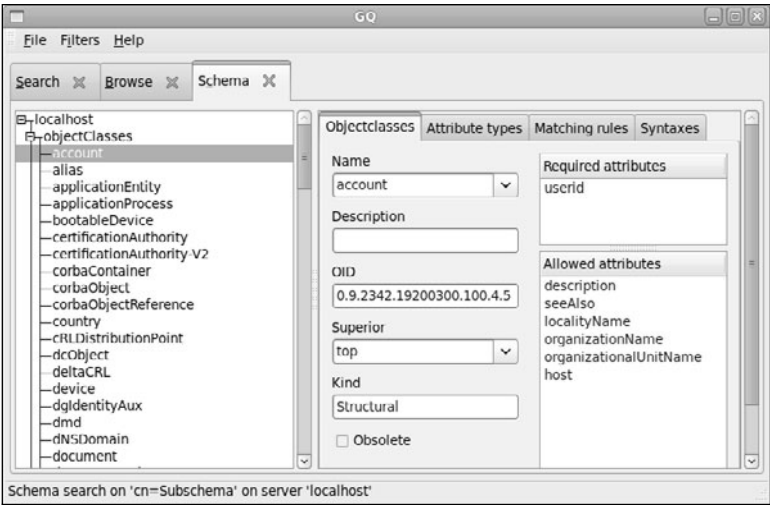


Figure 21-5 The gq Schema tab

## CHAPTER SUMMARY

NIS (Network Information Service) simplifies the management of common administrative files by maintaining them in a central database and having clients contact the database server to retrieve information from the database. The network that NIS

serves is called an NIS domain. Each NIS domain has one master server; larger networks may have slave servers.

NIS derives the information it offers from local configuration files, such as `/etc/passwd` and `/etc/hosts`. These files are called source files or master files. Before NIS can store the information contained in a source file, it must be converted to dbm-format files, called maps. The `ypcat` and `ypmatch` utilities display information from NIS maps.

The `yppasswd` utility replaces the functionality of `passwd` on clients when you are using NIS to authenticate passwords. The `/etc/ypserv.conf` file, which holds NIS server configuration information, specifies options and access rules for the NIS server. To enhance system security, you can create a `/var/yp/securenets` file, which prevents unauthorized systems from sending RPC requests to the NIS server and retrieving NIS maps.

An LDAP (Lightweight Directory Access Protocol) server holds a search and read optimized database, called a directory. LDAP clients, such as email clients, query and update this directory. In addition, authentication servers can use an LDAP directory to authenticate users.

Fedora and RHEL provide the OpenLDAP implementation of LDAP. OpenLDAP uses the Sleepycat Berkeley Database, which supports distributed architecture, replication, and encryption.

---

## EXERCISES

1. What is the difference between the `passwd` and `yppasswd` utilities?
2. How would you prevent NIS from exporting the `root` user and other system users to clients?
3. How would you make NIS user information override local user information on client systems?
4. Why does the `/etc/passwd` file need two NIS maps?
5. How does an LDAP directory differ from a relational database system?
6. What is the basic unit of information in an LDAP directory? What is the structure of an attribute?

---

## ADVANCED EXERCISES

7. How can you use NIS to mirror the functionality of a private DNS server for a small network? Why should NIS not be used this way on a large network?



8. How can you find out if the working directory is the home directory of an NIS user?
9. What advantage does NIS provide when you use it with NFS?
10. Suggest a way to implement NIS maps so they can be indexed on more than one field.
11. Where is the LDAP **device** object class defined? Which of its attributes are mandatory and which are optional?
12. How would you determine the longer name for the **l** (lowercase “l”) LDAP object class?

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## NFS: SHARING FILESYSTEMS

### IN THIS CHAPTER

Setting Up an NFS Client . . . . .	730
JumpStart I: Mounting a Remote Directory Hierarchy . . . . .	730
Improving Performance . . . . .	734
Setting Up an NFS Server . . . . .	736
JumpStart II: Configuring an NFS Server Using system-config-nfs . . . . .	737
Exporting a Directory Hierarchy . .	738
automount: Automatically Mounts Directory Hierarchies . . . . .	744

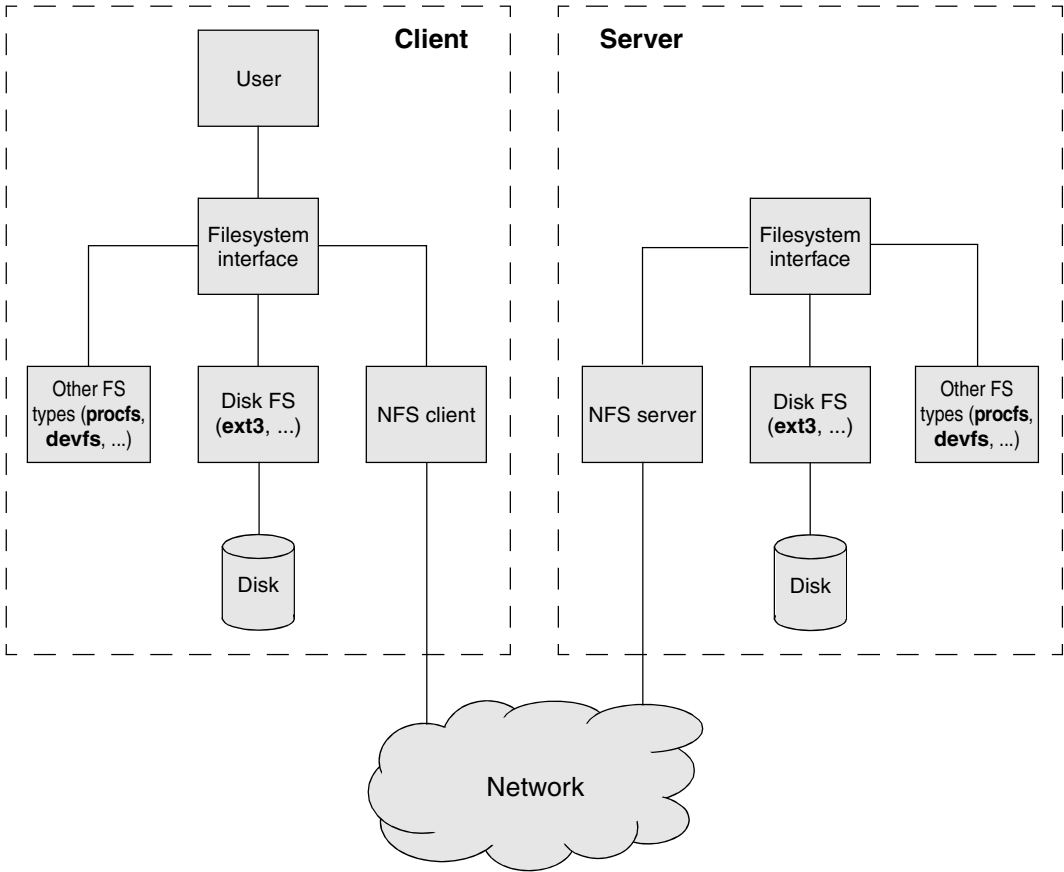
The NFS (Network Filesystem) protocol, a UNIX de facto standard originally developed by Sun Microsystems, allows a server to share selected local directory hierarchies with client systems on a heterogeneous network. NFS runs on UNIX, DOS, Windows, VMS, Linux, and more. Files on the remote computer (the *fileserv*) appear as if they are present on the local system (the client). The physical location of a file is irrelevant to an NFS user.

NFS reduces storage needs and system administration workload. As an example, each system in a company traditionally holds its own copy of an application program. To upgrade the program, the administrator needs to upgrade it on each system. NFS allows you to store a copy of a program on a single system and give other users access to it over the network. This scenario minimizes storage requirements by reducing the number of locations that need to maintain the same data. In addition to boosting efficiency, NFS gives users on the network access to the same data (not just application programs), thereby improving data consistency and reliability. By consolidating data, NFS reduces administrative overhead and provides a convenience to users.

# INTRODUCTION

Figure 22-1 shows the flow of data from a client to a server in a typical NFS client/server setup. An NFS directory hierarchy appears to users and application programs as just another directory hierarchy. By looking at it, you cannot tell that a given directory holds a remotely mounted NFS directory hierarchy and not a local `ext3` filesystem. The NFS server translates commands from the client into operations on the server's filesystem.

**Diskless systems** In many computer facilities, user files are stored on a central fileserver equipped with many large-capacity disk drives and devices that quickly and easily make backup copies of the data. A *diskless* system boots from a fileserver (netboots, discussed next), a CD, or a floppy diskette and loads system software from a fileserver. The Linux Terminal Server Project (ltsp.org) Web site says it all: “Linux makes a great platform for deploying diskless workstations that boot from a network server.



**Figure 22-1** Flow of data in a typical NFS client/server setup

The LTSP is all about running thin client computers in a Linux environment.” Because a diskless workstation does not require a lot of computing power, you can give older, retired computers a second life by using them as diskless systems.

**Netboot/PXE** You can *netboot* (page 1095) systems that are appropriately set up. Fedora/RHEL includes the PXE (Preboot Execution Environment) server package for netbooting Intel systems. Older systems sometimes use *tftp* (Trivial File Transfer Protocol) for netbooting. Non-Intel architectures have historically included netboot capabilities, which Fedora/RHEL also supports. You can build the Linux kernel so that it mounts **root (/)** using NFS. Given the many ways to set up a system, the one you choose depends on what you want to do. See the *Remote-Boot mini-HOWTO* for more information.

**Dataless systems** Another type of Linux system is a *dataless* system, in which the client has a disk but stores no user data (only Linux and the applications are kept on the disk). Setting up this type of system is a matter of choosing which directory hierarchies are mounted remotely.

**df: shows where directory hierarchies are mounted** The *df* utility displays a list of the directory hierarchies available on the system, along with the amount of disk space, free and used, on each. The **-h** (human) option makes the output more intelligible. Directory hierarchy names that are prepended with **hostname:** are available through NFS.

```
[bravo]$ cd;pwd
/speedy.home/jenny
[bravo]$ df -h
Filesystem      Size  Used Avail Use% Mounted on
/dev/sda1        981M  287M  645M  31% /
/dev/sda6        20G   2.7G   16G  15% /usr
/dev/sda7        9.7G  384M   8.8G   5% /home
grape:/gc1       985M   92M  844M  10% /grape.gc1
grape:/gc5       3.9G   3.0G  738M  81% /grape.gc5
speedy:/home     3.9G   2.4G   1.4G  64% /speedy.home
```

In the preceding example, Jenny’s home directory, **/home/jenny**, is on the remote system **speedy**. Using NFS, the **/home** filesystem on **speedy** is mounted on **bravo**; to make it easy to recognize, it is mounted as **/speedy.home**. The **/gc1** and **/gc5** filesystems on **grape** are mounted on **bravo** as **/grape.gc1** and **/grape.gc5**, respectively.

You can use the **-T** option to *df* to add a Type column to the display. The following command uses **-t nfs** to display NFS filesystems only:

```
[grape]$ df -ht nfs
Filesystem      Size  Used Avail Use% Mounted on
grape:/gc1       985M   92M  844M  10% /grape.gc1
grape:/gc5       3.9G   3.0G  738M  81% /grape.gc5
speedy:/home     3.9G   2.4G   1.4G  64% /speedy.home
```

**Errors** Sometimes you may lose access to remote files. For example, a network problem or a remote system crash may make these files temporarily unavailable. When you try to access a remote file in these circumstances, you get an error message, such as **NFS server speedy not responding**. When the local system can contact the remote server

again, you see another message, such as **NFS server speedy OK**. Setting up a stable network and server (or not using NFS) is the best defense against these kinds of problems.

**Security** NFS is based on the trusted-host paradigm (page 376) and therefore has all the security shortcomings that plague other services based on this paradigm. In addition, NFS is not encrypted. Because of these issues, you should implement NFS on a single LAN segment only, where you can be (reasonably) sure that systems on a LAN segment are what they claim to be. Make sure a firewall blocks NFS traffic from outside the LAN and never use NFS over the Internet.

To improve security, make sure UIDs and GIDs are the same on the server and clients (page 741).

---

## MORE INFORMATION

**Web** [nfs.sourceforge.net](http://nfs.sourceforge.net)

**HOWTO** *NFS HOWTO*

Netboot and PXE: *Remote-Boot mini-HOWTO*

**Book** *NFS Illustrated* by Callaghan, Addison-Wesley (December 1999)

---

## SETTING UP AN NFS CLIENT

This section covers setting up an NFS client, mounting remote directory hierarchies, and improving NFS performance.

### PREREQUISITES

Install the following packages:

- **nfs-utils**
- **system-config-nfs** (optional)

Under *RHEL*, the **portmap** utility (part of the **portmap** package; refer to “RPC Network Services” on page 391) must be running to enable reliable file locking. Under *FEDORA*, this function is served by **rpcbind**.

There are no daemons to start for NFS clients.

## JUMPSTART I: MOUNTING A REMOTE DIRECTORY HIERARCHY

To set up an NFS client, mount the remote directory hierarchy the same way you mount a local directory hierarchy (page 487). The following sections detail this process.

### mount: MOUNTS A REMOTE DIRECTORY HIERARCHY

The following examples show two ways to mount a remote directory hierarchy, assuming that **speedy** is on the same network as the local system and is sharing **/home** and **/export** with the local system. The **/export** directory on **speedy** holds two directory hierarchies that you want to mount: **/export/progs** and **/export/oracle**.

The example mounts **speedy**'s **/home** directory on **/speedy.home** on the local system, **/export/progs** on **/apps**, and **/export/oracle** on **/oracle**.

First use **mkdir** to create the directories that are the mount points for the remote directory hierarchies:

```
# mkdir /speedy.home /apps /oracle
```

You can mount any directory from an exported directory hierarchy. In this example, **speedy** exports **/export** and the local system mounts **/export/progs** and **/export/oracle**. The following commands manually mount the directory hierarchies one time:

```
# mount speedy:/home /speedy.home
# mount -o ro,nosuid speedy:/export/progs /apps
# mount -o ro speedy:/export/oracle /oracle
```

If you receive the error **mount: RPC: Program not registered**, it may mean NFS is not running on the server.

By default, directory hierarchies are mounted read-write, assuming the NFS server is exporting them with read-write permissions. The first of the preceding commands mounts the **/home** directory hierarchy from **speedy** on the local directory **/speedy.home**. The second and third commands use the **-o ro** option to force a read-only mount. The second command adds the **nosuid** option, which forces **setuid** (page 205) executables in the mounted directory hierarchy to run with regular permissions on the local system.

**nosuid option** If a user has the ability to run a **setuid** program, that user has the power of Super-user. This ability should be limited. Unless you know that a user will need to run a program with **setuid** permissions from a mounted directory hierarchy, always mount a directory hierarchy with the **nosuid** option. For example, you would need to mount a directory hierarchy with **setuid** privileges when a diskless workstation has its root partition mounted using NFS.

**nodev option** Mounting a device file creates another potential security hole. Although the best policy is not to mount untrustworthy directory hierarchies, it is not always possible to implement this policy. Unless a user needs to use a device on a mounted directory hierarchy, mount directory hierarchies with the **nodev** option, which prevents character and block special files (page 484) on the mounted directory hierarchy from being used as devices.

**fstab file** If you mount directory hierarchies frequently, you can add entries for the directory hierarchies to the **/etc/fstab** file (page 735). (Alternatively, you can use **automount**; see page 744.) The following **/etc/fstab** entries automatically mount the same directory hierarchies as in the previous example at the same time as the system mounts the local filesystems:

```
$ cat /etc/fstab
...
speedy:/home          /speedy.home  nfs    -          0 0
speedy:/export/progs  /apps         nfs    r,nosuid   0 0
speedy:/export/oracle /oracle       nfs    r          0 0
```

A file that is mounted using NFS is always type **nfs** on the local system, regardless of what type it is on the remote system. Typically you do not run **fsck** on or back up an NFS directory hierarchy. The entries in the third, fifth, and sixth columns of **fstab** are usually **nfs** (filesystem type), **0** (do not back up this directory hierarchy with **dump** [page 563]), and **0** (do not run **fsck** [page 492] on this directory hierarchy). The options for mounting an NFS directory hierarchy differ from those for mounting an **ext3** or other type of filesystem. See the next section for details.

### **umount: UNMOUNTS A REMOTE DIRECTORY HIERARCHY**

Use **umount** to unmount a remote directory hierarchy the same way you would unmount a local filesystem (page 490).

## **mount: MOUNTS A DIRECTORY HIERARCHY**

The **mount** utility (page 487) associates a directory hierarchy with a mount point (a directory). You can use **mount** to mount an NFS (remote) directory hierarchy. This section describes some **mount** options. It lists default options first, followed by non-default options (enclosed in parentheses). You can use these options on the command line or in **/etc/fstab** (page 735). For a complete list of options, refer to the **mount** and **nfs** man pages.

### **ATTRIBUTE CACHING**

File attributes, which are stored in a file's inode (page 481), provide information about a file, such as file modification time, size, links, and owner. File attributes do not include the data stored in a file. Typically file attributes do not change very often for an ordinary file; they change even less often for a directory file. Even the size attribute does not change with every write instruction: When a client is writing to an NFS-mounted file, several write instructions may be given before the data is actually transferred to the server. In addition, many file accesses, such as that performed by **ls**, are readonly operations and do not change the file's attributes or its contents. Thus a client can cache attributes and avoid costly network reads.

The kernel uses the modification time of the file to determine when its cache is out-of-date. If the time the attribute cache was saved is later than the modification time of the file itself, the data in the cache is current. The attribute cache of an NFS-mounted file must be periodically refreshed from the server to determine whether another process has modified the file. This period is specified as a minimum and maximum number of seconds for ordinary and directory files. Following is a list of options that affect attribute caching:

- ac (noac)** (**attribute cache**) Permits attribute caching (default). The **noac** option disables attribute caching. Although **noac** slows the server, it avoids stale attributes when two NFS clients actively write to a common directory hierarchy.
- acdirmax=*n*** (**attribute cache directory file maximum**) The *n* is the number of seconds, at a maximum, that NFS waits before refreshing directory file attributes (default is 60 seconds).



- acdirmin=*n*** (**attribute cache directory file minimum**) The *n* is the number of seconds, at a minimum, that NFS waits before refreshing directory file attributes (default is 30 seconds).
- acregmax=*n*** (**attribute cache regular file maximum**) The *n* is the number of seconds, at a maximum, that NFS waits before refreshing regular file attributes (default is 60 seconds).
- acregmin=*n*** (**attribute cache regular file minimum**) The *n* is the number of seconds, at a minimum, that NFS waits before refreshing regular file attributes (default is 3 seconds).
- actimeo=*n*** (**attribute cache timeout**) Sets **acregmin**, **acregmax**, **acdirmin**, and **acdirmx** to *n* seconds (without this option, each individual option takes on its assigned or default value).

## ERROR HANDLING

The following options control what NFS does when the server does not respond or when an I/O error occurs. To allow for a mount point located on a mounted device, a missing mount point is treated as a timeout.

- fg (bg)** (**foreground**) Retries failed NFS mount attempts in the foreground (default). The **bg** (background) option retries failed NFS mount attempts in the background.
- hard (soft)** Displays **server not responding** on the console on a major timeout and keeps retrying (default). The **soft** option reports an I/O error to the calling program on a major timeout. In general, it is not advisable to use **soft**. As the **mount** man page says of **soft**, “Usually it just causes lots of trouble.” For more information refer to “Improving Performance” on page 734.
- nointr (intr)** (**no interrupt**) Does not allow a signal to interrupt a file operation on a **hard**-mounted directory hierarchy when a major timeout occurs (default). The **intr** option allows this type of interrupt.
- retrans=*n*** (**retransmission value**) After *n* minor timeouts, NFS generates a major timeout (default is 3). A major timeout aborts the operation or displays **server not responding** on the console, depending on whether **hard** or **soft** is set.
- retry=*n*** (**retry value**) The number of minutes that NFS retries a mount operation before giving up (default is 10,000).
- timeo=*n*** (**timeout value**) The *n* is the number of tenths of a second that NFS waits before retransmitting following an RPC, or minor, timeout (default is 7). The value is increased at each timeout to a maximum of 60 seconds or until a major timeout occurs (see **retrans**). On a busy network, in case of a slow server, or when the request passes through multiple routers/gateways, increasing this value may improve performance.

## MISCELLANEOUS OPTIONS

Following are additional useful options:

- lock (nolock)** Permits NFS locking (default). The **nolock** option disables NFS locking (does not start the **lockd** daemon) and is useful with older servers that do not support NFS locking.
- mounthost=*name*** The name of the host running **mountd**, the NFS mount daemon.

- mountport=*n*** The port used by **mountd**.
- nodev** (**no device**) Causes mounted device files not to function as devices (page 731).
- port=*n*** The port used to connect to the NFS server (defaults to 2049 if the NFS daemon is not registered with **rpcbind/portmap**). When **n=0** (default), NFS queries **rpcbind/portmap** on the server to determine the port.
- rsiz=*n*** (**read block size**) The number of bytes read at one time from an NFS server. The default block size is 4096. Refer to “Improving Performance.”
- wsiz=*n*** (**write block size**) The number of bytes written at one time to an NFS server. The default block size is 4096. Refer to “Improving Performance.”
- tcp** Use TCP in place of the default UDP protocol for an NFS mount. This option may improve performance on a congested network; however, some NFS servers support UDP only.
- udp** Use the default UDP protocol for an NFS mount.

## IMPROVING PERFORMANCE

- hard/soft** Several parameters can affect the performance of NFS, especially over slow connections such as a line with a lot of traffic or one controlled by a modem. If you have a slow connection, make sure **hard** (page 733) is set (this is the default) so that timeouts do not abort program execution.
- Block size** One of the easiest ways to improve NFS performance is to increase the block size—that is, the number of bytes NFS transfers at a time. The default of 4096 is low for a fast connection using modern hardware. Try increasing **rsiz** and **wsiz** to 8192 or higher. Experiment until you find the optimal block size. Unmount and mount the directory hierarchy each time you change an option. See the *NFS HOWTO* for more information on testing different block sizes.
- Timeouts** NFS waits the amount of time specified by the **timeo** (timeout, page 733) option for a response to a transmission. If it does not receive a response in this amount of time, it sends another transmission. The second transmission uses bandwidth that, over a slow connection, may slow things down further. You may be able to increase performance by increasing **timeo**.

The default value of **timeo** is seven-tenths of a second (700 milliseconds). After a timeout, NFS doubles the time it waits to 1400 milliseconds. On each timeout it doubles the amount of time it waits to a maximum of 60 seconds. You can test the speed of a connection with the size packets you are sending (**rsiz** and **wsiz**) by using ping with the **-s** (size) option:

```
$ ping -s 4096 speedy
PING speedy.tcorp.com (192.168.0.1) 4096(4124) bytes of data.
4104 bytes from speedy.tcorp.com (192.168.0.1): icmp_seq=0 ttl=64 time=1.43 ms
4104 bytes from speedy.tcorp.com (192.168.0.1): icmp_seq=1 ttl=64 time=1.17 ms
4104 bytes from speedy.tcorp.com (192.168.0.1): icmp_seq=2 ttl=64 time=1.17 ms
...
```

```
4104 bytes from speedy.tcorp.com (192.168.0.1): icmp_seq=26 ttl=64 time=1.16 ms
4104 bytes from speedy.tcorp.com (192.168.0.1): icmp_seq=27 ttl=64 time=1.16 ms
4104 bytes from speedy.tcorp.com (192.168.0.1): icmp_seq=28 ttl=64 time=1.16 ms
4104 bytes from speedy.tcorp.com (192.168.0.1): icmp_seq=29 ttl=64 time=1.26 ms
```

```
--- speedy.tcorp.com ping statistics ---
30 packets transmitted, 30 received, 0% packet loss, time 29281ms
rtt min/avg/max/mdev = 1.154/1.192/1.431/0.067 ms
```

The preceding example uses Fedora/RHEL's default packet size of 4096 bytes and shows a fast average packet round-trip time of slightly more than 1 millisecond. Over a modem line, you can expect times of several seconds. If the connection is dealing with other traffic, the time will be longer. Run the test during a period of heavy traffic. Try increasing **timeo** to three or four times the average round-trip time (to allow for unusually bad network conditions, as when the connection is made) and see whether performance improves. Remember that the **timeo** value is given in tenths of a second (100 milliseconds = one-tenth of a second).

## /etc/fstab: MOUNTS DIRECTORY HIERARCHIES AUTOMATICALLY

The **/etc/fstab** file (page 490) lists directory hierarchies that the system mounts automatically as it comes up. You can use the options discussed in the preceding section on the command line or in the **fstab** file.

The first example line from **fstab** mounts **grape's /gc1** filesystem on the **/grape.gc1** mount point:

```
grape:/gc1          /grape.gc1      nfs      rsize=8192,wsiz=8192          0 0
```

A mount point should be an empty, local directory. (Files in a mount point are hidden when a directory hierarchy is mounted on it.) The type of a filesystem mounted using NFS is always **nfs**, regardless of its type on the local system. You can increase the **rsize** and **wsiz** options to improve performance. Refer to “Improving Performance” on page 734.

The next example from **fstab** mounts a filesystem from **speedy**:

```
speedy:/export      /speedy.export  nfs      timeo=50,hard                0 0
```

Because the local system connects to **speedy** over a slow connection, **timeo** is increased to 5 seconds (50 tenths of a second). Refer to “Timeouts” on page 734. In addition, **hard** is set to make sure that NFS keeps trying to communicate with the server after a major timeout. Refer to “**hard/soft**” on page 734.

The final example from **fstab** shows a remote-mounted home directory. Because **speedy** is a local server and is connected via a reliable, high-speed connection, **timeo** is decreased and **rsize** and **wsiz** are increased substantially:

```
speedy:/export/home /home          nfs      timeo=4,rsize=16384,wsiz=16384 0 0
```

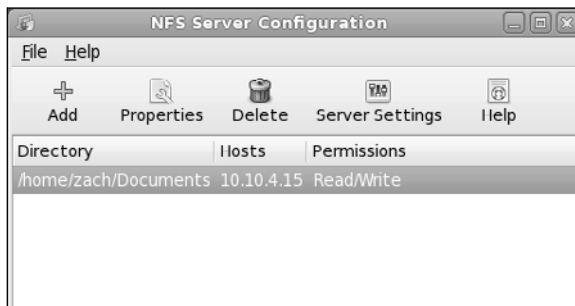


Figure 22-2 NFS Server Configuration window

## SETTING UP AN NFS SERVER

### PREREQUISITES

Install the following package:

- **nfs-utils**
- **system-config-nfs** (optional)

Run `chkconfig` to cause `nfs` to start when the system enters multiuser mode:

```
# /sbin/chkconfig nfs on
```

Start `nfs`:

```
# /sbin/service nfs start
```

The `nfs` init script starts `mountd`, `nfstd`, and `rquotad`.

*RHEL* Under RHEL, the `portmap` daemon (part of the `portmap` package; refer to “RPC Network Services” on page 391) must be running to enable reliable file locking.

### NOTES

**SELinux** When SELinux is set to use a targeted policy, NFS is protected by SELinux. You can disable this protection if necessary. For more information refer to “Setting the Targeted Policy with `system-config-selinux`” on page 416.

**Firewall** If the system is running a firewall, you generally need to open TCP port 111 for `rpcbind` (*FEDORA*) or `portmap` (*RHEL*), TCP ports 1013 and 1016 for `mountd`, and TCP port 2049 for `nfs`. If these ports do not allow NFS access, use `rpcinfo -p` (page 443) to determine the TCP ports that the local server uses for these services and then open those ports. Using the Firewall Configuration window Other Ports tab (page 825), open the necessary ports. For more general information, see Chapter 25, which details `iptables`.

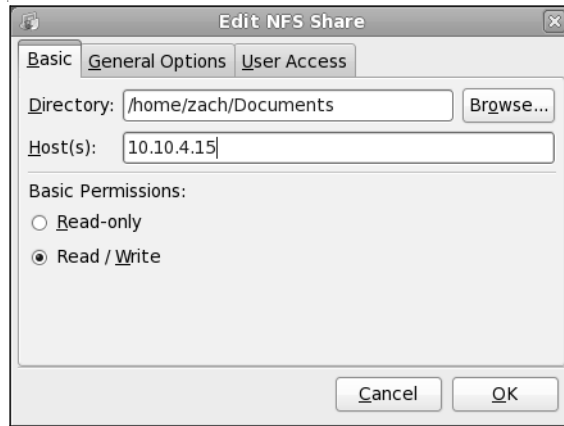


Figure 22-3 Edit NFS Share window

## JUMPSTART II: CONFIGURING AN NFS SERVER

### USING `system-config-nfs`

To display the NFS Server Configuration window (Figure 22-2), enter the command `system-config-nfs` or select **Main Menu: System**⇒**Administration**⇒**[Server Settings]⇒[NFS]**. From this window you can generate an `/etc/exports` file, which is almost all there is to setting up an NFS server. If the system is running a firewall, see “Notes” in the preceding section. The `system-config-nfs` utility allows you to specify which directory hierarchies are shared and how they are shared using NFS. Each exported hierarchy is called a *share*.

To add a share, click **Add** on the toolbar. To modify a share, highlight the share and click **Properties** on the toolbar. Clicking **Add** displays the Add NFS Share window, while clicking **Properties** displays the Edit NFS Share window. These windows are identical except for their titles.

The Add/Edit NFS Share window has three tabs: Basic, General Options, and User Access. On the Basic tab (Figure 22-3) you can specify the pathname of the root of the shared directory hierarchy, the names or IP addresses of the systems (hosts) that the hierarchy will be shared with, and whether users from the specified systems will be able to write to the shared files.

The selections in the other two tabs correspond to options that you can specify in the `/etc/exports` file. Following is a list of the check box descriptions in these tabs and the option each corresponds to:

- |                     |                                                                                     |
|---------------------|-------------------------------------------------------------------------------------|
| General Options tab | Allow connections from ports 1024 and higher: <b>insecure</b> (page 740)            |
|                     | Allow insecure file locking: <b>no_auth_nlm</b> or <b>insecure_locks</b> (page 740) |

Disable subtree checking: **no\_subtree\_check** (page 740)  
Sync write operations on request: **sync** (page 740)  
Force sync of write operations immediately: **no\_wdelay** (page 740)  
Hide filesystems beneath: **nohide** (page 740)  
Export only if mounted: **mountpoint** (page 740)

User Access tab    Treat remote root user as local root: **no\_root\_squash** (page 741)  
                      Treat all client users as anonymous users: **all\_squash** (page 742)  
                      Local user ID for anonymous users: **anonuid** (page 742)  
                      Local group ID for anonymous users: **anongid** (page 742)

After making the changes you want, click **OK** to close the Add/Edit NFS Share window and click **OK** again to close the NFS Server Configuration window. There is no need to restart any daemons.

## EXPORTING A DIRECTORY HIERARCHY

Exporting a directory hierarchy makes the directory hierarchy *available* for mounting by a client on the network. “Exported” does not mean “mounted”: When a directory hierarchy is exported, it is placed in the list of directory hierarchies that can be mounted by other systems. An exported directory hierarchy may be mounted (or not) at any given time. A server holds three lists of exported directory hierarchies:

- **/etc/exports**—Access control list for exported directory hierarchies (discussed in the next section). The system administrator can modify this file by editing it or by running **system-config-nfs**.
- **/var/lib/nfs/xtab**—Access control list for exported directory hierarchies. Initialized from **/etc/exports** when the system is brought up. Read by **mountd** when a client asks to mount a directory hierarchy. Modified by **exportfs** (page 742) as directory hierarchies are mounted and unmounted by NFS.
- Kernel’s export table—List of active exported directory hierarchies. The kernel obtains this information from **/var/lib/nfs/xtab**. You can display this table by giving the command **cat /proc/fs/nfs/exports**.

### Exporting symbolic links and device files

---

**tip** When you export a directory hierarchy that contains a symbolic link, make sure the file the link points to is available on the client (remote) system. If this file does not exist on a client system, you must export and mount it along with the exported link. Otherwise, the link will not point to the file it points to on the server.

A device file refers to a Linux kernel interface. When you export a device file, you export that interface. If the client system does not have the same type of device, the exported device will not work. From a client, you can use **mount**’s **nodev** option (page 731) to prevent device files on mounted directory hierarchies from being used as devices.

---

A mounted filesystem with a mount point within an exported filesystem will not be exported with the exported filesystem. You need to explicitly export each filesystem that you want exported, even if it resides within an already exported filesystem. For example, when you have two filesystems, `/opt/apps` and `/opt/apps/oracle`, residing on two partitions to export, you must export each explicitly, even though `oracle` is a subdirectory of `apps`. Most other subdirectories and files are exported automatically.

## `/etc/exports`: HOLDS A LIST OF EXPORTED DIRECTORY HIERARCHIES

The `/etc/exports` file is the access control list for exported directory hierarchies that NFS clients can mount; it is the only file you need to edit to set up an NFS server. The `exports` file controls the following aspects:

- Which clients can access files on the server
- Which directory hierarchies on the server each client can access
- How each client can access each directory hierarchy
- How client usernames are mapped to server usernames
- Various NFS parameters

Each line in the `exports` file has the following format:

```
export-point client1(options) [client2(options) ... ]
```

where *export-point* is the absolute pathname of the root directory of the directory hierarchy to be exported, *client1-n* is the name of one or more clients or is one or more IP addresses, separated by SPACES, that are allowed to mount the *export-point*. The *options*, which are described in the next section, apply to the preceding *client*.

You can either use `system-config-nfs` (page 737) to make changes to `exports` or you can edit this file directly. The following simple `exports` file gives `grape` read and write access and gives `speedy` read-only access to the files in `/home`:

```
# cat /etc/exports
/home grape(rw,no_subtree_check)
/home speedy(ro,no_subtree_check)
```

In each case, access is implicitly granted for all subdirectories. You can use IP addresses and include more than one system on a line:

```
# cat /etc/exports
/home grape(rw, sync) 192.168.0.22(rw, sync)
```

## GENERAL OPTIONS

This section lists default options first, followed by nondefault options (enclosed in parentheses). Refer to the `exports` man page for more information.

**auth\_nlm** (**no\_auth\_nlm**) or **secure\_locks** (**insecure\_locks**)

Causes the server to require authentication of lock requests (using the NLM [NFS Lock Manager] protocol). Use **no\_auth\_nlm** for older clients when you find that only files that anyone can read can be locked.

**mountpoint**[=*path*]

Allows a directory to be exported only if it has been mounted. This option prevents a mount point that does not have a directory hierarchy mounted on it from being exported and prevents the underlying mount point from being exported. Also **mp**.

**nohide** (**hide**) When a server exports two directory hierarchies, one of which is mounted on the other, a client has to mount both directory hierarchies explicitly to access both. When the second (child) directory hierarchy is not explicitly mounted, its mount point appears as an empty directory and the directory hierarchy is hidden. The **nohide** option causes the underlying second directory hierarchy to appear when it is not explicitly mounted, but this option does not work in all cases.

**ro** (**rw**) (**readonly**) Permits only read requests on an NFS directory hierarchy. Use **rw** to permit read and write requests.

**secure** (**insecure**) Requires that NFS requests originate on a *privileged port* (page 1100) so that a program without **root** permissions cannot mount a directory hierarchy. This option does not guarantee a secure connection.

**subtree\_check** (**no\_subtree\_check**)

Checks subtrees for valid files. Assume that you have an exported directory hierarchy that has its root below the root of the filesystem that holds it (that is, an exported subdirectory of a filesystem). When the NFS server receives a request for a file in that directory hierarchy, it performs a subtree check to confirm the file is in the exported directory hierarchy.

Subtree checking can cause problems with files that are renamed while opened and, when **no\_root\_squash** is used, files that only **root** can access. The **no\_subtree\_check** option disables subtree checking and can improve reliability in some cases.

For example, you may need to disable subtree checking for home directories. Home directories are frequently subtrees (of **/home**), are written to often, and can have files within them frequently renamed. You would probably not need to disable subtree checking for directory hierarchies that contain files that are mostly read, such as **/usr**.

**sync** (**async**) (**synchronize**) Specifies that the server is to reply to requests only after disk changes made by the request are written to disk. The **async** option specifies that the server does not have to wait for information to be written to disk and can improve performance, albeit at the cost of possible data corruption if the server crashes or the connection is interrupted.

Because the default changed with release 1.0.0 of **nfs-utils**, **exportfs** displays a warning when you do not specify either **sync** or **async**.

**wdelay** (**write delay**) Causes the server to delay committing write requests when it anticipates that another, related request follows, thereby improving performance by committing multiple write requests within a single operation. The **no\_wdelay** option does not



delay committing write requests and can improve performance when the server receives multiple, small, unrelated requests.

## USER ID MAPPING OPTIONS

Each user has a UID number and a primary GID number on the local system. The local `/etc/passwd` and `/etc/group` files map these numbers to names. When a user makes a request of an NFS server, the server uses these numbers to identify the user on the remote system, raising several issues:

- The user may not have the same ID numbers on both systems and may therefore have owner access to files of another user (see “NIS and NFS” for a solution).
- You may not want the **root** user on the client system to have owner access to **root**-owned files on the server.
- You may not want a remote user to have owner access to some important system files that are not owned by **root** (such as those owned by **bin**).

### Critical files in NFS-mounted directories should be owned by root

#### security

Despite the mapping done by the **root-squash** option, the **root** user on a client system can use su to assume the identity of any user on the system and then access that user's files on the server. Thus, without resorting to **all-squash**, you can protect only files owned by **root** on an NFS server. Make sure that **root**—and not **bin** or another user—owns and is the only user who can modify or delete all critical files within any NFS-mounted directory hierarchy.

Taking this precaution does not completely protect against an attacker with **root** privileges, but it can help protect a system from less experienced malicious users.

*Owner access* means that the remote user can execute, remove, or—worse—modify the file. NFS gives you two ways to deal with these cases:

- You can use the **root\_squash** option to map the ID number of the **root** user on a client to the **nfsnobody** user on the server.
- You can use the **all-squash** option to map all NFS users on the client to **nfsnobody** on the server.

The `/etc/passwd` file shows that **nfsnobody** has a UID and GID of 65534. You can use the **anonuid** and **anongid** options to override these values.

NIS and NFS When you use NIS (page 695) for user authorization, users automatically have the same UIDs on both systems. If you are using NFS on a large network, it is a good idea to use a directory service such as *LDAP* (page 1090) or NIS for authorization. Without such a service, you must synchronize the **passwd** files on all the systems manually.

#### root\_squash (no\_root\_squash)

Maps requests from **root** on a remote system so that they appear to come from the UID for **nfsnobody**, an unprivileged user on the local system, or as specified by **anonuid**. Does not affect other sensitive UIDs such as **bin**. The **no\_root\_squash** option turns off this mapping so that requests from **root** appear to come from **root**.

- no\_all\_squash** Does not change the mapping of users making requests of the NFS server. The **(all\_squash)** **all\_squash** option maps requests from all users, not just **root**, on remote systems to appear to come from the UID for **nfsnobody**, an unprivileged user on the local system, or as specified by **anonuid**. This option is useful for controlling access to exported public FTP, news, and other directories.
- anonuid=*un* and anongid=*gn*** Set the UID or the GID of the anonymous account to *un* or *gn*, respectively. NFS uses these accounts when it does not recognize an incoming UID or GID and when instructed to do so by **root\_squash** or **all\_squash**.

## showmount: DISPLAYS NFS STATUS INFORMATION

Without any options, the **showmount** utility displays a list of systems that are allowed to mount local directories. To display information for a remote system, give the name of the remote system as an argument. You typically use **showmount** to display a list of directory hierarchies that a server is exporting. The information that **showmount** provides may not be complete, however, because it depends on **mountd** and trusts that remote servers are reporting accurately.

In the following example, **bravo** and **grape** can mount local directories, but you do not know which ones:

```
# /usr/sbin/showmount
Hosts on localhost:
bravo.tcorp.com
grape.tcorp.com
```

If **showmount** displays an error such as **RPC: Program not registered**, NFS is not running on the server. Start NFS on the server with the **nfs** init script (page 736).

- a (all) Tells which directories are mounted by which remote systems. This information is stored in **/etc/exports**.

```
# /usr/sbin/showmount -a
All mount points on localhost:
bravo.tcorp.com:/home
grape.tcorp.com:/home
```

- e (exports) Displays a list of exported directories.

```
# /usr/sbin/showmount -e
Export list for localhost:
/home bravo.tcorp.com,grape.tcorp.com
```

## exportfs: MAINTAINS THE LIST OF EXPORTED DIRECTORY HIERARCHIES

The **exportfs** utility maintains the kernel's list of exported directory hierarchies. Without changing **/etc/exports**, **exportfs** can add to or remove from the list of exported directory hierarchies. An **exportfs** command has the following format:

```
/usr/sbin/exportfs [options] [client:dir ...]
```

where *options* is one or more options (as detailed in the next section), *client* is the name of the system that *dir* is exported to, and *dir* is the absolute pathname of the directory at the root of the directory hierarchy being exported.

The system executes the following command when it comes up (it is in the **nfs** init script). This command reexports the entries in **/etc/exports** and removes invalid entries from **/var/lib/nfs/xtab** (page 738) so that **/var/lib/nfs/xtab** is synchronized with **/etc/exports**:

```
# exportfs -r
```

Replace the **-r** with **-a** to export only the entries in **/etc/exports**. Remove an exported directory hierarchy with the **-u** option; remove all exported directory hierarchies with the **-ua** options.

## OPTIONS

- a (all) Exports directory hierarchies specified in **/etc/exports**. This option does not *unexport* entries you have removed from **exports** (that is, it does not remove invalid entries from **/var/lib/nfs/xtab**); use **-r** to perform this task.
- i (ignore) Ignores **/etc/exports**; uses what is specified on the command line only.
- o (options) Specifies options. You can specify options following **-o** the same way you do in the **exports** file. For example, **exportfs -i -o ro speedy:/home/sam** exports **/home/sam** on the local system to **speedy** for readonly access.
- r (reexport) Reexports the entries in **/etc/exports** and removes invalid entries from **/var/lib/nfs/xtab** so that **/var/lib/nfs/xtab** is synchronized with **/etc/exports**.
- u (unexport) Makes an exported directory hierarchy no longer exported. If a directory hierarchy is mounted when you unexport it, you will see the message **Stale NFS file handle** if you try to access the directory hierarchy from the remote system.
- v (verbose) Provides more information. Displays export options when you use **exportfs** to display export information.

## TESTING THE SERVER SETUP

From the server, run the **nfs** init script with an argument of **status**. If all is well, the system displays something similar to the following:

```
# /sbin/service nfs status
rpc.mountd (pid 15795) is running...
nfsd (pid 15813 15812 15811 15810 15809 15808 15807 15806) is running...
rpc.rquotad (pid 15784) is running...
```

Next, from the server, use **rpcinfo** to make sure NFS is registered with **rpcbind/portmap**:

```
$ /usr/sbin/rpcinfo -p localhost | grep nfs
100003      2      udp      2049  nfs
100003      3      udp      2049  nfs
```

Repeat the preceding command from the client, replacing **localhost** with the name of the server. The results should be the same.

Finally, try mounting directory hierarchies from remote systems and verify access.

---

## automount: AUTOMATICALLY MOUNTS DIRECTORY HIERARCHIES

With distributed computing, when you log in on any system on the network, all of your files, including startup scripts, are available. In a distributed computing environment, all systems are commonly able to mount all directory hierarchies on all servers: Whichever system you log in on, your home directory is waiting for you.

As an example, assume that **/home/alex** is a remote directory hierarchy that is mounted on demand. When you issue the command **ls /home/alex**, **autofs** goes to work: It looks in the **/etc/auto.home** map, finds that **alex** is a key that says to mount **bravo:/export/home/alex**, and mounts the remote directory hierarchy. Once the directory hierarchy is mounted, **ls** displays the list of files you want to see. If you give the command **ls /home** after this mounting sequence, **ls** shows that **alex** is present within the **/home** directory. The **df** utility shows that **alex** is mounted from **bravo**.

### PREREQUISITES

Install the following package:

- **autofs**

Run **chkconfig** to cause **autofs** to start when the system enters multiuser mode:

```
# /sbin/chkconfig autofs on
```

Start **autofs**:

```
# /sbin/service autofs start
```

### MORE INFORMATION

Local man pages: **autofs**, **automount**, **auto.master**

Web tutorial: [www.linuxhq.com/lg/issue24/nielsen.html](http://www.linuxhq.com/lg/issue24/nielsen.html)

HOWTO *Automount mini-HOWTO*

### autofs: AUTOMATICALLY MOUNTED DIRECTORY HIERARCHIES

An **autofs** directory hierarchy is like any other directory hierarchy, but remains unmounted until it is needed, at which time the system mounts it automatically (*demand mounting*). The system unmounts an **autofs** directory hierarchy when it is no longer needed—by default after five minutes of inactivity. Automatically mounted directory hierarchies are an important part of administrating a large collection of

systems in a consistent way. The **automount** daemon is particularly useful when an installation includes a large number of servers or a large number of directory hierarchies. It also helps to remove server–server dependencies (discussed next).

When you boot a system that uses traditional **fstab**-based mounts and an NFS server is down, the system can take a long time to come up as it waits for the server to time out. Similarly, when you have two servers, each mounting directory hierarchies from the other, and both systems are down, both may hang as they are brought up and each tries to mount a directory hierarchy from the other. This situation is called a *server–server dependency*. The **automount** facility gets around these issues by mounting a directory hierarchy from another system only when a process tries to access it.

When a process attempts to access one of the directories within an unmounted **autofs** directory hierarchy, the kernel notifies the **automount** daemon, which mounts the directory hierarchy. You have to give a command, such as `cd /home/alex`, that accesses the **autofs** mount point (in this case `/home/alex`) so as to create the demand that causes **automount** to mount the **autofs** directory hierarchy so you can see it. Before you issue the `cd` command, **alex** does not appear to be in `/home`.

The main file that controls the behavior of **automount** is `/etc/auto.master`. A simple example follows:

```
# cat /etc/auto.master
/free1 /etc/auto.misc --timeout 60
/free2 /etc/auto.misc2 --timeout 60
```

The **auto.master** file has three columns. The first column names the parent of the **autofs** *mount point*—the location where the **autofs** directory hierarchy is to be mounted (`/free1` and `/free2` in the example are not mount points but will hold the mount points when the directory hierarchies are mounted). The second column names the files, called *map files*, that store supplemental configuration information. The optional third column holds mount options for map entries that do not specify an option.

Although the map files can have any names, one is traditionally named **auto.misc**. Following are the two map files specified in **auto.master**:

```
# cat /etc/auto.misc
sam -fstype=ext3 :/dev/sda8

# cat /etc/auto.misc2
helen -fstype=ext3 :/dev/sda9
```

The first column of a map file holds the relative **autofs** mount point (**sam** and **helen**). This mount point is appended to the corresponding **autofs** mount point from column 1 of the **auto.master** file to create the absolute **autofs** mount point. In this example, **sam** (from **auto.misc**) is appended to `/free1` (from **auto.master**) to make `/free1/sam`. The second column holds the options, and the third column shows the server and directory hierarchy to be mounted. This example shows local drives; for

an NFS-mounted device, the hostname of the remote system would appear before the colon (for example, **grape:/home/sam**).

Before the new setup can work, you must create directories for the parents of the mount points (**/free1** and **/free2** in the preceding example) and start (or restart) the **automount** daemon using the **autofs** init script. The following command displays information about configured and active **autofs** mount points:

```
# /sbin/service autofs status
```

---

## CHAPTER SUMMARY

NFS allows a server to share selected local directory hierarchies with client systems on a heterogeneous network, reducing storage needs and administrative overhead. NFS defines a client/server relationship in which a server provides directory hierarchies that clients can mount.

On the server, the **/etc/exports** file lists the directory hierarchies that the system exports. Each line in **exports** lists the systems that are allowed to mount the hierarchy and specifies the options for each hierarchy (readonly, read-write, and so on). Give an **exportfs -r** command to cause NFS to reread this file.

From a client, you can give a **mount** command to mount an exported NFS directory hierarchy. Alternatively, you can put an entry in **/etc/fstab** to have the system automatically mount the directory hierarchy when it comes up.

Automatically mounted directory hierarchies help manage large groups of systems with many servers and filesystems in a consistent way and can help remove server-server dependencies. The **automount** daemon automatically mounts **autofs** directory hierarchies when they are needed and unmounts them when they are no longer needed.

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## EXERCISES

1. List three reasons to use NFS.
2. Which command would you give to mount on the local system the **/home** directory hierarchy that resides on the file server named **bravo**? Assume the mounted directory hierarchy will appear as **/bravo.home** on the local system. How would you mount the same directory hierarchy if it resided on the fileserver at 192.168.1.1? How would you unmount **/home**?
3. How would you list the mount points on the remote system named **bravo** that the local system named **grape** can mount?
4. Which command line lists the currently mounted NFS directory hierarchies?

5. What does the `/etc/fstab` file do?
6. From a server, how would you allow readonly access to `/opt` for any system in `example.com`?

---

## ADVANCED EXERCISES

7. When is it a good idea to disable attribute caching?
8. Describe the difference between the `root_squash` and the `all_squash` options in `/etc/exports`.
9. Why does the `secure` option in `/etc/exports` not really provide any security?
10. Some diskless workstations use NFS as swap space. Why is this useful? What is the downside?
11. NFS maps client users to users on the server. Explain why this mapping is a security risk.
12. What does the mount `nosuid` option do? Why would you want to do this?

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# SAMBA: INTEGRATING LINUX AND WINDOWS

## IN THIS CHAPTER

About Samba .....	751
JumpStart: Configuring a Samba Server Using system-config-samba .....	753
swat: Configures a Samba Server .....	755
Manually Configuring a Samba Server .....	759
Accessing Linux Shares from Windows .....	765
Accessing Windows Shares from Linux. ....	766
Troubleshooting .....	768

Samba is a free suite of programs that enables UNIX-like operating systems, including Linux, Solaris, FreeBSD, and Mac OS X, to work with other operating systems, such as OS/2 and Windows, as both a server and a client.

As a server, Samba shares Linux files and printers with Windows systems. As a client, Samba gives Linux users access to files on Windows systems. Its ability to share files across operating systems makes Samba an ideal tool in a heterogeneous computing environment.

Refer to “Printing Using Samba” on page 539 and “Printing to Windows” on page 540 for information about printing using Samba.

# INTRODUCTION

This chapter starts by providing a list of Samba tools followed by some basic information. The JumpStart section discusses how to set up a Samba server using `system-config-samba`, a minimal GUI. The next section covers how to use `swat`, a Web-based advanced configuration tool, to set up a Samba server. The final server section discusses how to set up a Samba server by hand, using a text editor to manually edit the files that control Samba. The next two sections, “Accessing Linux Shares from Windows” (page 765) and “Accessing Windows Shares from Linux” (page 766), explain how to work with Linux and Windows files and printers. The final section of the chapter, “Troubleshooting” (page 768), offers tips on what to do when you have a problem setting up or using Samba.

Table 23-1 lists the utilities and daemons that make up the Samba suite of programs.

**Table 23-1**    Samba utilities and daemons

Utility or daemon	Function
net	This utility has the same syntax as the DOS <code>net</code> command and, over time, will eventually replace other Samba utilities such as <code>smbpasswd</code> .
nmbd	The <i>NetBIOS</i> (page 1095) nameserver program, run as a daemon by default. Provides NetBIOS over IP naming services for Samba clients. Also provides browsing (as in the Windows Network Neighborhood or My Network Places view) support.
nmblookup	Makes <i>NetBIOS</i> (page 1095) name queries (page 769).
smbclient	Displays shares on a Samba server such as a Windows machine (page 767).
smbd	The Samba program, run as a daemon by default. Provides file and print services for Samba clients.
smbpasswd	Changes Windows NT password hashes on Samba and Windows NT servers (page 752).
smbstatus	Displays information about current <b>smbd</b> connections.
smbtree	Displays a hierarchical diagram of available shares (page 766).
swat	Samba Web Administration Tool. A graphical editor for the <b>smb.conf</b> file (page 755).
testparm	Checks syntax of the <b>smb.conf</b> file (page 768).

## ABOUT SAMBA

This section covers the packages you need to install to run Samba, sources of more information on Samba, and users and passwords under Samba.

## PREREQUISITES

Install the following packages:

- **samba**
- **samba-client**
- **samba-common**
- **system-config-samba** (optional)
- **samba-swat** (optional, but a good idea; this package is dependent on the **xinetd** package)

Run **chkconfig** to cause **smb** to start when the system enters multiuser mode:

```
# /sbin/chkconfig smb on
```

Start **smb**:

```
# /sbin/service smb start
```

If you want to use **swat**, modify **/etc/xinetd.d/swat**, as explained in “**swat: Configures a Samba Server**” on page 755, and restart **xinetd** (part of the **xinetd** package):

```
# /sbin/service xinetd restart
```

## MORE INFORMATION

Local Samba/swat home page has links to local Samba documentation (page 755)

Documentation: **/usr/share/doc/samba-\***

Web Samba: [www.samba.org](http://www.samba.org) (mailing lists, documentation, downloads, and more)

Samba documentation: [www.samba.org/samba/docs](http://www.samba.org/samba/docs)

CIFS: [samba.org/cifs](http://samba.org/cifs)

## NOTES

Firewall The Samba server normally uses UDP ports 137 and 138 and TCP ports 139 and 445. If the Samba server system is running a firewall, you need to open these ports. Using the Firewall Configuration window Trusted Services tab (page 824), put a check in the box labeled **Samba** to open these ports. For more general information, see Chapter 25, which details **iptables**.

- SELinux When SELinux is set to use a targeted policy, Samba is protected by SELinux. You can disable this protection if necessary. For more information refer to “Setting the Targeted Policy with `system-config-selinux`” on page 416.
- Share Under Samba, an exported directory hierarchy is called a *share*.
- Samba The name *Samba* is derived from *SMB* (page 1106), the protocol that is the native method of file and printer sharing for Windows.

## SAMBA USERS, USER MAPS, AND PASSWORDS

For a Windows user to gain access to Samba services on a Linux system, the user must provide a Windows username and a Samba password. In some cases, Windows supplies the username and password for you. It is also possible to authenticate using other methods. For example, Samba can use *LDAP* (page 1090) or *PAM* (page 458) instead of the default password file. Refer to the Samba documentation for more information on authentication methods.

- Username The supplied username must be the same as a Linux username or must map to a Linux username. Samba keeps the username maps in `/etc/samba/smbusers`. Users with the same username on Linux and Samba do not need to appear in this file, but they still need a Samba password.

When you install Samba, `smbusers` has two entries:

```
$ cat /etc/samba/smbusers
# Unix_name = SMB_name1 SMB_name2 ...
root = administrator admin
nobody = guest pcguest smbguest
```

The first entry maps the two Windows usernames (**administrator** and **admin**) to the Linux username **root**. The second entry maps three Windows usernames, including **guest**, to the Linux username **nobody**: When a Windows user attempts to log in on the Samba server as **guest**, Samba authenticates the Linux user named **nobody**.

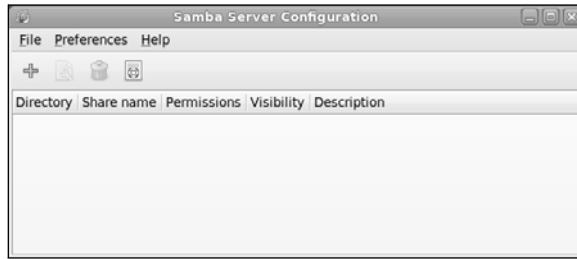
- Passwords Samba uses Samba passwords—not Linux passwords—to authenticate users. By default, Samba keeps passwords in `/etc/samba/smbpasswd`. As Samba is installed, authentication for **root** or **nobody** would fail because Samba is installed without passwords: The `smbpasswd` file does not exist.

Each of the configuration techniques described in this chapter allows you to add users to `smbusers` and passwords to `smbpasswd`. You can always use `smbpasswd` as discussed later in this section to add and change passwords in `smbpasswd`.

- Note When you attempt to connect from Windows to a Samba server, Windows presents your Windows username and password to Samba. If your Windows username is the same as or maps to your Linux username, and if your Windows and Samba passwords are the same, you do not have to enter a username or password to connect to the Samba server.

- Example You can add the following line to `smbusers` to map the Windows username **sam** to the Linux username **sls**:

```
sls = sam
```



**Figure 23-1** Samba Server Configuration window

You can add a password for `sls` to `smbpasswd` with the following command:

```
# smbpasswd -a sls
New SMB password:
Retype new SMB password:
Added user sls.
```

Now when Sam uses the username `sam` to log in on the Samba server, Samba maps `sam` to `sls` and looks up `sls` in `smbpasswd`. Assuming Sam provides the correct password, he logs in on the Samba server as `sls`.

## JUMPSTART: CONFIGURING A SAMBA SERVER USING system-config-samba

The `system-config-samba` utility can set up only basic features of a Samba server. It is, however, the best tool to use if you are not familiar with Samba and you want to set up a simple Samba server quickly. The `system-config-samba` utility performs three basic functions: configuring the server, configuring users, and setting up shares (directory hierarchies) that are exported to the Windows machines.

### Make a copy of `smb.conf`

**tip** As installed, the `/etc/samba/smb.conf` file has extensive comments (page 759). The `system-config-samba` utility overwrites this file. Make a copy of `smb.conf` for safekeeping before you run this utility for the first time.

To display the Samba Server Configuration window (Figure 23-1), enter `system-config-samba` on a command line or select **Main menu: System⇒Administration⇒Samba (FEDORA)** or **Main menu: System⇒Administration⇒Server Settings⇒Samba (RHEL)**.

Select **Menubar: Preferences⇒Server Settings** to display the Server Settings window Basic tab (Figure 23-2, next page). Change the workgroup to the one in use on the Windows machines. Change the description of the server if you like. Click the **Security** tab and make sure Authentication Mode is set to **User**; you do not need to specify an Authentication Server or a Kerberos Realm. If you are using Windows 98 or



**Figure 23-2** Server Settings window, Basic tab

later, set Encrypt Passwords to **Yes**. When you specify a username in the Guest Account, anyone logging in on the Samba server as **guest** maps to that user's ID. Typically the **guest** account maps to the UID of the Linux user named **nobody**. Click **OK**.

**Samba users** Select **Menubar: Preferences** ⇒ **Samba Users** to display the Samba Users window (Figure 23-3). If the user you want to log in as is not already specified in this window, click **Add User**. When you have the proper permissions, the Create New Samba User window displays a combo box next to Unix Username that allows you to select a Linux user; otherwise, your username is displayed as the Unix Username. The Windows Username is the Windows username that you want to map to the specified Linux (UNIX) username. The Samba Password is the password this user or Windows enters to gain access to the Samba server.

If Zach has accounts named **zach** on both the Windows and Linux systems, you would select **zach** from the Unix Username combo box, enter **zach** in the Windows Username text box, and enter Zach's Windows password in the two Samba Password text boxes. Click **OK** to close the Create New Samba User window and click **OK** to close the Samba Users window.

### **Adding a Samba password for the Linux user *nobody***

**tip** Because the user **nobody** exists in **smbusers** when you install Samba, you cannot add the user **nobody**, nor can you add a password for **nobody** from **system-config-samba**. Instead, you must use **smbpasswd** from the command line as follows:

```
# smbpasswd -a nobody
New SMB password:
Retype new SMB password:
```

Normally the user **nobody** does not have a password because it is the guest login. Press RETURN (without typing any characters) in response to each of the **SMB password** prompts to add **nobody** to the Samba password file without a password.

**Linux shares** Next you need to add a *share*, which is the directory hierarchy you export from the Linux system to the Windows system. Click the plus sign (+) on the toolbar to display the Basic tab in the Create Samba Share window (Figure 23-4). In the Directory text box, enter the absolute pathname of the directory you want to share (**/tmp** is an easy directory to practice with). Enter a description if you like. It can be useful



**Figure 23-3** Samba Users window

to enter the Linux hostname and the pathname of the directory you are sharing here. Specify Writable if you want to be able to write to the directory from the Windows machine; Visible allows the share to be seen from the Windows machine. Click the Access tab and specify whether you want to limit access to specified users or whether you want to allow anyone to access this share. Click **OK**. Close the Samba Server Configuration window.

You should now be able to access the share from a Windows machine (page 765). There is no need to restart the Samba server.

## swat: CONFIGURES A SAMBA SERVER

### Make a copy of `smb.conf`

**tip** As installed, the `/etc/samba/smb.conf` file contains extensive comments (page 759). Older versions of swat overwrite this file. Make a copy of **smb.conf** for safekeeping before you run this utility for the first time.

The swat (Samba Web Administration Tool) utility is a browser-based graphical editor for the `smb.conf` file. It is part of the **samba-swat** package. For each of the configurable parameters, it provides help links, default values, and a text box to change



**Figure 23-4** Create Samba Share window, Basic tab

the value. The `swat` utility is a well-designed tool in that it remains true to the lines in the `smb.conf` file you edit: You can use and learn from `swat`, so that making the transition to using a text editor to modify `smb.conf` will be straightforward.

The `swat` utility is run from `xinetd` (page 445). Before you can run `swat`, you need to edit `/etc/xinetd.d/swat` (as discussed next):

```
$ cat /etc/xinetd.d/swat
# Default: off
# description: SWAT is the Samba Web Admin Tool. Use swat \
#              to configure your Samba server. To use SWAT, \
#              connect to port 901 with your favorite web browser.
service swat
{
    port                = 901
    socket_type         = stream
    wait               = no
    only_from          = 127.0.0.1
    user               = root
    server             = /usr/sbin/swat
    log_on_failure     += USERID
    disable            = yes
}
```

First you must turn `swat` on by changing the `yes` that follows `disable =` to `no`. If you want to access `swat` from other than the local system, add the names or IP addresses of the other systems you want to access `swat` from on the line that starts with `only_from`. Separate the system names or IP addresses with SPACES. If you want to access `swat` only from the local system, giving the command `chkconfig swat on` is an easier way of making this change. Then start or restart `xinetd` so it rereads its configuration files:

```
# /sbin/service xinetd restart
Stopping xinetd:           [ OK ]
Starting xinetd:           [ OK ]
```

After making these changes and restarting `xinetd`, you should be able to run `swat`. From the local system, open a browser, enter either `http://127.0.0.1:901` in the location bar, and enter the username `root` and the `root` password in response to `swat`'s request for a username and password. From a remote system, replace `127.0.0.1` with the IP address of the server (but see the adjacent security tip). If a firewall is running on the local system and you want to access `swat` from a remote system, open TCP port 901 (page 825).

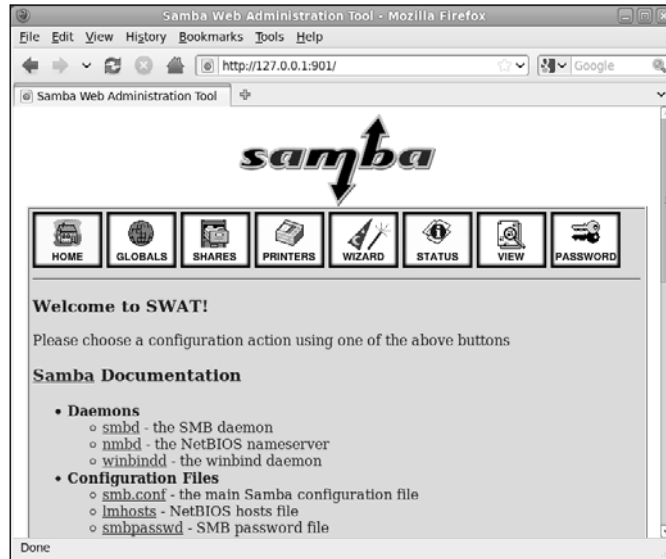
### Do not allow remote access to swat

**security** Do not allow access to `swat` from a remote system on an insecure network. When you do so and log in, your password is sent in cleartext over whatever connection you are using and can easily be sniffed.

---

The browser displays the local Samba/`swat` home page (Figure 23-5). This page includes links to local Samba documentation and the following buttons:





**Figure 23-5** The local swat home page

- HOME** Links to local Samba documentation. When you click the word **Samba** (not the logo, but the one just before the word **Documentation** in the HOME window), swat displays the Samba man page, which defines each Samba program.
- GLOBALS** Edits global variables (parameters) in **smb.conf**.
- SHARES** Edits share information in **smb.conf**.
- PRINTERS** Edits printer information in **smb.conf**.
- WIZARD** Rewrites the **smb.conf** file, removing all comment lines and lines that specify default values.
- STATUS** Shows the active connections, active shares, and open files. Stops and restarts **smbd** and **nmbd**.
- VIEW** Displays a subset or all of the configuration parameters as determined by default values and settings in **smb.conf**.
- PASSWORD** Manages passwords.
- It is quite easy to establish a basic Samba setup so that you can see a Linux directory from a Windows system (Windows 3.1 or later). More work is required to set up a secure connection or one with special features. The following example creates a basic setup based on the sample **smb.conf** file that is included with Fedora/RHEL.
- swat Help and defaults Each of the variables/parameters in swat has a link named **Help** next to it. If you click **Help**, a new browser window containing an explanation of the parameter appears. Each variable/parameter also has a **Set Default** button that you can click to reset the variable/parameter to its default value.

For this example, do not click any of the **Set Default** buttons. Make sure to click **Commit Changes** at the top of each page after you finish making changes on a page but before you click a menu button at the top of the window. Otherwise, **swat** will not keep your changes.

**GLOBALS page** First click **GLOBALS** at the top of the Samba/swat home page. Leave everything at its current setting with three exceptions: **workgroup**, **hosts allow**, and **hosts deny**. Set **workgroup** to the workgroup used on the Windows systems. (If you followed the preceding JumpStart, the workgroup is already set.) Scroll to the bottom of the Security Options and set **hosts allow** to the names or IP addresses of machines that you want to be able to access the local system's shares and printers (including **localhost** [127.0.0.1]). Separate the entries with SPACES or commas. See page 761 for more information on various ways you can set **hosts allow**. Set **hosts deny** to **ALL**. Click **Commit Changes** (near the top of the page) when you are done with the **GLOBALS** page.

### If you can no longer use swat

---

**tip** If you can no longer use **swat**, you probably changed the **hosts allow** setting incorrectly. In this case, you need to edit **/etc/samba/smb.conf** and fix the line with the words **hosts allow** in it:

```
# grep hosts smb.conf
hosts allow = 127.0.0.1, 192.168.0.8
hosts deny = ALL
```

The preceding entries allow access from the local system and from 192.168.0.8 only.

---

**SHARES page** Next click **SHARES** at the top of the page. Three buttons and two text boxes appear in addition to the two **Change View To** buttons (Figure 23-6). In the box adjacent to the **Create Share** button, enter the name you want to assign to the share you are setting up. This name can be anything you want; it is the name that Windows displays and a user selects when working with the share. Click **Create Share**. When you want to modify an existing share, bring up the name of the share in the combo box adjacent to **Choose Share**, and click **Choose Share**. Either of these actions expands the Share Parameters window so that it displays information about the selected share.

Leave everything at its default setting except **path**, which specifies the absolute pathname on the local Linux system of the share, and optionally **comment**, which you can use to specify the Linux system and directory that this share points to. The values for **hosts allow** and **hosts deny** are taken from the global variables that you set previously. Click **Commit Changes** when you are done with the **SHARES** page. If you want to see how many parameters there really are, click **Advanced** near the top of the page.

Now, from a Windows machine, you should be able to access the share you just created (page 765).

### You do not need to restart Samba when you change smb.conf

---

**tip** Samba rereads its configuration files each time a client connects. Unless you change the **security** parameter (page 762), you do not need to restart Samba when you change **smb.conf**.

---

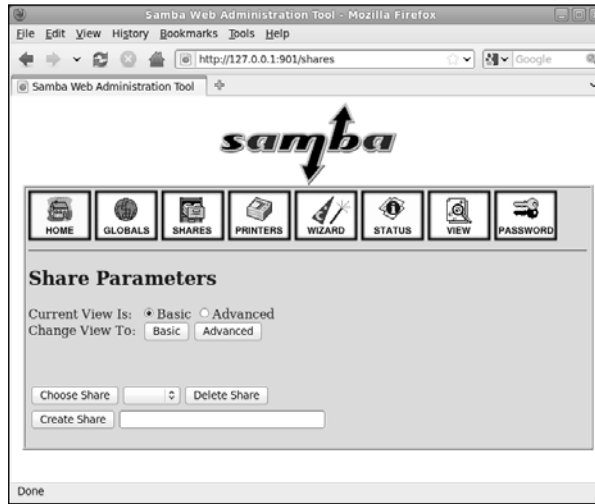


Figure 23-6 Share Parameters page

## MANUALLY CONFIGURING A SAMBA SERVER

The `/etc/samba/smb.conf` file controls most aspects of how Samba works and is divided into sections. Each section begins with a line that starts with an open bracket (`[`), includes some text, and ends with a close bracket (`]`). The text within the brackets identifies the section. Typical sections are

- `[globals]` Defines global parameters
- `[printers]` Defines printers
- `[homes]` Defines shares in the `homes` directory
- `[share name]` Defines a share (you can have more than one of these sections)

**smb.conf comments** As installed on a Fedora/RHEL system, the `/etc/samba/smb.conf` sample configuration file contains extensive comments and commented-out examples. Comment lines in `smb.conf` can start with either a pound sign (`#`) or a semicolon (`;`). The sample file uses pound signs to begin lines that are intended to remain as comments and semicolons to begin lines that you may want to mimic or use as is by removing the semicolons. The following segment of a `smb.conf` file contains two lines of true comments and seven lines beginning with semicolons that you may want to uncomment and make changes to:

```
# A private directory, usable only by fred. Note that fred requires
# write access to the directory.
;[fredsdir]
; comment = Fred's Service
; path = /usr/somewhere/private
; valid users = fred
; public = no
; writable = yes
; printable = no
```

Assuming the global parameters in **smb.conf** are set properly, you need to add a share for a Windows system to be able to access a directory on the local Linux system. Add the following simple share to the end of the **smb.conf** file to enable a user on a Windows system to be able to read from and write to the local **/tmp** directory:

```
[tmp]
    comment = temporary directory
    path = /tmp
    writable = yes
    guest ok = yes
```

The name of the share under Windows is **tmp**; the path under Linux is **/tmp**. Any Windows user, including **guest**, who can log in on Samba, can read from and write to this directory, assuming that the user's Linux permissions allow it. The Linux permissions that apply to a Windows user using Samba are the permissions that apply to the Linux user that the Windows user maps to.

## PARAMETERS IN THE **smbd.conf** FILE

The the **smb.conf** man page and the Help feature of **swat** list all the parameters you can set in **smb.conf**. The following sections identify some of the parameters you are likely to want to change.

### GLOBAL PARAMETERS

- interfaces** A SPACE-separated list of the networks that Samba uses. Specify as interface names (such as **eth0**) or as IP address/net mask pairs (page 443).  
Default: all active interfaces except 127.0.0.1
- server string** The string that is displayed in various places on the Windows machine. Within the string, Samba replaces **%v** with the Samba version number and **%h** with the hostname.  
Default: Samba %v  
Fedora/RHEL: Samba Server
- workgroup** The workgroup that the server belongs to. Set to the same workgroup as the Windows clients that use the server. This parameter controls the domain name that Samba uses when **security** (page 762) is set to **DOMAIN**.  
Default: **WORKGROUP**  
Fedora/RHEL: **MYGROUP**

### SECURITY PARAMETERS

- encrypt passwords** YES accepts only encrypted passwords from clients. Windows 98 and Windows NT 4.0 Service Pack 3 and later use encrypted passwords by default. This parameter uses **smbpasswd** to authenticate passwords unless you set **security** to **SERVER** or **DOMAIN**, in which case Samba authenticates using another server.  
Default: YES

Samba defaults to storing encrypted passwords in the **smbpasswd** file if you do not set up **passwd** (a password database). Storing passwords in the **smbpasswd** file is sensible on servers with fewer than 250 users. For high-load servers, consult the Samba HOWTO collection for information about configuring a database back end.

**guest account** The username that is assigned to users logging in as **guest** or mapped to **guest**; applicable only when **guest ok** (page 765) is set to YES. This username should be present in **/etc/passwd** but should not be able to log in on the system. Typically **guest account** is assigned a value of **nobody** because the user **nobody** can access only files that any user can access. If you are using the **nobody** account for other purposes on the Linux system, set this variable to a name other than **nobody**.

Default: **nobody**

**hosts allow** Analogous to the **/etc/hosts.allow** file (page 447), this parameter specifies hosts that are allowed to connect to the server. Overrides hosts specified in **hosts deny**. A good strategy is to specify ALL in **hosts deny** and to specify the hosts you want to grant access to in this file. Specify hosts in the same manner as in **hosts.allow**.

Default: none (all hosts permitted access)

**hosts deny** Analogous to the **/etc/hosts.deny** file (page 447), this parameter specifies hosts that are not allowed to connect to the server. Overridden by hosts specified in **hosts allow**. If you specify ALL in this file, remember to include the local system (127.0.0.1) in **hosts allow**. Specify hosts in the same manner as in **hosts.deny**.

Default: none (no hosts excluded)

**map to guest** Defines when a failed login is mapped to the **guest account**. Useful only when **security** is not set to **SHARE**.

**Never:** Allows **guest** to log in only when the user explicitly provides **guest** as the username and a blank password.

**Bad User:** Treats any attempt to log in as a user who does not exist as a **guest** login. This parameter is a security risk because it allows a malicious user to retrieve a list of users on the system quickly.

**Bad Password:** Silently logs in as **guest** any user who incorrectly enters his or her password. This parameter may confuse a user when she mistypes her password and is unknowingly logged in as **guest** because she will suddenly see fewer shares than she is used to.

Default: Never

**passwd chat** The chat script that Samba uses to converse with the **passwd** program. If this script is not followed, Samba does not change the password. Used only when **unix password sync** is set to YES.

Default: **\*new\*password\* %n\n\*new\*password\* %n\n \*changed\***

**passwd program** The program Samba uses to set Linux passwords. Samba replaces **%u** with the user's username.

Default: **/usr/bin/passwd %u**

**security** Specifies if and how clients transfer user and password information to the server. Choose one of the following:

**USER:** Causes Samba to require a username and password from users or Windows when logging in on the Samba server. With this setting you can use

- **username map** to map usernames to other names
- **encrypt passwords** (page 760) to encrypt passwords (recommended)
- **guest account** (page 761) to map users to the **guest** account

**SHARE:** Causes Samba not to authenticate clients on a per-user basis. Instead, Samba uses the system found in Windows 9x, in which each share can have an individual password for either read or full access. This option is not compatible with more recent versions of Windows.

**SERVER:** Causes Samba to use another SMB server to validate usernames and passwords. Failing remote validation, the local Samba server tries to validate as though **security** were set to **USER**.

**DOMAIN:** Samba passes an encrypted password to a Windows NT domain controller for validation.

**ADS:** Instructs Samba to use an Active Directory server for authentication, allowing a Samba server to participate as a native Active Directory member. (Active Directory is the centralized information system that Windows 2000 and later use. It replaces Windows Domains, which was used by Windows NT and earlier.)

Default: **USER**

**unix password sync** YES causes Samba to change a user's Linux password when the associated user changes the encrypted Samba password.

Default: **NO**

**update encrypted** YES allows users to migrate from cleartext passwords to encrypted passwords without logging in on the server and using **smbpasswd**. To migrate users, set to **YES** and set **encrypt passwords** to **NO**. As each user logs in on the server with a cleartext Linux password, **smbpasswd** encrypts and stores the password in **/etc/samba/smbpasswd**. Set to **NO** and set **encrypt passwords** to **YES** after all users have been converted.

Default: **NO**

**username map** The name of the file that maps usernames from a client to usernames on the server. Each line of the map file starts with a server username, followed by a **SPACE**, an equal sign, another **SPACE**, and one or more **SPACE**-separated client usernames. An asterisk (\*) on the client side matches any client username. This file frequently maps Windows usernames to Linux usernames and/or maps multiple Windows usernames to a single Linux username to facilitate file sharing. A sample map file is shown here:

```
$ cat /etc/samba/smbusers
# Unix_name = SMB_name1 SMB_name2 ...
root = administrator admin
```

```
nobody = guest
sam = sams
```

Default: no map  
 Fedora/RHEL: `/etc/samba/smbusers`

## LOGGING PARAMETERS

- log file** The name of the Samba log file. Samba replaces `%m` with the name of the client system, allowing you to generate a separate log file for each client.
- Default: none  
 Fedora/RHEL: `/var/log/samba/%m.log`
- log level** Sets the log level, with 0 (zero) being off and higher numbers being more verbose.
- Default: 0 (off)
- max log size** An integer specifying the maximum size of the log file in kilobytes. A 0 (zero) specifies no limit. When a file reaches this size, Samba appends a `.old` to the filename and starts a new log, deleting any old log file.
- Default: 5000  
 Fedora/RHEL: 50

## BROWSER PARAMETERS

The *domain master browser* is the system that is responsible for maintaining the list of machines on a network used when browsing a Windows Network Neighborhood or My Network Places. *SMB* (page 1106) uses weighted elections every 11–15 minutes to determine which machine will be the domain master browser.

Whether a Samba server wins this election depends on two parameters: First, setting **domain master** to YES instructs the Samba server to enter the election. Second, the **os level** determines how much weight the Samba server's vote receives. Setting **os level** to 2 should cause the Samba server to win against any Windows 9x machines. NT Server series domain controllers, including Windows 2000, XP, and 2003, use an **os level** of 32. The maximum setting for **os level** is 255, although setting it to 65 should ensure that the Samba server wins.

- domain master** YES causes **nmbd** to attempt to be the domain master browser. If a domain master browser exists, then local master browsers will forward copies of their browse lists to it. If there is no domain master browser, then browse queries may not be able to cross subnet boundaries. A Windows PDC (Primary Domain Controller) will always try to become the domain master and may behave in unexpected ways if it fails. Refer to the preceding discussion.

Default: AUTO

- local master** YES causes **nmbd** to enter elections for the local master browser on a subnet. A local master browser stores a cache of the *NetBIOS* (page 1095) names of entities on the local subnet, allowing browsing. Windows machines automatically enter

elections; for browsing to work, the network must have at least one Windows machine or one Samba server with **local master** set to YES. It is poor practice to set **local master** to NO. If you do not want a computer to act as a local master, set its **os level** to a lower number, allowing it to be used as the local master if all else fails.

Default: YES

**os level** An integer that controls how much Samba advertises itself for browser elections and how likely **nmbd** is to become the local master browser for its workgroup. A higher number increases the chances of the local server becoming the local master browser. Refer to the discussion at the beginning of this section.

Default: 20

**preferred master** YES forces **nmbd** to hold an election for local master and enters the local system with a slight advantage. With **domain master** set to YES, this parameter helps ensure that the local Samba server becomes the domain master. Setting this parameter to YES on more than one server causes the servers to compete to become master, generating a lot of network traffic and sometimes leading to unpredictable results. A Windows PDC (Primary Domain Controller) automatically acts as if this parameter is set.

Default: AUTO

## COMMUNICATION PARAMETERS

**dns proxy** When acting as a *WINS server* (page 1115), YES causes **nmbd** to use DNS if *Net-BIOS* (page 1095) resolution fails.

Default: YES

Fedora/RHEL: NO

**socket options** Tunes the network parameters used when exchanging data with a client. The Fedora/RHEL setting is appropriate in most cases.

Default: TCP\_NODELAY

**wins server** The IP address of the WINS server that **nmbd** should register with.

Default: not enabled

**wins support** YES specifies that **nmbd** act as a WINS server.

Default: NO

## SHARE PARAMETERS

Each of the following parameters can appear many times in **smb.conf**, once in each share definition.

**available** YES specifies the share as active. Set this parameter to NO to disable the share, but continue logging requests for it.

Default: YES



- browseable** Determines whether the share can be browsed, for example, in Windows My Network Places.  
Default: YES  
Fedora/RHEL: NO
- comment** A description of the share, shown when browsing the network from Windows.  
Default: none  
Fedora/RHEL: varies
- guest ok** Allows a user who logs in as **guest** to access this share.  
Default: NO
- path** The path of the directory that is being shared.  
Default: none  
Fedora/RHEL: various
- read only** Does not allow write access.  
Default: YES

## THE [HOMES] SHARE: SHARING USERS' HOME DIRECTORIES

Frequently users want to share their Linux home directories with a Windows machine. To make this task easier, Samba provides the **[homes]** share. When you define this share, each user's home directory is shared with the specified parameters. In most cases, the following parameters are adequate:

```
[homes]
    comment = Home Directories
    browseable = no
    writable = yes
```

These settings prevent users other than the owners from browsing home directories, while allowing logged-in owners full access.

**SELinux** If the system is running SELinux with a targeted policy and you want to allow users to share their home directories as explained in this section, you must turn on the SELinux setting **Samba⇒Allow Samba to export user home directories** as displayed by `system-config-selinux` (page 416) in the Boolean tab.

---

## ACCESSING LINUX SHARES FROM WINDOWS

### BROWSING SHARES

To access a share on a Samba server from Windows, open My Computer or Explorer on the Windows system and, in the Address text box, enter \\ followed by the NetBIOS name (or just the hostname if you have not assigned a different NetBIOS

name) of the Samba server. Windows then displays the directories that the Linux system is sharing. To view the shares on the Linux system named **bravo**, for example, you would enter **\\bravo**. From this window, you can view and browse the shares available on the Linux system. If you set a share so that it is not browseable, you need to enter the path of the share using the format **\\servername\sharename**.

## MAPPING A SHARE

Another way to access a share on a Samba server is by mapping a share. Open My Computer or Explorer on the Windows system and click **Map Network Drive** from one of the drop-down menus on the menubar (found on the **Tools** menu on Windows XP). Windows displays the Map Network Drive window. Select an unused Windows drive letter from the Drive combo box and enter the Windows path to the share you just created. (When you use **system-config-samba** to create a share, the share has the same name as the name of the directory you are sharing.) The format of the windows path is **\\hostname\sharename**. For example, to map **/tmp** on **bravo** to Windows drive J, assuming the share is named **tmp** on the Linux system, select **J** in the Drive combo box, enter **\\bravo\tmp** in the Folder text box, and click **Finish**. You should be able to access the **/tmp** directory from **bravo** as **J (tmp)** on the Windows machine. If you cannot map the drive, refer to “Troubleshooting” on page 768.

---

## ACCESSING WINDOWS SHARES FROM LINUX

As a client, Samba enables you to view and work with files on a Windows system from a Linux system. This section discusses several ways of accessing Windows files from Linux.

### smbtree: DISPLAYS WINDOWS SHARES

The **smbtree** utility displays a hierarchical diagram of available shares. When you run **smbtree**, it prompts you for a password; do not enter a password if you want to browse shares that are visible to the **guest** user. The password allows you to view restricted shares, such as a user’s home directory in the **[homes]** share. Following is sample output from **smbtree**:

```
$ smbtree
Password:
MGS

    \\PB
        \\PB\mark
        \\PB\MainPrinter
        \\PB\ADMIN$
        \\PB\IPC$
        \\PB\tmp

pb Samba
Home Directories
MainPrinter
IPC Service (pb Samba)
IPC Service (pb Samba)
mgs temp
```

In the preceding output, **MGS** is the name of the workgroup, **PB** is the name of the Windows machine, **mark** and **tmp** are directory shares, and **MainPrinter** is a shared printer. Workgroup and machine names are always shown in capitals. Refer to the `smbtree` man page for more information.

## smbclient: CONNECTS TO WINDOWS SHARES

The `smbclient` utility functions similarly to `ftp` (page 643) and connects to a Windows share; however, `smbclient` uses Linux-style forward slashes (/) as path separators rather than Windows-style backslashes (\). The next example connects to one of the shares displayed in the preceding example:

```
$ smbclient //PB/mark
Password:
Domain=[PB] OS=[Unix] Server=[Samba 3.0.10-1.fc2]
smb: \> ls
.
```

D	0	Wed Feb 20 15:10:03 2008
D	0	Mon Feb 4 12:40:17 2008
.kde	DH	0 Tue Feb 5 22:24:17 2008
.xemacs	DH	0 Mon Feb 4 10:12:45 2008
.bash_logout	H	24 Tue Oct 23 06:15:04 2007
.bash_profile	H	191 Tue Oct 23 06:15:04 2007
.bashrc	H	124 Tue Oct 23 06:15:04 2007

```
...
```

You can use most `ftp` commands from `smbclient`. Refer to “Tutorial Session” on page 646 for some examples or give the command **help** to display a list of commands.

## BROWSING WINDOWS NETWORKS

Browsing Windows shares using `smbtree` and `smbclient` is quite awkward compared with the ease of browsing a network from Windows; GNOME provides a more user-friendly alternative. From Nautilus (the Gnome file manager), enter **smb:/** in the location bar to browse the Windows shares on the network.

Nautilus uses a virtual filesystem add-on, which is part of the desktop environment and not part of the native Linux system. As a consequence, only native Gnome applications can open files on remote shares; normal Linux programs cannot. For example, `gedit` will be able to open files on remote shares, while `OpenOffice`, `mplayer`, and `xedit` cannot.

## MOUNTING WINDOWS SHARES

The `mount` utility (page 487) with a **-t cifs** option mounts a Windows share as if it were a Linux directory hierarchy. See page 1075 for more information on the CIFS protocol. When you mount a Windows share, you can write to the files on the share; you cannot write to files on a share using `smbclient`.

A mount command that mounts a Windows share has the following syntax:

```
# mount -t cifs //host/share dir
```

where *host* is the name of the system that the share is on, *share* is the name of the Windows share that you want to mount, and *dir* is the absolute pathname of the Linux directory that you are mounting the share on (the mount point).

The following command, when run as **root**, mounts on the **/share** directory the share used in the preceding example. If you omit the **password** argument (which you may want to do for security reasons), mount prompts for it.

```
# mount -t cifs //PB/mark /share -o username=mark,password=pizza
# ls /share
Desktop      mansmbconf          smb.conf  smbout
httpd.conf   NVIDIA-Linux-x86-1.0-5336-pkg1.run  smbhold   x
```

You can use the **uid**, **file\_mode**, and **dir\_mode** mount options with type **cifs** filesystems to establish ownership and permissions of mounted files.

```
# mount -t cifs //PB/mark /share -o username=mark,uid=mark,file_mode=0644,dir_mode=0755
```

Permissions must be expressed as octal numbers preceded by a zero. For more information refer to the **mount.cifs** man page.

---

## TROUBLESHOOTING

Samba provides three utilities that can help you troubleshoot a connection: The **smbstatus** utility displays a report on open Samba connections; **testparm** checks the syntax of **/etc/samba/smb.conf** and displays its contents; and **testprns** checks the validity of the name of a printer.

The following steps can help you narrow down the problem when you cannot get Samba to work.

1. Restart the **smbd** and **nmdb** daemons. Make sure the last two lines of output end with **OK**.

```
# /sbin/service smb restart
Shutting down SMB services:      [ OK ]
Starting SMB services:          [ OK ]
```

- testparm 2. Run **testparm** to check whether the **smb.conf** file is syntactically correct:

```
$ testparm
Load smb config files from /etc/samba/smb.conf
Processing section "[homes]"
Processing section "[printers]"
Processing section "[tmp]"
Loaded services file OK.
```

```
Server role: ROLE_STANDALONE
Press enter to see a dump of your service definitions
...
```

If you misspell a keyword in **smb.conf**, you get an error such as the following:

```
# testparm
Load smb config files from /etc/samba/smb.conf
Unknown parameter encountered: "workgruop"
Ignoring unknown parameter "workgruop"
...
```

- ping 3. Use **ping** (page 379) from both sides of the connection to make sure the network is up.
- net view 4. From a Windows command prompt, use **net view** to display a list of shares available from the server (**pb** in this example):
- ```
C:>net view \\pb
Shared resources at \\pb

pb Samba

Share name    Type    Used as    Comment
-----
MainPrinter   Print           MainPrinter
mark           Disk (UNC)      Home Directories
tmp            Disk           mgs temp
The command completed successfully.
```
- net use 5. Try to map the drive from a Windows command prompt. The following command attempts to mount the share named **tmp** on **pb** as drive X:
- ```
C:>net use x: \\pb\tmp
The command completed successfully.
```
- nmblookup 6. From the server, query the **nmbd** server, using the special name **\_\_SAMBA\_\_** for the server's NetBIOS name. The **-d 2** option turns the debugger on at level 2, which generates a moderate amount of output:
- ```
$ nmblookup -d 2 -B pb __SAMBA__
added interface ip=192.168.0.10 bcast=192.168.0.255
nmask=255.255.255.0
querying __SAMBA__ on 192.168.0.10
Got a positive name query response from 192.168.0.10 ( 192.168.0.10 )
192.168.0.10 __SAMBA__<00>
```
- nmblookup 7. From the server, query the **nmbd** server for the client's NetBIOS name. (The machine named **jam** is the Windows client.)
- ```
$ nmblookup -B jam \*
querying * on 192.168.0.9
192.168.0.9 *<00>
```

Omit the **-B jam** option to query for all NetBIOS names.

- smbclient 8. From the server, use smbclient with the `-L` option to generate a list of shares offered by the server:

```
$ smbclient -L pb
Enter mark's password:
Domain=[PB] OS=[Unix] Server=[Samba 3.0.10-1.fc2]

      Sharename      Type      Comment
      -----
      tmp            Disk      mgs temp
      IPC$           IPC       IPC Service (pb Samba)
      ADMIN$         IPC       IPC Service (pb Samba)
      MainPrinter    Printer   MainPrinter
      mark           Disk      Home Directories
Domain=[PB] OS=[Unix] Server=[Samba 3.0.10-1.fc2]

      Server          Comment
      -----
      Workgroup       Master
      -----
      MGS             TUNAER
```

- nmblookup 9. To query for the master browser from the server, run nmblookup with the `-M` option followed by the name of the workgroup:

```
$ nmblookup -M MGS
querying MGS on 192.168.0.255
192.168.0.8 MGS<1d>
```

# CHAPTER SUMMARY

Samba is a suite of programs that enables Linux and Windows to share directories and printers. A directory or printer that is shared between Linux and Windows systems is called a *share*. To access a share on a Linux system, a Windows user must supply a username and password. Usernames must correspond to Linux usernames either directly or as mapped by the `/etc/samba/smbusers` file. Samba passwords are generated by `smbpasswd` and kept in `/etc/samba/smbpasswd`.

The main Samba configuration file is `/etc/samba/smb.conf`, which you can edit using a text editor, `swat` (a Web-based administration utility), or `system-config-samba` (a minimal-configuration GUI). The `swat` utility is a powerful configuration tool that provides integrated online documentation and clickable default values to help you set up Samba.

From a Windows machine, you can access a share on a Linux Samba server by opening My Computer or Explorer and, in the Address text box, entering `\\` followed by the name of the server. Windows displays the shares on the server and you can work with them as though they were Windows files.

From a Linux system, you can use any of several Samba tools to access Windows shares. These tools include `smbtree` (displays shares), `smbclient` (similar to `ftp`), and `mount` with the `-t cifs` option (mounts shares). In addition, you can enter `smb://` in the location bar of Konqueror or Nautilus and browse the shares.

---

## EXERCISES

1. Which two daemons are part of the Samba suite? What does each do?
2. What steps are required for mapping a Windows user to a Linux user?
3. How would you allow access to `swat` only from machines on the 192.168.1.0/8 subnet?
4. What is the purpose of the `[homes]` share?

---

## ADVANCED EXERCISES

5. Describe how Samba's handling of users differs from that of NFS.
6. Which configuration changes would you need to apply to routers if you wanted to allow SMB/CIFS browsing across multiple subnets without configuring master browsers?
7. How could you use `swat` securely from a remote location?
8. WINS resolution allows hosts to define their own names. Suggest a way to use Samba to assign names from a centralized list.

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# DNS/BIND: TRACKING DOMAIN NAMES AND ADDRESSES

## IN THIS CHAPTER

Introduction to DNS .....	774
About DNS.....	785
JumpStart I: Setting Up a DNS Cache .....	787
JumpStart II: Setting Up a Domain Using system-config-bind .....	789
Setting Up BIND .....	793
Troubleshooting .....	805
A Full-Functioned Nameserver ...	807
A Slave Server.....	810
A Split Horizon Server.....	811

DNS (Domain Name System) maps domain names to IP addresses, and vice versa. It reduces the need for humans to work with IP addresses, which, with the introduction of IPv6, are complex. The DNS specification defines a secure, general-purpose database that holds Internet host information. It also specifies a protocol that is used to exchange this information. Further, DNS defines library routines that implement the protocol. Finally, DNS provides a means for routing email. Under DNS, *nameservers* work with clients, called *resolvers*, to distribute host information in the form of *resource records* in a timely manner as needed.

This chapter describes BIND (Berkeley Internet Name Domain) version 9, a popular open-source implementation of DNS. Part of the Fedora/RHEL distribution, BIND includes the DNS server daemon (**named**), a DNS resolver library, and tools for working with DNS. Although DNS can be used for private networks, this chapter covers DNS as used by the Internet.

## INTRODUCTION TO DNS

You normally use DNS when you display a Web page. For example, to display Red Hat's home page, you enter its name, `www.redhat.com`, in a browser and the browser displays the page you want. You never enter or see the IP address for the displayed page. However, without the IP address, the browser could not display the page. DNS works behind the scenes to find the IP address when you enter the name in the browser. The DNS database is

- **Hierarchical**, so that it provides quick responses to queries: DNS has a root, branches, and nodes.
- **Distributed**, so that it offers fast access to servers. The DNS database is spread across thousands of systems worldwide; each system is referred to as a *DNS server* (or a *domain server* or *nameserver*).
- **Replicated**, to enhance reliability. Because many systems hold the same information, when some systems fail, DNS does not stop functioning.

As implemented, DNS is

- **Secure**, so that your browser or email is directed to the correct location.
- **Flexible**, so that it can adapt to new names, deleted names, and names whose information changes.
- **Fast**, so that Internet connections are not delayed by slow DNS lookups.

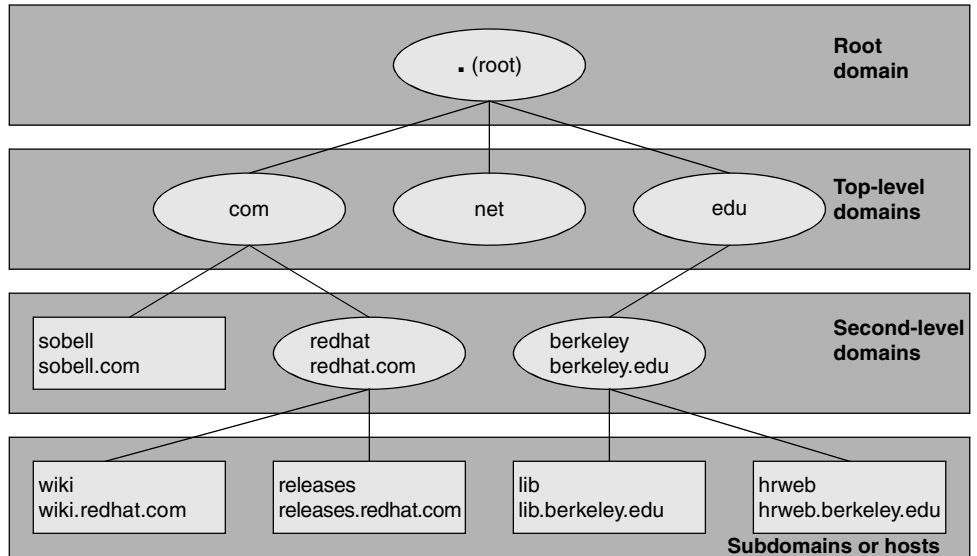
**History** The mapping that DNS does was originally done statically in a `/etc/hosts` file (page 472) on each system on a network. Small LANs still make use of this file. As networks—specifically the Internet—grew, a dynamic mapping system was required. DNS was specified in 1983 and BIND became part of BSD in 1985.

**Security** BIND is by far the most popular implementation of a DNS. However, recently concerns about its security have arisen. You may want to run BIND inside a `chroot` jail (page 804) or under SELinux (page 414) and use transaction signatures (TSIG, page 803) to improve security.

**host and dig** The `host` and `dig` utilities (page 382) query DNS servers. The `host` utility is simpler, is easier to use, and returns less information than `dig`. This chapter uses both tools to explore DNS.

## NODES, DOMAINS, AND SUBDOMAINS

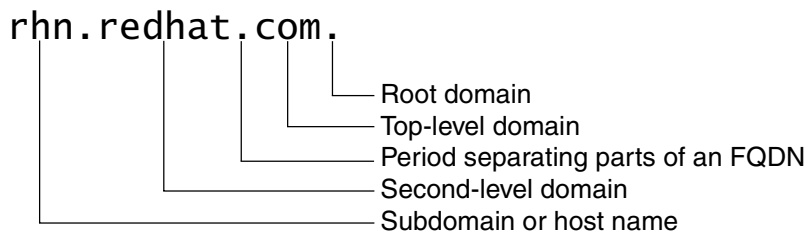
Each node in the hierarchical DNS database is called a *domain* and is labeled with a (domain) name. As with the Linux file structure, the node at the top of the DNS hierarchy is called the *root node* or *root domain*. While the Linux file structure separates the nodes (directory and ordinary files) with slashes (/) and labels the root node (directory) with a slash, the DNS structure uses periods (Figure 24-1).



**Figure 24-1** The DNS domain structure (FQDNs are shown below hostnames.)

You read an absolute pathname in a Linux filesystem from left to right: It starts with the root directory (/) at the left and, as you read to the right, describes the path to the file being identified (for example, `/var/named/named.ca`). Unlike a Linux pathname, you read a DNS domain name from right to left: It starts with the root domain at the right (represented by a period [.]) and, as you read to the left, works its way down through the top-level and second-level domains to a subdomain or host. Frequently the name of the root domain (the period at the right) is omitted from a domain name. The term *domain* refers both to a single node in the DNS domain structure and to a catenated, period-separated list (path) of domain names that describes the location of a domain.

**FQDN** A fully qualified domain name (FQDN) is the DNS equivalent of a filesystem's absolute pathname: It is a pointer that positively locates a domain on the Internet. Just as you (and Linux) can identify an absolute pathname by its leading slash (/) that names the root directory, so an FQDN can be identified by its trailing period (.) that names the root domain (Figure 24-2).



**Figure 24-2** A fully qualified domain name (FQDN)

**Resolver** The resolver comprises the routines that turn an unqualified domain name into an FQDN that is passed to DNS to be mapped to an IP address. The resolver can append several domains, one at a time, to an unqualified domain name, producing several FQDNs that it passes, one at a time, to DNS. For each FQDN, DNS reports success (it found the FQDN and is returning the corresponding IP address) or failure (the FQDN does not exist).

The resolver always appends the root domain (.) to an unqualified domain name first, allowing you to type **www.redhat.com** instead of **www.redhat.com.** (including the trailing period) in a browser. You can specify other domains for the resolver to try if the root domain fails. Put the domain names, in the order you want them tried, after the **search** keyword in **/etc/resolv.conf** (page 476). For example, if your search domains include **redhat.com.**, then the domains **rhn** and **rhn.redhat.com.** resolve to the same address.

**Subdomains** Each node in the domain hierarchy is a domain. Each domain that has a parent (that is, every domain except the root domain) is also a subdomain, regardless of whether it has children. All subdomains *can* resolve to hosts—even those with children. For example, the **redhat.com.** domain resolves to the host that serves the Red Hat Web site, without preventing its children—domains such as **fedora.redhat.com.**—from resolving. The leftmost part of an FQDN is often called the *hostname*.

**Hostnames** In the past, hostnames could contain only characters from the set a–z, A–Z, 0–9, and –. As of March 2004, however, hostnames can include various accents, umlauts, and so on ([www.nic.ch/reg/ocView.action](http://www.nic.ch/reg/ocView.action)). DNS considers uppercase and lowercase letters to be the same (it is not case sensitive), so **www.sobell.com** is the same as **WWW.sObEll.coM**.

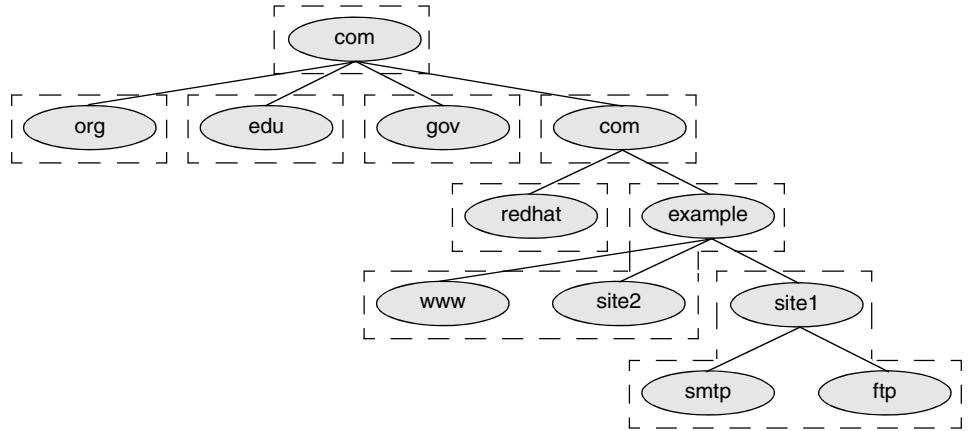
## ZONES

For administrative purposes, domains are grouped into zones that extend downward from a domain (Figure 24-3). A single DNS server is responsible for (holds the information required to resolve) all domains within a zone. The DNS server for a zone also holds pointers to DNS servers that are responsible for the zones immediately below the zone it is responsible for. Information about zones originates in zone files, one zone per file.

**Root domain** The highest zone, the one containing the root domain, does not contain any hosts. Instead, this domain delegates to the DNS servers for the top-level domains (Figure 24-1, page 775).

**Authority** Each zone has at least one authoritative DNS server. This server holds all information about the zone. A DNS query returns information about a domain and specifies which DNS server is authoritative for that domain.

DNS employs a hierarchical structure to keep track of names and authority. At the top or root of the structure is the root domain, which employs 13 authoritative nameservers. These are the only servers that are authoritative for the root and top-level domains.



**Figure 24-3** DNS structure showing zones

**Delegation of authority** When referring to DNS, the term *delegation* means *delegation of authority*. ICANN (Internet Corporation for Assigned Names and Numbers, [www.icann.org](http://www.icann.org)) delegates authority to the root and top-level domains. In other words, ICANN says which servers are authoritative for these domains. Authority is delegated to each domain below the top-level domains by the authoritative server at the next-higher-level domain. ICANN is not authoritative for most second-level domains. For example, Red Hat is authoritative for the `redhat.com` domain. This scheme of delegating authority allows for local control over segments of the DNS database while making all segments available to the public.

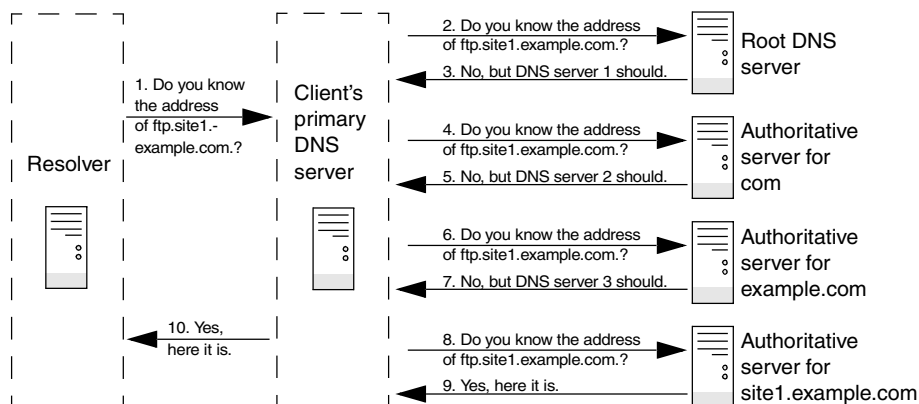
## QUERIES

**Iterative query** There are two types of DNS queries: *iterative* and *recursive*.<sup>1</sup> An iterative query sends a domain name to a DNS server and asks the server to return either the IP address of the domain or the name of the DNS server that is authoritative for the domain or one of its parents: The server does not query other servers when seeking an answer. Nameservers typically send each other iterative queries.

**Recursive query** A recursive query sends a domain name to a DNS server and asks the server to return the IP address of the domain: The server may need to query other servers to get the answer. Both types of queries can fail, in which case the server returns a message saying it is unable to locate the domain.

When a client, such as a browser, needs the IP address that corresponds to a domain name, the client queries a resolver. Most resolvers are quite simple and require a DNS server to do most of the work: That is, they send recursive queries. The

1. There is a third type of query that is not covered in this book: *inverse*. An inverse query provides a domain name given a resource record. Reverse name resolution (page 783), not an inverse query, is used to query for a domain name given an IP address.



**Figure 24-4** A recursive query that starts several iterative queries to find the answer

resolver communicates with a single DNS server, which can perform multiple iterative queries in response to the resolver's recursive query.

All DNS servers must answer iterative queries. DNS servers can also be set up to answer recursive queries. A DNS server that is not set up to answer recursive queries treats a recursive query as though it is an iterative query.

In Figure 24-4, the resolver on a client system is trying to discover the address of the server `ftp.site1.example.com` on the network with the DNS layout shown in Figure 24-3 on page 777. The resolver on the client sends a recursive query to its primary DNS server. This server interrogates the root server and one additional server for each zone until it receives an answer, which it returns to the resolver on the client. In practice, the query would not start with the root server because most servers usually have the location of the authoritative nameserver for the `com` domain stored in cache (memory).

## SERVERS

There are three main types of DNS servers: primary (master), secondary (slave), and caching-only.

- A *primary master server*, also called a *primary server* or *master server*, is the authoritative server that holds the master copy of zone data. It copies information from the *zone* or *master file*, a local file that the server administrator maintains. For security and efficiency, a primary master server should provide iterative answers only. A primary master server that provides recursive answers is more easily subverted by a *DoS attack* (page 1080) than one that provides iterative answers only.
- *Slave servers*, also called *secondary servers*, are authoritative and copy zone information from the primary master server or another slave server.

On some systems, when information on the primary master server changes, the primary master server sends a message to the slave servers. When a slave receives such a message, it uses a process called *zone transfer* to copy the new zone information from the master server to itself.

- *DNS caches*, also called *caching-only servers*, are not authoritative. These servers store answers to previous queries in cache (memory). When a DNS cache receives a query, it answers it from cache if it can. If the DNS cache does not have the answer in cache, it forwards the query to an authoritative server.

It is possible—but for reasons of security not recommended—for the same server to be the primary master server (authoritative) for some zones and a DNS cache for others. When the same server acts as both a DNS cache and a master server, if a malicious local user or malfunctioning resolver on the local network floods the DNS cache with more traffic than it can handle (a DoS attack), users may be prevented from accessing the public servers that the primary master server handles. Conversely, if the authoritative server is compromised, the attacker can subvert all traffic leaving the network.

## RESOURCE RECORDS

Information about nodes (domains) in the DNS database is stored in resource records. Resource records are kept in zone files (page 796). The zone that a resource record pertains to is defined by the zone file that contains the resource record. The zone is named in the **named.conf** file (page 794) that references the zone file.

A resource record has the following fields:

- **Name**—The domain name or IP address
- **TTL**—Time to live (not in all resource records; see page 1112)
- **Class**—Always IN for Internet (the only class that DNS supports)
- **Type**—Record type (discussed in the next section)
- **Data**—Varies with record type

If the Name field is missing, the resource record inherits the name from the previous resource record in the same file. Cached resource records become out-of-date when the information in the record changes on the authoritative server. The TTL field indicates the maximum time a server may keep a record in cache before checking whether a newer one is available. Typically, the TTL is on the order of days. A TTL of 0 means that the resource record should not be cached.

More than 30 types of resource records exist, ranging from common types, such as address records that store the address of a host, to those that contain geographical information. The following paragraphs describe the types of resource records you are most likely to encounter.

- A IPv4 Address**—Maps a domain name to the IPv4 address of a host. There must be at least one address record for each domain; multiple address records can point to the same IP address. The Name field holds the domain name, which is assumed to be in the same zone as the domain. The Data field holds the IP address associated with the name. The following address resource record maps the **ns** domain in the zone to 192.168.0.1:

```
ns      IN      A      192.168.0.1
```

- AAAA IPv6 Address**—Maps a domain name to the IPv6 address of a host. The following address resource record maps the **ns** domain in the zone to an IPv6 address:

```
ns      IN      AAAA    2001:630:d0:131:a00:20ff:feb5:ef1e
```

- CNAME Canonical Name**—Maps an alias or nickname to a domain name. The Name field holds the alias or nickname; the Data field holds the official or canonical name. CNAME is useful for specifying an easy-to-remember name or multiple names for the same domain. It is also useful when a system changes names or IP addresses. In this case the alias can point to the real name that must resolve to an IP address.

When a query returns a CNAME, a client or DNS tool performs a DNS lookup on the domain name returned with the CNAME. It is acceptable to provide multiple levels of CNAME records. The following resource record maps **ftp** in the zone to **www.sam.net.**:

```
ftp     IN      CNAME   www.sam.net.
```

- MX Mail Exchange**—Specifies a destination for mail addressed to the domain. MX records must always point to A (or AAAA) records. The Name field holds the domain name, which is assumed to be in the zone; the Data field holds the name of a mail server preceded by its priority. Unlike A records, MX records contain a priority number that allows mail delivery agents to fall back to a backup server in case the primary server is down. Several mail servers can be ranked in priority order, where the lowest number has the highest priority. DNS selects randomly from among mail servers with the same priority. The following resource records forward mail sent to **speedy** in the zone first to **mail** in the zone and then, if that fails, to **mail.sam.net.**. The value of **speedy** in the Name field on the second line is implicit.

```
speedy      MX      10 mail
             MX      20 mail.sam.net.
```

- NS Nameserver**—Specifies the name of the system that provides domain service (DNS records) for the domain. The Name field holds the domain name; the Data field holds the name of the DNS server. Each domain must have at least one NS record. DNS servers do not need to reside in the domain and, in fact, it is better if at least one does not. The system name **ns** is frequently used to specify a nameserver, but this name is not required and does not have any significance beyond assisting humans in identifying a nameserver. The following resource record specifies **ns.max.net.** as a nameserver for **peach** in the zone:

```
peach      NS      ns.max.net.
```





The second format is more readable because of its layout and the comments. The `@` symbol at the start of the SOA resource record stands for the zone name, also called the origin, as specified in the **named.conf** file. Because the **named.conf** file specifies the zone name to be **zach.net**, you could rewrite the first line as follows:

```
zach.net. IN SOA ns.zach.net. mgs@sobell.com. (
```

The `host` utility returns something closer to the first format with each of the times specified in seconds:

```
$ host -t soa zach.net
zach.net. SOA ns.zach.net. mgs@sobell.com. 03111 28800 7200 2419200 86400
```

**TXT Text**—Associates a character string with a domain. The Name field holds the domain name. The data field can contain up to 256 characters and must be enclosed within quotation marks. TXT records can contain any arbitrary text value. As well as general information, they can be used for things such as public key distribution. Following is a TXT resource record that specifies a company name:

```
zach.net IN TXT "Sobell Associates Inc."
```

## DNS QUERY AND RESPONSE

**Query** A DNS query has three parts:

1. Name—Domain name, FQDN, or IP address for reverse name resolution
2. Type—Type of record requested (page 779)
3. Class—Always IN for Internet class

**Cache** Most DNS servers store in cache memory the query responses from other DNS servers. When a DNS server receives a query, it first tries to resolve the query from its cache. Failing that, the server may query other servers to get an answer.

Because DNS uses cache, when you make a change to a DNS record, the change takes time—sometimes a matter of days—to propagate through the DNS hierarchy.

**Response** A DNS message that is sent in response to a query has the following structure:

- Header record—Information about this message
- Query record—Repeats the query
- Answer records—Resource records that answer the query
- Authority records—Resource records for servers that have authority for the answers
- Additional records—Additional resource records, such as NS records

The `dig` utility does not consult **/etc/nsswitch.conf** (page 455) to determine which server to query. The following example uses `dig` to query a DNS server:

```

$ dig fedoraproject.org
...
;; QUESTION SECTION:
;fedoraproject.org.                IN      A

;; ANSWER SECTION:
fedoraproject.org.                16      IN      A      209.132.176.122
fedoraproject.org.                16      IN      A      66.35.62.162

;; AUTHORITY SECTION:
fedoraproject.org.                3556    IN      NS      dns1.j2solutions.net.
fedoraproject.org.                3556    IN      NS      ns1.fedoraproject.org.

;; ADDITIONAL SECTION:
ns1.fedoraproject.org.            12739   IN      A      64.34.184.179
dns1.j2solutions.net.            5415    IN      A      209.124.61.35
...

```

## REVERSE NAME RESOLUTION

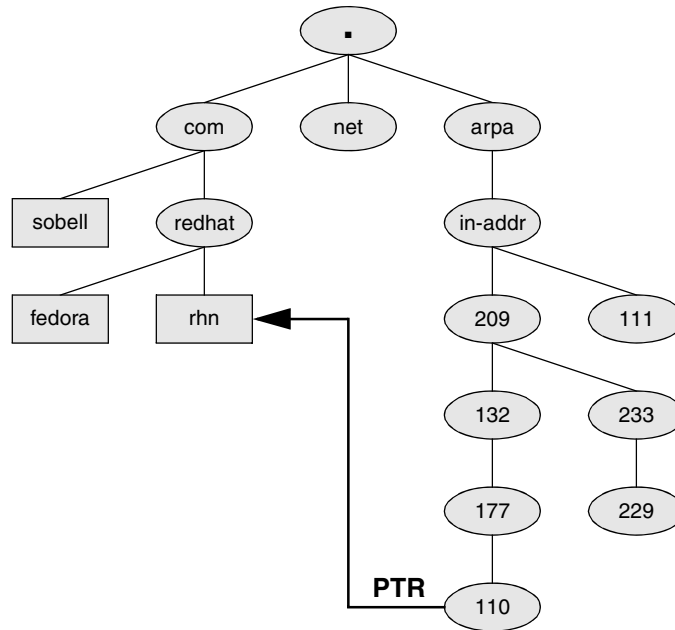
In addition to normal or forward name resolution, DNS provides *reverse name resolution*, also referred to as *inverse mapping* or *reverse mapping*, so that you can look up domain names given an IP address. Because resource records in the forward DNS database are indexed hierarchically by domain name, DNS cannot perform an efficient search by IP address on this database.

DNS implements reverse name resolution by means of a special domain named **in-addr.arpa** (IPv4) or **ip6.arpa** (IPv6). Resource records in these domains have Name fields that hold IP addresses; the records are indexed hierarchically by IP address. The Data fields hold the FQDN that corresponds to the IP address.

Reverse name resolution can verify that someone is who he says he is or at least is from the domain he says he is from. In general, it allows a server to retrieve and record the domain names of the clients it provides services to. For example, legitimate mail contains the domain of the sender and the IP address of the sending machine. A mail server can verify the stated domain of a sender by checking the domain associated with the IP address. Reverse name resolution is also used by anonymous FTP servers to verify that a domain specified in an email address used as a password is legitimate.

For example, to determine the domain name that corresponds to an IP address of 209.132.177.110, a resolver would query DNS for information about the domain named 110.177.132.209.in-addr.arpa (Figure 24-5, next page).

The following example uses **dig** to query DNS for the IP address that corresponds to **rhn.redhat.com**, which is 209.132.177.110. The second command line uses the **dig** utility to query the same IP address, reversed, and appended with **.in-addr.arpa**:



**Figure 24-5** Reverse name resolution and the `in-addr.arpa` domain

110.177.132.209.in-addr.arpa to display a PTR resource record (page 781). The data portion of the resultant resource record is the domain name from the original query: `rhn.redhat.com`.

```

$ dig rhn.redhat.com
...
;; QUESTION SECTION:
;rhn.redhat.com.                IN      A

;; ANSWER SECTION:
rhn.redhat.com.                 60      IN      A      209.132.177.110
...

$ dig 110.177.132.209.in-addr.arpa PTR
...
;; QUESTION SECTION:
;110.177.132.209.in-addr.arpa.  IN      PTR

;; ANSWER SECTION:
110.177.132.209.in-addr.arpa.  245     IN      PTR      rhn.redhat.com.
...

```

Instead of reformatting the IP address as in the preceding example, you can use the `-x` option to `dig` to perform a reverse query:

```

$ dig -x 209.132.177.110
...
;; QUESTION SECTION:
;110.177.132.209.in-addr.arpa.  IN      PTR

```

```
;; ANSWER SECTION:
110.177.132.209.in-addr.arpa. 269 IN      PTR      rhn.redhat.com.
...
```

Or you can just use `host`:

```
$ host 209.132.177.110
110.177.132.209.in-addr.arpa domain name pointer rhn.redhat.com.
```

## ABOUT DNS

This section discusses how DNS works and provides resources for additional information on DNS.

## How DNS WORKS

Application programs do not issue DNS queries directly but rather use the `gethostbyname()` system call. How the system comes up with the corresponding IP address is transparent to the calling program. The `gethostbyname()` call examines the `hosts` line in `/etc/nsswitch.conf` file (page 455) to determine which files it should examine and/or which services it should query and in what order to obtain the IP address corresponding to a domain name. When it needs to query DNS, the local system (i.e., the DNS client) queries the DNS database by calling the resolver library on the local system. This call returns the required information to the application program.

## PREREQUISITES

Install the following packages:

- **bind**
- **bind-utils** (provides `dig` among other utilities)
- **caching-nameserver** (*RHEL*, optional, used to set up a caching-only nameserver; *FEDORA* includes the contents of this package in the **bind** package)
- **system-config-bind** (optional)
- **bind-chroot** (optional, sets up BIND to run in a chroot jail)

Run `chkconfig` to cause **named** to start when the system enters multiuser mode:

```
# /sbin/chkconfig named on
```

After you have configured **named**, start it with `service`:

```
# /sbin/service named start
Starting named:
```

[ OK ]

## MORE INFORMATION

DNS for Rocket Scientists is an excellent site that makes good use of links to present information on DNS in a very digestible form.

Local *Bind Administrator Reference Manual: /usr/share/doc/bind\*/arm/Bv9ARM.html* or see the tip “Using this JumpStart” on page 790.

Web DNS for Rocket Scientists: [www.zytrax.com/books/dns](http://www.zytrax.com/books/dns)  
DNS security: [www.sans.org/rr/papers/index.php?id=1069](http://www.sans.org/rr/papers/index.php?id=1069)

HOWTO *DNS HOWTO*

Book *DNS & BIND*, fifth edition, by Albitz & Liu, O'Reilly & Associates (May 2006)

## NOTES

Firewall The **named** server normally accepts queries on TCP and UDP port 53. If the server system is running a firewall, you need to open these ports. Using the Firewall Configuration window Trusted Services tab (page 824), put a check in the box labeled **DNS** to open this port. For more general information, see Chapter 25, which discusses **iptables** in detail.

SELinux According to the Fedora/RHEL **named** man page, the default Fedora/RHEL SELinux policy for **named** is very secure and prevents known BIND security vulnerabilities from being exploited. This setup has some limitations, however. Refer to the **named** man page for more information.

If the system is running SELinux with a targeted policy and you want to modify the SELinux **named** settings, see **system-config-selinux** (page 416).

chroot jail The **bind-chroot** package sets up **named** to run in a chroot jail. With this package installed, all files that control BIND are located within this jail. In this case the file-names used in this chapter are symbolic links to the files in the chroot jail. See page 804 for more information.

**named** options See the comments in the **/etc/sysconfig/named** file for information about **named** options that you can set there. The most important of these options sets the value of the **ROOTDIR** variable, which controls the location of the chroot jail (page 804) that BIND runs in.

**named.conf** (RHEL) Traditionally, **named** looks for configuration information in the **/etc/named.conf** file. The caching-only nameserver, which is part of the RHEL **caching-nameserver** package, places configuration information in **/etc/named.caching-nameserver.conf**.

For the caching-only nameserver to work without any setup, and so that **named** will work normally if you create a **/etc/named.conf** file, the RHEL **named** init script (**/etc/rc.d/init.d/named**) first looks for configuration information in **/etc/named.conf**. If that file does not exist, it looks for configuration information in **/etc/named.caching-nameserver.conf**.

**named.conf** (FEDORA) The Fedora **named** daemon obtains configuration information from the file named **/etc/named.conf**. The **named.conf** file that the **bind** package installs uses an **include**

statement to incorporate the `/etc/named.rfc1912.zones` file (page 799), which implements a caching-only nameserver.

## JUMPSTART I: SETTING UP A DNS CACHE

As explained earlier, a DNS cache (caching-only nameserver) is a bridge between a resolver and authoritative DNS servers: It is not authoritative; it simply stores the results of its queries in memory. Most ISPs provide a DNS cache for the use of their customers. Setting up a local cache can reduce traffic between a LAN and the outside world and can improve response times. While it is possible to set up a DNS cache on each system on a LAN, setting up a single DNS cache on a LAN prevents multiple systems on the LAN from having to query a remote server for the same information.

After installing BIND (under RHEL you must also install the **caching-nameserver** package), you have most of a caching-only nameserver ready to run. Refer to “A DNS Cache” (page 797) for an explanation of which files this nameserver uses and how it works. Before you start the DNS cache, working as **root**, follow these steps:

1. See the instructions on setting up networking on a server (turn off NetworkManager) on page 605 and then give the following command to shut down active network interfaces:

```
# /sbin/service network stop
```

The network script displays the names of the interfaces it is shutting down, which usually include the primary interface (e.g., `eth0` or `eth1`) and the loopback interface.

2. Add/change the following line in `/etc/sysconfig/network-scripts/ifcfg-ethx`, where `x` is usually `0` or `1` and corresponds to the primary network interface (whose name was displayed in the previous step):

```
PEERDNS=no
```

This line prevents **dhclient-script** from overwriting `/etc/resolv.conf` when you reboot the system (run the **network** init script).

3. Put the following line in `/etc/resolv.conf` (page 476), before any other nameserver lines:

```
nameserver 127.0.0.1
```

This line tells the resolver to use the local system (**localhost** or `127.0.0.1`) as the primary nameserver. To experiment with using the local system as the only nameserver, comment out other nameserver lines in `resolv.conf` by preceding each with a pound sign (`#`).

4. In `/etc/named.conf`, put a pound sign (`#`) at the left end of each of the three lines that start with **dnssec** (Fedora only).

5. Give the command `/sbin/service network start` to bring up the network interfaces.
6. Start the **named** daemon using `service` as explained in the “Prerequisites” section (page 785). Refer to “Troubleshooting” on page 805 for ways to check that the DNS cache is working.

Once **named** is running, you can see the effect of the cache by using `dig` to look up the IP address of `www.sobell.com`, a remote system:

```
$ dig www.sobell.com

; <<>> DiG 9.6.1-P1-RedHat-9.6.1-11.P1.fc12 <<>> www.sobell.com
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 45364
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 2, ADDITIONAL: 1

;; QUESTION SECTION:
www.sobell.com.                IN      A

;; ANSWER SECTION:
www.sobell.com.                3600    IN      A      64.13.141.21

;; AUTHORITY SECTION:
sobell.com.                    3600    IN      NS      ns2.meer.net.
sobell.com.                    3600    IN      NS      ns.meer.net.

;; ADDITIONAL SECTION:
ns2.meer.net.                  172800  IN      A      64.13.153.254

;; Query time: 266 msec
;; SERVER: 127.0.0.1#53(127.0.0.1)
;; WHEN: Tue Nov 24 11:20:47 2009
;; MSG SIZE rcvd: 107
```

The fourth line from the bottom shows that the query took 226 milliseconds (about one-quarter of a second). When you run the same query again, it runs more quickly because the DNS cache has saved the information in memory:

```
$ dig www.sobell.com

...
;; Query time: 5 msec
;; SERVER: 127.0.0.1#53(127.0.0.1)
;; WHEN: Tue Nov 24 11:21:09 2009
;; MSG SIZE rcvd: 123
```

### When you turn off the DNS cache

---

**tip** Remember to remove the **PEERDNS=no** line you added in step 2 if you want to turn off the DNS cache. Under RHEL you must also remove the **caching-nameserver** package.

---



## JUMPSTART II: SETTING UP A DOMAIN USING system-config-bind

To display the BIND Configuration GUI window (Figure 24-6), enter **system-config-bind** on a command line or select **Main menu: Applications⇒System Tools⇒Domain Name System (FEDORA)** or **Main menu: System⇒Administration⇒Server Settings⇒Domain Name System (RHEL)**.

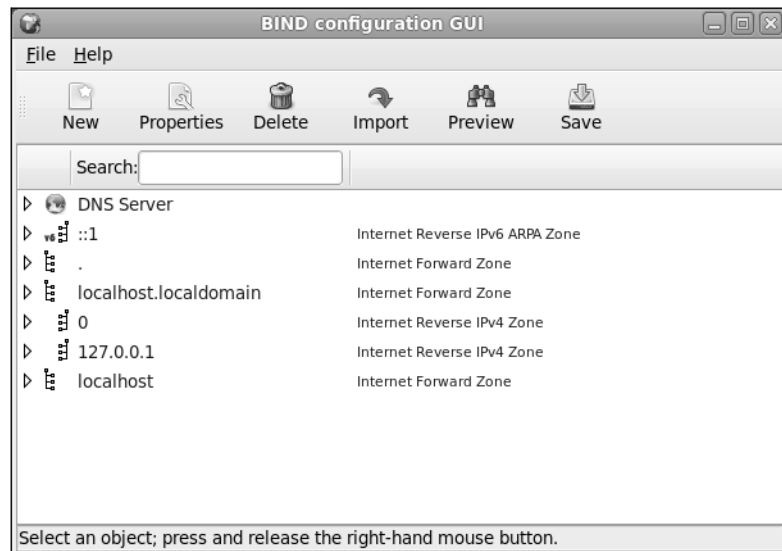
### NOTES

If `/etc/named.conf` does not exist, **system-config-bind** displays a dialog box that informs you that it is installing a default configuration. Click **OK**.

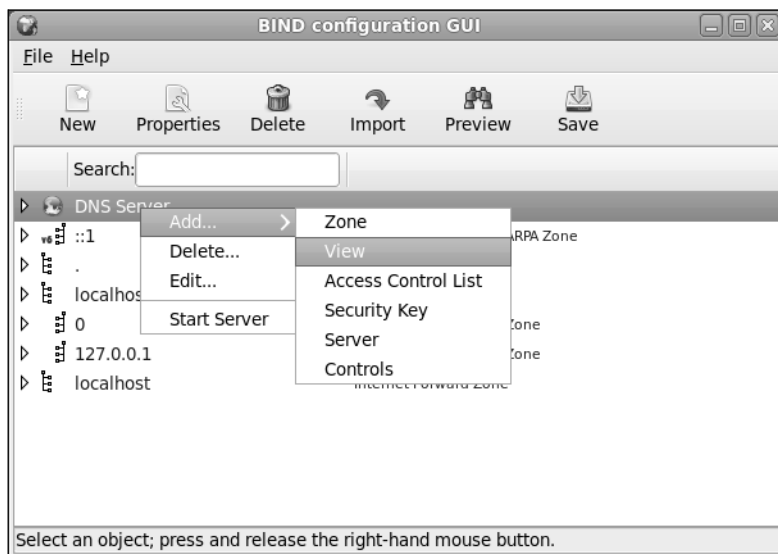
The `/etc/named.caching-nameserver.conf` file, which is installed as a dependency with the *RHEL* **caching-nameserver** package, is not recognized by **system-config-bind** as a **named** configuration file. See “**named.conf**” on page 786 for more information about this file.

Each zone file that **system-config-bind** creates has a filename extension of **.db**.

Because the windows displayed by **system-config-bind** contain a lot of information, you may find it helpful to expand or maximize these windows so you can view the information more easily.



**Figure 24-6** The BIND Configuration GUI window



**Figure 24-7** The BIND Configuration GUI window with a right-click menu

### Using this JumpStart

**tip** The `system-config-bind` utility is a complex tool that you may find helpful for setting up BIND. Run this utility and click **Help**⇒**Manual** on the menubar to display the Fedora/RHEL manual for this utility. Click **Help**⇒**ISC ARM** to display the BIND 9 Administrator Reference Manual. You may want to experiment with this utility after you have set up one of the servers described at the end of this chapter, as its configuration information may make more sense after you go through the process of manually configuring BIND.

This section explains how to use `system-config-bind` but does not go into detail about what each of the files and settings does. That information is covered in other sections of this chapter.

## USING THE BIND CONFIGURATION GUI WINDOW

Right-click on an object (line) in the BIND Configuration GUI window to display a pop-up context menu. This menu always has an **Edit** selection, which displays a window in which you can edit information pertaining to the object you clicked. You can display the same window by double-clicking the object or by highlighting the object and clicking **Properties** on the toolbar. This pop-up menu also always has an **Add** selection that displays a submenu with choices appropriate to the object you are working with. Figure 24-7 shows the pop-up menu for the **DNS Server** object, along with the **Add** submenu.

In the BIND Configuration GUI window, a triangle at the left end of a line indicates that the object holds other objects. Click a triangle so that it points down to expand an entry. Click it so that it points to the right to collapse an entry.



**Figure 24-8** The first New Zone window

## SETTING UP A DOMAIN SERVER

Highlight **DNS Server** in the BIND Configuration GUI window and click **New⇒Zone** on the toolbar (or right-click and select **Add⇒Zone**) to add a new zone (page 776) and its associated nameserver. In response, system-config-bind displays the first New Zone window (Figure 24-8), which allows you to specify information about the zone you are setting up.

With the drop-down list labeled **Class** displaying **IN Internet**, click **OK** under this list.

Select the origin type from the drop-down list labeled **Origin Type**. The most common choices are **Forward** or **IPV4 Reverse**. Click **OK**. If you selected a forward zone, the **Forward Zone Origin** text box replaces the origin type information. Enter the domain name of the zone, including a trailing period, in the text box.

Select the type of zone you want to set up from the drop-down list labeled **Zone Type**. You can select from **master**, **slave**, **forward**, **hint**, and other types of zones. Refer to “Servers” on page 778 and **type** on page 796 for information on types of zones.

After you make your selections and click **OK**, system-config-bind displays the second New Zone window (Figure 24-9, next page). This window enables you to set up SOA information for the zone. Refer to “SOA” on page 781 for information about the fields in the SOA record, including the serial number and the various times (refresh intervals). In this window, the authoritative (primary) nameserver (page 778) defaults to the local system and the email address of the person responsible for the zone defaults to **root** on the local system. If you enter names that do not end with a period in these text boxes, system-config-bind appends the domain name of the zone to the names you have entered. Change the values in this window as necessary. By default, all zone files that system-config-bind creates have the **.db** file-name extension. The default filename for the zone file is the name of the domain you are setting up with an extension of **.db**. Click **OK**.

**New Zone**

sobell.com. Zone Authority Information

Domain Name  
sobell.com.

Cache Time To Live  
weeks days hours minutes seconds  
0 0 1 0 0

Authoritative Name Server  
localhost.

Responsible Person E-Mail Address  
root@localhost.

Zone Modification Serial Number  
1

Refresh Interval  
weeks days hours minutes seconds  
0 0 3 0 0

Refresh Retry Interval  
weeks days hours minutes seconds  
0 0 1 0 0

Expiration Interval  
weeks days hours minutes seconds  
1 0 0 0 0

Default Minimum Cache TTL  
weeks days hours minutes seconds  
0 0 1 0 0

Zone File Path  
sobell.com.db

**Figure 24-9** The second New Zone window

After you add a new zone, information about this zone appears in the BIND Configuration GUI window (Figure 24-6, page 789). Click **Save** on the toolbar to save the changes you made before you close the window.

To view information about the new zone, you can expand the object that holds the name of the new zone. You can further expand the Zone Authority Information and Name Server objects that appear when you expand the new zone object. Right-click any object to add to or modify the information in the object or to delete the object.

## ADDING RESOURCE RECORDS

You can add any of an extensive list of resource records to a domain. Right-click the object representing the domain you just added to display a pop-up menu. Slide the mouse pointer over **Add** to display the domain Add menu (Figure 24-10). The uppercase letters at the left end of each selection specify the type of resource record (page 779) that the selection adds to the domain. Following are some of the choices available on this menu:

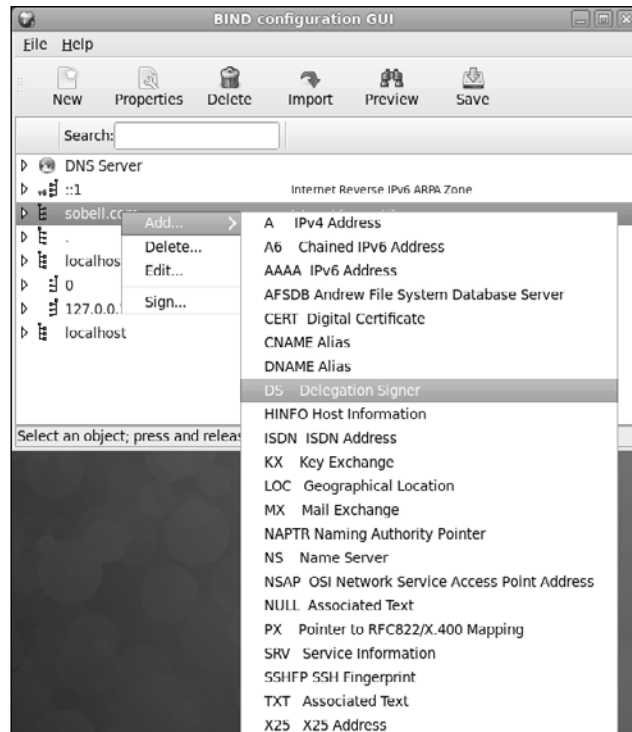
<b>A</b>	IPv4 Address record (page 780)
<b>CNAME</b>	Alias record (page 780)
<b>MX</b>	Mail Exchange record (page 780)
<b>NS</b>	Nameserver record (page 780)
<b>TXT</b>	Text record (page 782)

To add a reverse zone (a PTR record; page 781), add a new zone as before, but this time select **IPv4 (or IPv6) Reverse** as the origin type. For more information refer to “Reverse Name Resolution” on page 783.

Click **Save** when you are done, close the BIND Configuration GUI window, and start the **named** daemon as explained on page 785.

## SETTING UP BIND

This section discusses the `/etc/named.conf` file, zone files, implementation of a DNS cache, and running DNS inside a chroot jail.



**Figure 24-10** The domain Add drop-down menu

## named.conf: THE named CONFIGURATION FILE

Configuration information for **named**, including zone names and the names and locations of zone files, is kept in **/etc/named.conf**. By default, the zone files are kept in **/var/named**. If you are running **named** in a chroot jail, these files are kept in **/var/named/chroot/var/named** (page 804).

**FEDORA** A sample **named.conf** configuration file is included with the **bind** package. This file implements a caching-only nameserver.

**RHEL** The **bind** package does not include **named.conf**. The **/usr/share/doc/bind-\*/sample** directory provides example configuration files, including a sample **named.conf** file in the **etc** subdirectory.

A sample configuration file, **named.caching-nameserver.conf**, is included with the RHEL **caching-nameserver** package. See “**named.conf**” on page 786 for information about this file and its relationship to **named.conf**. If you want to make changes to this file, copy it to **named.conf** and then make changes to the copy. This way your changes will not be overwritten when the **caching-nameserver** package is updated.

### IP-LIST

In the descriptions in this section, **IP-list** is a semicolon-separated list of IP addresses, each optionally followed by a slash and subnet mask length (page 443). You can prefix an **IP-list** with an exclamation point (!) to negate it. Builtin names that you can use in **IP-list** include **any**, **none**, and **localhost**. You must enclose builtin names within double quotation marks.

### COMMENTS

Within **named.conf**, you can specify a comment by preceding it with a pound sign (#) as in a Perl or shell program, preceding it with a double slash (//) as in a C++ program, or enclosing it between **/\*** and **\*/** as in a C program.

### OPTIONS SECTION

Option statements can appear within two sections of **named.conf**: Options and Zone. Option statements within the Options section apply globally. When an option statement appears in a Zone section, the option applies to the zone and overrides any corresponding global option within that zone. An Options section starts with the keyword **options** and continues with braces surrounding the statements.

Following is a list of some option statements. Statements that can appear only in an Options section are so noted.

**allow-query {IP-list}**

Allows ordinary DNS queries from **IP-list** only. Without this option, the server responds to all queries.

**allow-recursion {*IP-list*}**

Specifies systems for which this server will perform recursive queries (page 777). For systems not in *IP-list*, the server performs iterative queries only. Without this option, the server performs recursive queries for any system. This statement may be overridden by the **recursion** statement.

**allow-transfer {*IP-list*}**

Specifies systems that are allowed to perform zone transfers from this server. Specify an *IP-list* of "none" (include the quotation marks) to prevent zone transfers.

**directory *path*** Specifies the absolute pathname of the directory containing the zone files; under Fedora/RHEL, this directory is initially */var/named*. Filenames specified in this *named.conf* file are relative to this directory. Options section only.

**forward ONLY|FIRST**

**ONLY** forwards all queries and fails if it does not receive an answer. **FIRST** forwards all queries and, if a query does not receive an answer, attempts to find an answer using additional queries. This option is valid with the **forwarders** statement only.

**forwarders {*IP* [*port*] [: ...]}**

Specifies IP addresses and (optionally) port numbers that queries are forwarded to. See the **forward** statement.

**listen-on [*port port*] {*IP-list*}**

Specifies IPv4 addresses and (optionally) a port number (specified by *port*) to listen for queries on.

**listen-on-v6 [*port port*] {*IP-list*}**

Specifies IPv6 addresses and (optionally) a port number (specified by *port*) to listen for queries on.

**notify YES|NO** **YES** sends a message to slave servers for the zone when zone information changes. Master servers only.

**recursion YES|NO**

**YES** (default) provides recursive queries (page 777) if the client requests. **NO** provides iterative queries only (page 777). An answer is always returned if it appears in the server's cache. This statement overrides the **allow-recursion** statement. Options section only.

## ZONE SECTION

A Zone section defines a zone and can include any of the statements listed for the Options section except as noted. A Zone section is introduced by the keyword **zone**, the name of the zone enclosed within double quotation marks, and the class (always **IN**). The body of the Zone section consists of a pair of braces surrounding one or more zone statements. See the listing of **named.rfc1912.zones** on page 799 for examples of Zone sections. Following is a list of some zone statements.

**allow-update** *{IP-list}*

Specifies systems that are allowed to update this zone dynamically. This statement may be useful when hosting a master DNS server for a domain owned by someone other than the local administrator because it allows a remote user to update the DNS entry without granting the user access to the server.

**file** *filename* Specifies the *zone file*, the file that specifies the characteristics of the zone. The *filename* is relative to the directory specified by the **directory** statement in the Options section. The **file** statement is mandatory for master and hint zones; it is a good idea for slave zones (see **type**).

**masters** *(IP-list)* Specifies systems that a slave zone can use to update zone files. Slave zones only.

**type** *ztype* Specifies the type of zone that this section defines. Specify *ztype* from the following list:

- **forward**—Specifies a forward zone, which forwards queries directed to this zone. See the **forward** and **forwarders** statements in the Options section.
- **hint**—Specifies a hint zone. A hint zone lists root servers that the local server queries when it starts and when it cannot find an answer in its cache.
- **master**—Specifies the local system as a primary master server (page 778) for this zone.
- **slave**—Specifies the local system as a slave server (page 778) for this zone.

## ZONE FILES

Zone files define zone characteristics. The name of the zone is typically specified in **named.conf** (or **named.caching-nameserver.conf**). In contrast to **named.conf**, zone files use periods at the ends of domain names. See page 800 for sample zone files. To improve security, master and hint zone files should be kept in **/var/named**, which is owned by **root** and is not writable by processes running with a user ID of **named**. Slave zone files should be kept in **/var/named/slaves**, which is owned by **named** and is writable by processes running with a user ID of **named**. This configuration enables SELinux to offer better security. When you set up a chroot jail, the slaves directory is not put in the jail. Both of these setups ensure that master and hint zone files cannot be updated by dynamic DNS updates or by zone transfers. See the **named** man page for more information.

## TIME FORMATS

All times in BIND files are given in seconds, unless they are followed by one of these letters (uppercase or lowercase): S (seconds), M (minutes), H (hours), D (days), or W (weeks). You can combine formats: The time 2h25m30s means 2 hours, 25 minutes, and 30 seconds and is the same as 8,730 seconds.



## DOMAIN QUALIFICATION

An unqualified domain in a zone file is assumed to be in the current zone (the zone being defined by the zone file and named by the **named.conf** file that refers to the zone file). For example, the name **zach** would be expanded to the FQDN **zach.myzone.com.** in the zone file for **myzone.com.** Use an FQDN (include the trailing period) to specify a domain that is not in the current zone. Any name that does not end with a period is regarded as a subdomain of the current zone.

## ZONE NAME

Within a zone file, an @ (at sign) is replaced with the zone name as specified by the **named.conf** file that refers to the zone file. The zone name (referred to as the *origin*) is also used to complete unqualified domain names. See “\$ORIGIN” in the next section.

## ZONE FILE DIRECTIVES

The following directives can appear within a zone file. Each directive is identified by a leading dollar sign. The \$TTL directive is mandatory and must be the first entry in a zone file.

- \$TTL Defines the default time to live for all resource records in the zone. This directive must appear in a zone file before any resource records that it applies to. Any resource record can include a TTL value to override this value, except for the resource record in the root zone (.).
- \$ORIGIN Changes the zone name from that specified in the **named.conf** file. This name, or the zone name if this directive does not appear in the zone file, replaces an @ sign in the Name field of a resource record.
- \$INCLUDE Includes a file as though it were part of the zone file. The scope of an \$ORIGIN directive within an included file is the included file. That is, an \$ORIGIN directive within an included file does not affect the file that holds the \$INCLUDE directive.

## A DNS CACHE

You install a DNS cache (also called a resolving, caching nameserver) when you install the **bind** package (*FEDORA*) or the **bind** and **caching-nameserver** packages (*RHEL*). The section “JumpStart I: Setting Up a DNS Cache” (page 787) explains how to run this server. This section explains how the files Fedora provides implement this server. The RHEL **caching-nameserver** package provides a similar setup.

### **named.conf: THE named CONFIGURATION FILE (*FEDORA*)**

The default **named.conf** file is shown next. Fedora has incorporated the old **caching-nameserver** package in the **bind** package; the comments in the file reflect the original division. RHEL maintains the two packages separately.

```
# cat /etc/named.conf
//
// named.conf
//
// Provided by Red Hat bind package to configure the ISC BIND named(8) DNS
// server as a caching only nameserver (as a localhost DNS resolver only).
//
// See /usr/share/doc/bind*/sample/ for example named configuration files.
//

options {
    listen-on port 53 { 127.0.0.1; };
    listen-on-v6 port 53 { ::1; };
    directory      "/var/named";
    dump-file       "/var/named/data/cache_dump.db";
    statistics-file "/var/named/data/named_stats.txt";
    memstatistics-file "/var/named/data/named_mem_stats.txt";
    allow-query     { localhost; };
    recursion yes;
    dnssec-enable yes;
    dnssec-validation yes;
    dnssec-lookaside . trust-anchor dlv.isc.org.;
};

logging {
    channel default_debug {
        file "data/named.run";
        severity dynamic;
    };
};

zone "." IN {
    type hint;
    file "named.ca";
};

include "/etc/named.rfc1912.zones";

include "/etc/pki/dnssec-keys//named.dnssec.keys";
include "/etc/pki/dnssec-keys//dlv/dlv.isc.org.conf";
```

**Options section** The first two lines of the Options section instruct **named** to listen on port 53 (the default **named** port) on the local system for incoming queries. The **directory** statement specifies the directory that all relative pathnames in this file are relative to. Specifically, the files named in the Zone sections (of the included **named.rfc1912.zones** file) are in the **/var/named** directory. If you are running **named** in a chroot jail, this directory is located under **/var/named/chroot** (page 804). This section also specifies the locations of the **dump-file** (cache dump), **statistics-file** (statistics file), and **memstatistics-file** (memory statistics file). The **allow-query** statement specifies which IP addresses are allowed to query the server. This file specifies that only **localhost** can query the server. The **recursion** statement specifies that this server perform recursive queries. The **dnssec\*** statements implement DNSSEC (DNS Security Extensions), which adds security to DNS.

**Logging section** The Logging section causes debugging messages to be sent to **data/named.run**. For more information refer to “Logging” on page 808.

- Zone section The Zone section specifies the hint zone, whose name is a period. This zone specifies that when the server starts or when it does not know which server to query, it should look in the `/var/named/named.ca` (`ca` stands for *cache*) file to find the addresses of authoritative servers for the root domain.
- Include statement The **include** statements include `/etc/named.rfc1912.zones` (next section) as though it were present in this file. The `named.rfc1912.zones` file specifies additional zones.

## named.rfc1912.zones: THE ZONE CONFIGURATION FILE (*FEDORA*)

As explained in the previous section, the `named.conf` file incorporates the `/etc/named.rfc1912.zones` file by naming it in an **include** statement:

```
# cat /etc/named.rfc1912.zones
// named.rfc1912.zones:
//
// Provided by Red Hat caching-nameserver package
//
// ISC BIND named zone configuration for zones recommended by
// RFC 1912 section 4.1 : localhost TLDs and address zones
// and http://www.ietf.org/internet-drafts/draft-ietf-dnsop-default-local-zones-02.txt
// (c)2007 R W Franks
//
// See /usr/share/doc/bind*/sample/ for example named config files.

zone "localhost.localdomain" IN {
    type master;
    file "named.localhost";
    allow-update { none; };
};

zone "localhost" IN {
    type master;
    file "named.localhost";
    allow-update { none; };
};

zone "1.0.0.0.0.0.0.0.0.0. ... .0.0.0.0.0.0.ip6.arpa" IN {
    type master;
    file "named.loopback";
    allow-update { none; };
};

zone "1.0.0.127.in-addr.arpa" IN {
    type master;
    file "named.loopback";
    allow-update { none; };
};

zone "0.in-addr.arpa" IN {
    type master;
    file "named.empty";
    allow-update { none; };
};
```

Zone sections This file holds five Zone sections, each of which has an **allow-update** statement that specifies dynamic updates of the zone are not allowed. All filenames in the **named.rfc1912.zones** file are relative to the directory specified by the **directory** statement in the Options section of **named.conf**.

- **localhost.localdomain**—Specifies that **localhost.localdomain** points to 127.0.0.1, preventing the local server from looking upstream for this information.
- **localhost**—Sets up the normal server on the local system.
- **1.0 ... 0.0.ip6.arpa**—Sets up IPv6 reverse name resolution.
- **1.0.127.in-addr.arpa**—Sets up IPv4 reverse name resolution.
- **0.in-addr.arpa**—Specifies that IP addresses that start with 0 have their reverse lookup handled by the local server, preventing the local server from looking upstream for this information.

## ZONE FILES

There are three zone files in **/var/named** and one in **/etc**, each corresponding to one of the Zone sections in **named.conf** and **named.rfc1912.zones**. This section describes three of these zone files.

The root zone: **named.ca** The hint zone file, **named.ca**, is an edited copy of the output of a query of the root domain (**dig +bufsize=1200 +norec NS . @a.root-servers.net**). This information does not change frequently. See <ftp.internic.net/domain/named.cache> for more information. The **named.ca** file specifies authoritative servers for the root domain. The DNS server initializes its cache from this file and can determine an authoritative server for any domain from this information.

The root zone is required only for servers that answer recursive queries: If a server responds to recursive queries, it needs to perform a series of iterative queries starting at the root domain. Without the root domain hint file, it would not know the location of the root domain servers.

```
# cat /var/named/named.ca
; <<>> DiG 9.5.0b2 <<>> +bufsize=1200 +norec NS . @a.root-servers.net
;; global options: printcmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 34420
;; flags: qr aa; QUERY: 1, ANSWER: 13, AUTHORITY: 0, ADDITIONAL: 20

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags;; udp: 4096
;; QUESTION SECTION:
;.                               IN          NS
```

```
;; ANSWER SECTION:
.          518400 IN      NS      M.ROOT-SERVERS.NET.
.          518400 IN      NS      A.ROOT-SERVERS.NET.
.          518400 IN      NS      B.ROOT-SERVERS.NET.
...
;; ADDITIONAL SECTION:
A.ROOT-SERVERS.NET. 3600000 IN      A      198.41.0.4
A.ROOT-SERVERS.NET. 3600000 IN      AAAA   2001:503:ba3e::2:30
B.ROOT-SERVERS.NET. 3600000 IN      A      192.228.79.201
C.ROOT-SERVERS.NET. 3600000 IN      A      192.33.4.12
D.ROOT-SERVERS.NET. 3600000 IN      A      128.8.10.90
E.ROOT-SERVERS.NET. 3600000 IN      A      192.203.230.10
...

;; Query time: 147 msec
;; SERVER: 198.41.0.4#53(198.41.0.4)
;; WHEN: Mon Feb 18 13:29:18 2008
;; MSG SIZE rcvd: 615
```

**localhost.zone** The **localhost.zone** zone file defines the **localhost** zone, the normal server on the local system. It starts with a \$TTL directive and holds four resource records: SOA, NS, A, and AAAA. The \$TTL directive specifies that the default time to live for the resource records specified in this file is one day (1D):

```
# cat /var/named/named.localhost
$TTL 1D
@           IN SOA   @ rname.invalid. (
                                0           ; serial
                                1D          ; refresh
                                1H          ; retry
                                1W          ; expire
                                3H )        ; minimum

NS          @
A           127.0.0.1
AAAA        ::1
```

As explained earlier, the @ at the beginning of the SOA resource record stands for the origin (the name of the zone), which is **localhost**. The last three lines in the preceding file are the NS resource record, which specifies the nameserver for the zone as @ (**localhost**); the A resource record, which specifies the IPv4 address of the host as 127.0.0.1; and the AAAA resource record, which specifies the IPv6 address of the host as ::1. Because these three records have blank Name fields, each inherits this value from the preceding resource record—in this case, @.

**named.loopback** The **named.loopback** zone file provides information about the 1.0.0.127.in-addr.arpa reverse lookup zone and the equivalent IPv6 zone. It follows the same pattern as the **localhost** zone file, with one exception: Instead of the A resource record, this file has a PTR record that provides the name that the zone associates with the IP address. The

PTR resource record inherits the name `1.0.0.127.in-addr.arpa (@)`, which it equates to `localhost`:

```

# cat /var/named/named.loopback
$TTL 1D
@      IN SOA  @ rname.invalid. (
                                0      ; serial
                                1D     ; refresh
                                1H     ; retry
                                1W     ; expire
                                3H )   ; minimum

      NS      @
      PTR     localhost.

```

THE `named.conf` CONFIGURATION FILE (RHEL)

Under RHEL, the `named.conf` and `named.caching-nameserver.conf` files together hold similar zones to the `named.conf` file and the included `named.rfc1912.zones` file described in the previous section.

DNS GLUE RECORDS

It is common practice to put the nameserver for a zone inside the zone it serves. For example, you might put the nameserver for the zone starting at `site1.example.com` (Figure 24-3, page 777) in `ns.site1.example.com`. When a DNS cache tries to resolve `www.site1.example.com`, the authoritative server for `example.com` gives it the NS record pointing to `ns.site1.example.com`. In an attempt to resolve `ns.site1.example.com`, the DNS cache again queries the authoritative server for `example.com`, which points back to `ns.site1.example.com`. This loop does not allow `ns.site1.example.com` to be resolved.

The simplest solution to this problem is not to allow any nameserver to reside inside the zone it points to. Because every zone is a child of the root zone, this solution means that every domain would be served by the root server and would not scale at all. A better solution is *glue records*. A glue record is an A record for a nameserver that is returned in addition to the NS record when an NS query is performed. Because the A record provides an IP address for the nameserver, it does not need to be resolved and does not create the problematic loop.

The nameserver setup for `redhat.com` illustrates the use of glue records. When you query for NS records for `redhat.com`, DNS returns three NS records. In addition, it returns three A records that provide the IP addresses for the hosts that the NS records point to:

```

$ dig -t NS redhat.com
...
;; QUESTION SECTION:
;redhat.com.                IN      NS

;; ANSWER SECTION:
redhat.com.                 600     IN      NS      ns1.redhat.com.
redhat.com.                 600     IN      NS      ns2.redhat.com.
redhat.com.                 600     IN      NS      ns3.redhat.com.

```

```
;; ADDITIONAL SECTION:
ns1.redhat.com.      161952 IN      A      66.187.233.210
ns2.redhat.com.      77938  IN      A      209.132.183.2
ns3.redhat.com.      77938  IN      A      66.187.229.10
...

```

You can create a glue record by providing an A record for the nameserver inside the delegating domain's zone file:

```
site1.example.com.      IN      NS      ns.site1.example.com
ns.site1.example.com.   IN      A      1.2.3.4

```

## TSIGs: TRANSACTION SIGNATURES

Interaction between DNS components is based on the query-response model: One part queries another and receives a reply. Traditionally a server determines whether and how to reply to a query based on the IP client's address. *IP spoofing* (page 1089) is relatively easy to carry out, making this situation less than ideal. Recent versions of BIND support transaction signatures (TSIGs), which allow two systems to establish a trust relationship by using a shared secret key.

TSIGs provide an additional layer of authentication between master and slave servers for a zone. When a slave server is located at a different site than the master server (as it should be), a malicious person operating a router between the sites could spoof the IP address of the master server and change the DNS data on the slave (a man-in-the-middle attack). With TSIGs, however, this person would need to know the secret key to change the DNS data on the slave.

### CREATING A SECRET KEY

A secret key is an encoded string of up to 512 bits. The `dnssec-keygen` utility, which is included with BIND, generates this key. The following command generates a 512-bit random key using MD5, a *one-way hash function* (page 1097):

```
$ /usr/sbin/dnssec-keygen -a hmac-md5 -b 512 -n HOST keyname
Kkeyname.+157+47586

```

In the preceding command, replace *keyname* with a string that is unique yet meaningful. This command creates a key in a file whose name is similar to the name `Kkeyname.+157+47586.private`, where *keyname* is replaced by the name of the key, `+157` indicates the algorithm used, and `+47586` is a hash of the key. If you run the same command again, the hash part will be different.

The key file is not used directly. Use `cat` with an argument of the private filename to display the algorithm and key information you will need in the next step:

```
$ cat Kkeyname.+157+47586.private
Private-key-format: v1.2
Algorithm: 157 (HMAC_MD5)
Key: uNPDouqVwR7fvo/zFyjKqKbQhcTd6Prm...
BITS: AAA=

```

## USING THE SHARED SECRET

The next step is to tell the nameservers about the shared secret by inserting the following code in the `/etc/named.conf` file on both servers. This code is a top-level section in `named.conf`; insert it following the Options section:

```
key keyname {
    algorithm "hmac-md5";
    secret "uNPDouqVwR7fvo/zFyjKqKbQhcTd6Prm...";
};
```

The *keyname* is the name of the key you created. The **algorithm** is the string that appears within parentheses in the output from `cat`. The **secret** is the string that follows **Key:** in the preceding output. You must enclose each string within double quotation marks. Be careful when you copy the key; although it is long, do not break it into multiple lines.

Because key names are unique, you can insert any number of key sections into `named.conf`. To keep the key a secret, make sure users other than **root** cannot read it: Either give `named.conf` permissions such that no one except **root** has access to it or put the key in a file that only **root** can read and incorporate it in `named.conf` using an **include** statement.

Once both servers know about the key, use the **server** statement in `named.conf` to tell them when to use it:

```
server 1.2.3.4 {
    # 1.2.3.4 is the IP address of the other server using this key
    keys {
        "keyname";
    };
};
```

Each server must have a server section, each containing the IP address of the other server. The servers will now communicate with each other only if they first authenticate each other using the secret key.

## RUNNING BIND IN A chroot JAIL

To increase security, you can run BIND in a chroot jail. See page 448 for information about the security advantages of and ways to set up a chroot jail. See also the note about SELinux on page 786 and the `named` man page for information about BIND, SELinux, and chroot jails. The **bind-chroot** package, which sets up BIND to run in a chroot jail, creates a directory named `/var/named/chroot` that takes the place of the root directory (`/`) for all BIND files. With this package installed, all files that control BIND are located within this chroot jail and the filenames used in this chapter are hard (*FEDORA*) or symbolic (*RHEL*) links to the files in the chroot jail. As the following example shows, under Fedora the `named` script links `/var/named/chroot/var/named`



to `/var/named` when you start **named** (and removes the link when you stop **named**). You can verify the link by comparing the inode numbers of the two directories.

```
# ls /var/named/chroot/var/named
# ls -ldi /var/named/chroot/var/named
139323 drwxr-x---. 2 root named 4096 2009-09-21 03:46 /var/named/chroot/var/named
# ls -ldi /var/named
139302 drwxr-x---. 6 root named 4096 2009-11-24 11:42 /var/named
# service named start
Starting named: [ OK ]
# ls -ldi /var/named/chroot/var/named
139302 drwxr-x---. 6 root named 4096 2009-11-24 11:42 /var/named/chroot/var/named
```

With the **bind-chroot** package installed, you must set the **ROOTDIR** shell variable to `/var/named/chroot` in the `/etc/sysconfig/named` file, which is sourced by the **named** init script. To do so, add the following line to `/etc/sysconfig/named`:

```
ROOTDIR="/var/named/chroot"
```

## TROUBLESHOOTING

When you start a DNS cache, the `/var/log/messages` file contains lines similar to the following. Other types of DNS servers display similar messages.

```
# cat /var/log/messages
...
... named[134]: starting BIND 9.5.0b1 -u named -t /var/named/chroot
... named[134]: found 1 CPU, using 1 worker thread
... named[134]: loading configuration from '/etc/named.conf'
... named[134]: listening on IPv6 interface lo, ::1#53
... named[134]: listening on IPv4 interface lo, 127.0.0.1#53
... named[134]: automatic empty zone: 127.IN-ADDR.ARPA
... named[134]: automatic empty zone: 254.169.IN-ADDR.ARPA
... named[134]: automatic empty zone: 2.0.192.IN-ADDR.ARPA
...
... named[134]: automatic empty zone: B.E.F.IP6.ARPA
... named[134]: command channel listening on 127.0.0.1#953
... named[134]: command channel listening on ::1#953
... named[134]: zone 0.in-addr.arpa/IN: NS '0.in-addr.arpa' has no address records (A or AAAA)
... named[134]: zone 0.in-addr.arpa/IN: loaded serial 0
... named[134]: zone 1.0.0.127.in-addr.arpa/IN: NS '1.0.0.127.in-addr.arpa' has no address records (A or AAAA)
... named[134]: zone 1.0.0.127.in-addr.arpa/IN: loaded serial 0
... named[134]: zone 1.0.0 ... 0.0.ip6.arpa/IN: NS '1.0.0 ... 0.0.ip6.arpa' has no address records (A or AAAA)
... named[134]: zone 1.0.0.0 ... .0.0.0.0.0.0.ip6.arpa/IN: loaded serial 0
... named[134]: zone localhost.localdomain/IN: loaded serial 0
... named[134]: zone localhost/IN: loaded serial 0
... named[134]: running
```

With an argument of **status**, the **named** init script displays useful information:

```
# /sbin/service named status
version: 9.6.1-P1-RedHat-9.6.1-11.P1.fc12
CPUs found: 1
worker threads: 1
number of zones: 15
debug level: 0
xfers running: 0
xfers deferred: 0
soa queries in progress: 0
query logging is OFF
recursive clients: 0/0/1000
tcp clients: 0/100
server is up and running
named (pid 31903) is running...
```

When you create or update DNS information, you can use **dig** or **host** to test that the server works the way you planned. The most useful part of the output from **dig** is usually the answer section, which gives the nameserver's reply to your query:

```
$ dig example.com
...
;; ANSWER SECTION:
example.com.          172800   IN      A       192.0.32.10
...
```

The preceding output shows that the **example.com.** domain has a single A record and that record points to 192.0.32.10. The TTL of this record, which tells you how long the record can be held in cache, is 172,800 seconds (two days). You can also use **dig** to query other record types by using **-t** option followed by the type of record you want to query for (**-t** works with **host**, too):

```
$ dig -t MX redhat.com
...
;; ANSWER SECTION:
redhat.com.           600      IN      MX      5 mx1.redhat.com.
redhat.com.           600      IN      MX      10 mx2.redhat.com.
...
```

If you query for a domain that does not exist, **dig** returns the SOA record for the authority section of the highest-level domain in your query that does exist:

```
$ dig domaindoesnotexist.info
...
;; AUTHORITY SECTION:
info.                 900      IN      SOA     a0.info.afiliast-nst.info. ...
...
```

Because it tells you the last zone that was queried correctly, this information can be useful in tracing faults.

**TSIGs** If two servers using TSIGs (page 803) fail to communicate, check the time is the same on both servers. The TSIG authentication mechanism is dependent on the current time. If the clocks on the two servers are not synchronized, TSIG will fail. Consider setting up *NTP* (page 1097) on the servers to prevent this problem.

## A FULL-FUNCTIONED NAMESERVER

Because the IP addresses used in this example are part of the *private address space* (page 1100) you can copy the example and run the server without affecting global DNS. Also, to prevent contamination of the global DNS, each zone has the **notify** option set to NO. When you build a nameserver that is integrated with the Internet, you will want to use IP addresses that are unique to your installation. You may want to change the settings of the **notify** statements.

**named.conf** The **named.conf** file in this example limits the IP addresses that **named** answers queries from and sets up logging:

```
$ cat /etc/named.conf
options {
    directory "/var/named";
    allow-query {127.0.0.1; 192.168.0.0/24;};};

zone "." IN {
    type    hint;
    file    "named.ca";};
zone "0.168.192.in-addr.arpa" IN {
    type    master;
    file    "named.local";
    notify  NO;
};

zone "sam.net" IN {
    type    master;
    file    "sam.net";
    notify  NO;
};

logging{
    channel "misc" {
        file "/var/log/bind/misc.log" versions 4 size 4m;
        print-time YES;
        print-severity YES;
        print-category YES;
    };
    channel "query" {
        file "/var/log/bind/query.log" versions 4 size 4m;
        print-time YES;
        print-severity NO;
        print-category NO;
    };
    category default {
        "misc";
    };
    category queries {
        "query";
    };
};
```

The **allow-query** statement in the Options section specifies the IP addresses of the systems that the server will answer queries from. You must include the local system as 127.0.0.1 if it will be querying the server. The zone that this server is authoritative for is **sam.net**; the zone file for sam.net is **/var/named/sam.net**.

**Logging** Logging is turned on by the Logging section. This section opens two logging channels: one that logs information to **/var/log/bind/misc.log** and one that logs information to **/var/log/bind/query.log**. When one of these logs grows to 4 megabytes (size **4m** in the file statement), it is renamed by appending **.1** to its filename and a new log is started. The numbers at the ends of other, similarly named logs are incremented. Any log that would have a larger number than that specified by the **versions** clause (**4** in the example) is removed. See **logrotate** (page 579) for another way to maintain log files. The **print** statements determine whether the time, severity, and category of the information are sent to the log; specify each as YES or NO. The category determines what information is logged to the channel. In the example, default information is sent to the **misc** channel and queries are sent to the **query** channel. Refer to the **named.conf** man page for more choices.

**named.local** The origin for the reverse zone file (**named.local**) is 0.168.192.in-addr.arpa (as specified in the Zone section that refers to this file in **named.conf**). Following the SOA and NS resource records, the first three PTR resource records equate address 1 in the subnet 0.168.192.in-addr.arpa (192.168.0.1) with the names **gw.sam.net.**, **www.sam.net.**, and **ftp.sam.net.**, respectively. The next three PTR resource records equate 192.168.0.3 with **mark.sam.net.**, 192.168.0.4 with **mail.sam.net.**, and 192.168.0.6 with **ns.sam.net.**

```
$ cat named.local
; zone "0.168.192.in-addr.arpa"
;
$TTL      3D
@         IN      SOA      ns.sam.net. mgs@sobell.com. (
                                2005110501      ; serial
                                8H                ; refresh
                                2H                ; retry
                                4W                ; expire
                                1D)              ; minimum
                                IN      NS       ns.sam.net.
1         IN      PTR      gw.sam.net.
1         IN      PTR      www.sam.net.
1         IN      PTR      ftp.sam.net.
3         IN      PTR      mark.sam.net.
4         IN      PTR      mail.sam.net.
6         IN      PTR      ns.sam.net.
```

**sam.net** The zone file for sam.net takes advantage of many BIND features and includes TXT (page 782), CNAME (page 780), and MX (page 780) resource records. When you query for resource records, **named** returns the TXT resource record along with the records you requested. The first of the two NS records specifies an unqualified name (**ns**) to which BIND appends the zone name (**sam.net**), yielding an FQDN of **ns.sam.net**. The second nameserver is specified with an FQDN name that BIND does

not alter. The MX records specify mail servers in a similar manner and include a priority number at the start of the data field; lower numbers indicate preferred servers.

```
$ cat sam.net
; zone "sam.net"
;
$TTL      3D
@         IN      SOA      ns.sam.net. mgs@sobell.com. (
                                200511051      ; serial
                                8H              ; refresh
                                2H              ; retry
                                4W              ; expire
                                1D )            ; minimum

                                TXT      "Sobell Associates Inc."
                                NS       ns      ; Nameserver address(unqualified)
                                NS       ns.max.net.; Nameserver address (qualified)
                                MX       10 mail ; Mail exchange (primary/unqualified)
                                MX       20 mail.max.net.; Mail exchange (2nd/qualified)

localhost IN      A        127.0.0.1

www       IN      CNAME    ns
ftp       IN      CNAME    ns

gw        IN      A        192.168.0.1
          TXT      "Router"

ns        IN      A        192.168.0.6
          MX       10 mail
          MX       20 mail.max.net.

mark      IN      A        192.168.0.3
          MX       10 mail
          MX       20 mail.max.net.
          TXT      "MGS"

mail      IN      A        192.168.0.4
          MX       10 mail
          MX       20 mail.max.net.
```

Some resource records have a value in the Name field; those without a name inherit the name from the previous resource record. In a similar manner, the previous resource record may have an inherited name value, and so on. The five resource records following the SOA resource record inherit the @, or zone name, from the SOA resource record. These resource records pertain to the zone as a whole. In the preceding example, the first TXT resource record inherits its name from the SOA resource record; it is the TXT resource record for the sam.net zone (give the command **host -t TXT sam.net** to display the TXT resource record).

Following these five resource records are resource records that pertain to a domain within the zone. For example, the MX resource records that follow the A resource record with the Name field set to **mark** are resource records for the **mark.sam.net.** domain.

The A resource record for **localhost** is followed by two CNAME resource records that specify **www.sam.net.** and **ftp.sam.net.** as aliases for the nameserver **ns.sam.net.** For example, a user connecting to **ftp.sam.net** will connect to 192.168.0.6. The resource records named **gw**, **ns**, **mark**, and **mail** are resource records for domains within the **sam.net** zone.

**Log files** Before restarting **named**, create the directory for the log files and give it permissions and ownership as shown below. If you are running **named** in a chroot jail, create the **bind** directory in **/var/named/chroot/var/log**.

```
# mkdir /var/log/bind
# chmod 744 /var/log/bind
# chown named /var/log/bind
# ls -ld /var/log/bind
drwxr--r-- 2 named root 4096 Nov  5 19:41 /var/log/bind
```

With the log directory in place, **named.conf** in **/etc** (or in **/var/named/chroot/etc** if you are running **named** in a chroot jail), and the **named.ca**, **named.local**, and **sam.net** zone files in **/var/named** (or in **/var/named/chroot/var/named** if you are running **named** in a chroot jail), restart **named** and check the log files. The file **/var/log/messages** should show something like the following:

```
# cat /var/log/messages
...
19:25:48 peach named[22416]: starting BIND 9.3.2 -u named -t /var/named/chroot
19:25:48 peach named[22416]: found 1 CPU, using 1 worker thread
19:25:48 peach named[22416]: loading configuration from '/etc/named.conf'
19:25:48 peach named[22416]: listening on IPv4 interface lo, 127.0.0.1#53
19:25:48 peach named[22416]: listening on IPv4 interface eth0, 192.168.0.10#53
19:25:48 peach named[22416]: command channel listening on 127.0.0.1#953
19:25:48 peach named[22416]: command channel listening on ::1#953
```

The **misc.log** file may show errors that do not appear in the **messages** file:

```
# cat /var/log/bind/misc.log
19:25:48.077 general: info: zone 0.168.192.in-addr.arpa/IN: loaded serial 2005110501
19:25:48.079 general: info: zone sam.net/IN: loaded serial 200511051
19:25:48.097 general: notice: running
```

---

## A SLAVE SERVER

To set up a slave server, copy the **/etc/named.conf** file from the master server to the slave server, replacing the **type master** statement with **type slave**. Remove any zones that the slave server will not be acting as a slave for, including the root (**.**) zone, if the slave server will not respond to recursive queries. Create the **/var/log/bind** directory for log files as explained at the end of the previous section.

**notify statement** Slave servers copy zone information from the primary master server or another slave server. The **notify** statement specifies whether you want a master server to notify slave servers when information on the master server changes. Set the (global)

value of **notify** in the Options section or set it within a Zone section, which overrides a global setting for a given zone. The format is

*notify YES | NO | EXPLICIT*

**YES** causes the master server to notify all slaves listed in NS resource records for the zone as well as servers at IP addresses listed in an **also-notify** statement. When you set **notify** to **EXPLICIT**, the server notifies servers listed in the **also-notify** statement only. **NO** turns off notification.

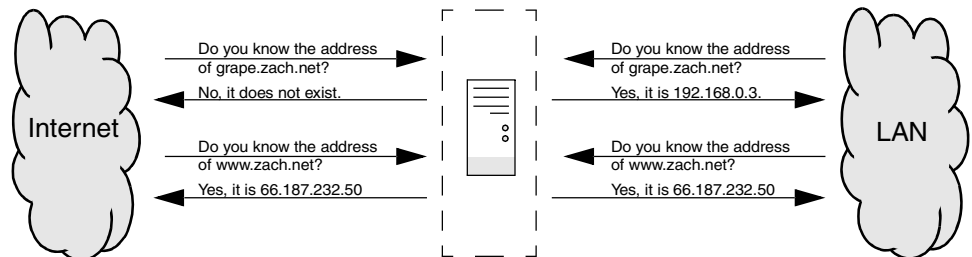
When you start **named**, it copies the zone files to **/var/named**. If you specify **notify YES** on the master server, the zone files on the slave server will be updated each time you change the serial field of the SOA resource record in a zone. You must manually distribute changes to the **/etc/named.conf** file.

## A SPLIT HORIZON SERVER

Assume you want to set up a LAN that provides all its systems and services to local users on internal systems, which may be behind a firewall, and only certain public services—such as Web, FTP, and mail—to Internet (public) users. A *split horizon* (also called *DMZ*) DNS server takes care of this situation by treating queries from internal systems differently from queries from public systems (systems on the Internet).

View sections BIND 9 introduced View sections in **named.conf**. View sections facilitate the implementation of a split DNS server. Each view provides a different perspective of the DNS namespace to a group of clients. When there is no View section, all zones specified in **named.conf** are part of the implicit default view.

Assume that an office has several systems on a LAN and public Web, FTP, DNS, and mail servers. The single connection to the Internet is NATed (page 1095) so that it is shared by the local systems and the servers. The gateway system—the one connected directly to the Internet—is a router, firewall, and server. This scenario takes advantage of the View sections in **named.conf** and supports separate secondary nameservers for local and public users. Although public users need access to the



**Figure 24-11** A split horizon DNS server

DNS server as the authority on the domain that supports the servers, they do not require the DNS server to support recursive queries. Not supporting recursion for public users limits the load on the DNS server and the Internet connection. For security reasons, public users must not have access to information about local systems other than the servers. Local users should have access to information about local systems and should be able to use the DNS server recursively.

Figure 24-11 (previous page) shows that the server responds differently to queries from the LAN and the Internet.

The `iptables` utility (page 819) controls which ports on which systems users on internal and external systems can access. DNS controls which systems are advertised to which users.

The `named.conf` file has four sections: Options, two View sections, and Logging. The Options section specifies that the zone files are in the `/var/named` directory. The View sections specify the characteristics and zones that a resolver is given access to, which depend on the resolver's address. One zone is for use by the LAN/local users and the other by Internet/public users. The Logging section sets up the `misc2.log` file for default messages.

There are several ways to specify which clients see a view. The following `named.conf` file uses `match-clients` statements:

```
$ cat /etc/named.conf
options {
    directory "/var/named";
}; //end options

view "local" IN {                                // start local view
    match-clients { 127.0.0.1; 192.168.0.0/24;};
    recursion YES;

    zone "zach.net" IN {
        type      master;
        file      "local.net";
        notify    YES;
    };

    zone "0.168.192.in-addr.arpa" IN {
        type      master;
        file      "named.local";
        notify    YES;
    };

    zone "." IN {
        type      hint;
        file      "named.ca";
    };
};                                     // end local view
```



```

view "public" IN {                                // start public view
match-clients { "all";};
recursion NO;

zone "zach.net" IN {
    type    master;
    file    "public.net";
    notify  YES;
};

zone "0.168.192.in-addr.arpa" IN {
    type    master;
    file    "named.public";
    notify  YES;
};
zone "." IN {
    type    hint;
    file    "named.ca";
};

};  // end public view

logging{
    channel "misc" {
        file "/var/log/bind/misc2.log" versions 2 size 1m;
        print-time YES;
        print-severity YES;
        print-category YES;
    };
    category default {
        "misc";
    };
};  //end logging

```

The ordering of View sections within **named.conf** is critical: The view that is presented to a client is the first view that the client matches. The preceding **named.conf** file holds two View sections: one for local users and one for public users, in that order. Local users are defined to be those on the 192.168.0.0/24 subnet or **localhost** (127.0.0.1); public users are defined to be any users. If you reversed the order of the View sections, all users—including local users—would get the view intended for the public and no users would see the local view.

Many statements from the Options section can be used within View sections, where they override statements in the (global) Options section. The **recursion** statement, which can appear within an Options section, appears in each View section. This **named.conf** file sets up a server that provides recursive answers to queries that originate locally and iterative answers to queries from the public. This setup provides quick, complete answers to local users, limiting the network and processor bandwidth that is devoted to other users while still providing authoritative name service for the local servers.

To make **named.conf** easier to understand and maintain, zones in different View sections can have the same name while having different zone files. Both the local and public View sections in the example have zones named **zach.net**: The public **zach.net** zone file is named **public.net**, while the local one is named **local.net**.

The Logging section is described on page 808.

The zone files defining **zach.net** are similar to the ones in the previous examples; the public file is a subset of the local one. Following the SOA resource record in both files is a TXT, two NS, and two MX resource records. Next are three CNAME resource records that direct queries addressed to **www.zach.net**, **ftp.zach.net**, and **mail.zach.net** to the system named **ns.zach.net**. The next four resource records specify two nameserver addresses and two mail servers for the **ns.zach.net** domain.

The final four resource records appear in the local **zach.net** zone file and not in the public zone file; they are address (A) resource records for local systems. Instead of keeping this information in **/etc/hosts** files on each system, you can keep it on the DNS server, where it can be updated easily. When you use DNS instead of **/etc/hosts**, you must change the **hosts** line in **/etc/nsswitch.conf** (page 455).

```
$ cat local.net
; zach.net local zone file
$TTL      3D
@         IN      SOA    ns.zach.net. mgs@sobell.com. (
                                200511118      ; serial
                                8H              ; refresh
                                2H              ; retry
                                4W              ; expire
                                1D )            ; minimum

                                IN      TXT     "Sobell Associates Inc."
                                IN      NS      ns          ; Nameserver address (unqualified)
                                IN      NS      ns.speedy.net.; Nameserver address (qualified)
                                IN      MX      10 mail      ; Mail exchange (primary/unqualified)
                                IN      MX      20 mail.max.net.; Mail exchange (2nd/qualified)

www        IN      CNAME  ns
ftp        IN      CNAME  ns
mail       IN      CNAME  ns

ns         IN      A       192.168.0.1
           IN      A       192.168.0.6
           IN      MX      10 mail
           IN      MX      20 mail.max.net.

speedy     IN      A       192.168.0.1
grape      IN      A       192.168.0.3
potato     IN      A       192.168.0.4
peach      IN      A       192.168.0.6
```

The public version of the **zach.net** zone file follows:

```

$ cat public.net
; zach.net public zone file
;
$TTL      3D
@         IN      SOA      ns.zach.net. mgs@sobell.com. (
                                200511118      ; serial
                                8H              ; refresh
                                2H              ; retry
                                4W              ; expire
                                1D )            ; minimum

                                IN      TXT      "Sobell Associates Inc."
                                IN      NS      ns      ; Nameserver address(unqualified)
                                IN      NS      ns.speedy.net.; Nameserver address (qualified)

                                IN      MX      10 mail; Mail exchange (primary/unqualified)
                                IN      MX      20 mail.max.net.; Mail exchange (2nd/qualified)
www       IN      CNAME     ns
ftp       IN      CNAME     ns
mail      IN      CNAME     ns

ns        IN      A         192.168.0.1
          IN      A         192.168.0.6
          IN      MX        10 mail
          IN      MX        20 mail.max.net.

```

There are two reverse zone files, each of which starts with SOA and NS resource records followed by PTR resource records for each of the names of the servers. The local version of this file also lists the names of the local systems:

```

$ cat named.local
;"0.168.192.in-addr.arpa" reverse zone file
;
$TTL      3D
@         IN      SOA      ns.zach.net. mgs@sobell.com. (
                                2005110501      ; serial
                                8H              ; refresh
                                2H              ; retry
                                4W              ; expire
                                1D)            ; minimum

                                IN      NS      ns.zach.net.
                                IN      NS      ns.speedy.net.
1         IN      PTR      gw.zach.net.
1         IN      PTR      www.zach.net.
1         IN      PTR      ftp.zach.net.
1         IN      PTR      mail.zach.net.
1         IN      PTR      speedy.zach.net.
3         IN      PTR      grape.zach.net.
4         IN      PTR      potato.zach.net.
6         IN      PTR      peach.zach.net.

```

## CHAPTER SUMMARY

DNS, which maps domain names to IP addresses, and vice versa, is implemented as a hierarchical, distributed, and replicated database on the Internet. Although BIND, which implements DNS, has security issues, you can improve its security by running it inside a chroot jail and using transaction signatures (TSIGs) and SELinux.

When a program on the local system needs to look up an IP address that corresponds to a domain name, it calls the resolver. The resolver queries the local DNS cache, if available, and then queries DNS servers on the LAN or Internet. There are two types of queries: iterative and recursive. When a server responds to an iterative query, it returns whatever information it has at hand; it does not query other servers. Recursive queries cause a server to query other servers if necessary to respond with an answer.

There are three types of servers. Master servers, which hold the master copy of zone data, are authoritative for a zone. Slave servers are also authoritative and copy their data from a master server or other slave servers. DNS caches are not authoritative and either answer queries from cache or forward queries to another server.

The DNS database holds resource records for domains. Many types of resource records exist, including A (address), MX (mail exchange), NS (nameserver), PTR (pointer for performing reverse name resolution), and SOA (start of authority, which describes the zone).

---

## EXERCISES

1. What kind of server responds to recursive queries?
2. What kind of DNS record is likely to be returned when a Web browser tries to resolve the domain part of a URI?
3. What are MX resource records for?
4. How would you find the IP address of example.com from the command line?
5. How would you instruct a Linux system to use the local network's DNS cache, located at 192.168.1.254, or the ISP's DNS cache, located on 1.2.3.4, if the LAN nameserver is unavailable?
6. How would you instruct a DNS server to respond only to queries from the 137.44.\* IP range?
7. How might a resolver attempt to find the IP address of the **example** domain?

---

## ADVANCED EXERCISES

8. How would you set up a private domain name hierarchy that does not include any of the official InterNIC-assigned domain names?
9. Which part of DNS is most vulnerable to an attack from a malicious user and why?
10. It is often irritating to have to wait for DNS records to update around the world when you change DNS entries. You could prevent this delay by setting the TTL to a small number. Why is setting the TTL to a small number a bad idea?
11. Outline a method by which DNS could be used to support encryption.

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# iptables: SETTING UP A FIREWALL

## IN THIS CHAPTER

How iptables Works . . . . .	820
Rules, matches, targets, and chains . . . . .	820
Network packet . . . . .	821
Jumps and targets . . . . .	822
JumpStart: Building a Firewall Using system-config-firewall . . .	824
Anatomy of an iptables Command . . . . .	825
Building a Set of Rules . . . . .	826
system-config-firewall: Generates a Set of Rules . . . . .	833
Sharing an Internet Connection Using NAT . . . . .	835

The `iptables` utility builds and manipulates network packet filtering rules in the Linux kernel. You can use `iptables` to create a firewall that protects a system from malicious users and to set up NAT (Network Address Translation, page 1095), which can allow multiple systems to share a single Internet connection. The `iptables` utility is flexible and extensible, allowing you to set up both simple and complex network packet filtering solutions. It provides connection tracking (stateful packet filtering), allowing you to handle packets based on the state of their connection. For example, you can set up rules that reject inbound packets trying to open a new connection and accept inbound packets that are responses to locally initiated connections. Features not included in the base `iptables` package are available as patches via the patch-o-matic program.

Some of the concepts required to fully understand `iptables` are beyond the scope of this book. Although you can use `iptables` at several different levels, this chapter presents only the fundamentals. There are, however, some sections of this chapter that delve into areas that may require additional understanding or explanation. If a concept is not clear, refer to one of the resources in “More Information” on page 822.

# How iptables WORKS

- netfilter and iptables

The functionality frequently referred to as `iptables` is actually composed of two components: `netfilter` and `iptables`. Running in *kernel space* (page 1090), the `netfilter` component is a set of tables that hold rules that the kernel uses to control network packet filtering. Running in *userspace* (page 1113), the `iptables` utility sets up, maintains, and displays the rules stored by `netfilter`.
- Rules, matches, targets, and chains

A *rule* comprises one or more criteria (*matches* or *classifiers*) and a single action (*target*). If, when a rule is applied to a network packet, the packet matches all of the criteria, the action is applied to the packet. Rules are stored in *chains*. Each rule in a chain is applied, in order, to a packet, until a match is found. If there is no match, the chain's *policy*, or default action, is applied to the packet (page 827).
- History

In the kernel, `iptables` replaces the earlier `ipchains` as a method of filtering network packets and provides multiple chains for increased filtration flexibility. The `iptables` utility also provides stateful packet inspection (page 822).
- Example rules

As an example of how rules work, assume that a chain has two rules (Figure 25-1). The first rule tests whether a packet's destination is port 23 (TELNET) and drops the packet if it is. The second rule tests whether a packet was received from the IP address 192.168.1.1 and alters the packet's destination if it was. When a packet is processed by the example chain, the kernel applies the first rule in the chain to see if the packet arrived on port 23. If the answer is yes, the packet is dropped and that is the end of processing for that packet. If the answer is no, the kernel applies the second rule in the chain to see if the packet came from the specified IP address. If yes, the destination in the packet's header is changed and the modified packet is sent on its way. If no, the packet is sent on without being changed.
- Chains are collected in three tables: Filter, NAT, and Mangle. Each of the tables has builtin chains (described next). You can create additional, user-defined chains in Filter, the default table.
- Filter

The default table. This table is mostly used to DROP or ACCEPT packets based on their content; it does not alter packets. Builtin chains are INPUT, FORWARD, and OUTPUT. All user-defined chains go in this table.
- NAT

The Network Address Translation table. Packets that create new connections are routed through this table, which is used exclusively to translate the source or destination field

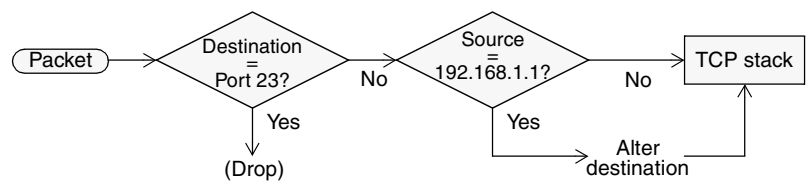


Figure 25-1    Example of how rules work

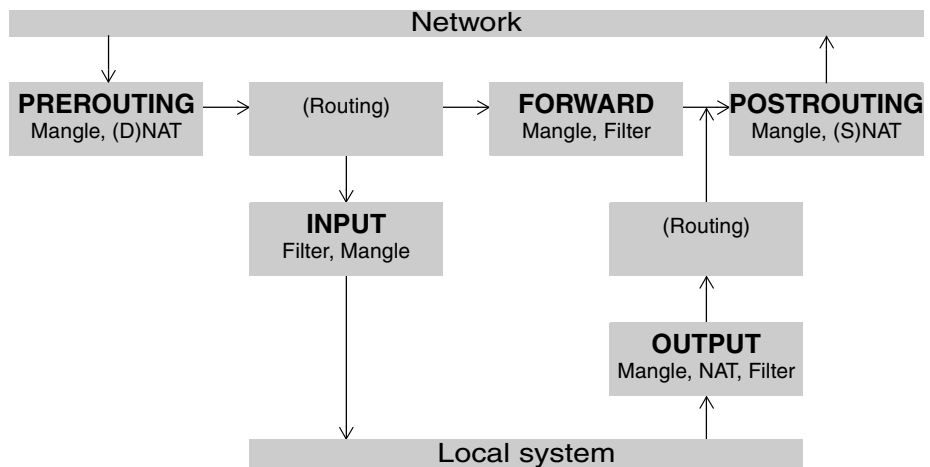


of the packet. Builtin chains are PREROUTING, OUTPUT, and POSTROUTING. Use this table with DNAT, SNAT, and MASQUERADE targets only.

- **DNAT** (destination NAT) alters the destination IP address of the first inbound packet in a connection so it is rerouted to another host. Subsequent packets in the connection are automatically DNATed. Useful for redirecting packets from the Internet that are bound for a firewall or a NATed server (page 838).
- **SNAT** (source NAT) alters the source IP address of the first outbound packet in a connection so that it appears to come from a fixed IP address—for example, a firewall or router. Subsequent packets in the connection are automatically SNATed. Replies to SNATed packets are automatically de-SNATed so they go back to the original sender. SNAT is useful for hiding LAN addresses from systems outside the LAN and using a single IP address to serve multiple local hosts. See also MASQUERADE (next).
- **MASQUERADE** differs from SNAT only in that it checks for an IP address to apply to each outbound packet, making it suitable for use with dynamic IP addresses such as those provided by DHCP (page 451). MASQUERADE is slightly slower than SNAT.

**Mangle** Used exclusively to alter the TOS (type of service), TTL (time to live), and MARK fields in a packet. Builtin chains are PREROUTING and OUTPUT.

**Network packet** When a packet from the network enters the kernel's network protocol stack, it is given some basic sanity tests, including checksum verification. After passing these tests, the packet goes through the PREROUTING chain, where its destination address may be changed (Figure 25-2).



**Figure 25-2** Filtering a packet in the kernel

Next the packet is routed based on its destination address. If it is bound for the local system, it first goes through the INPUT chain, where it can be filtered (accepted, dropped, or sent to another chain) or altered. If the packet is not addressed to the local system (the local system is forwarding the packet), it goes through the FORWARD and POSTROUTING chains, where it can again be filtered or altered.

Packets that are created locally pass through the OUTPUT and POSTROUTING chains, where they can be filtered or altered before being sent to the network.

**State** The connection tracking machine (sometimes called the state machine) provides information on the state of a packet, allowing you to define rules that match criteria based on the state of the connection the packet is part of. For example, when a connection is opened, the first packet is part of a NEW connection, whereas subsequent packets are part of an ESTABLISHED connection. Connection tracking is handled by the **conntrack** module.

The OUTPUT chain handles connection tracking for locally generated packets. The PREROUTING chain handles connection tracking for all other packets. For more information refer to “State” on page 830.

Before the advent of connection tracking, it was sometimes necessary to open many or all nonprivileged ports to make sure that you accepted all RETURN and RELATED traffic. Because connection tracking allows you to identify these kinds of traffic, you can keep many more ports closed to general traffic, thereby increasing system security.

**Jumps and targets** A *jump* or *target* specifies the action the kernel takes if a packet matches all the match criteria for the rule being processed (page 831).

---

## ABOUT iptables

This section contains information about iptables: resources to consult for more information on this utility, prerequisites for running iptables, and notes.

## MORE INFORMATION

- Web** Documentation, HOWTOs, FAQs, patch-o-matic, security information: [www.netfilter.org](http://www.netfilter.org)  
Tutorial: [www.faqs.org/docs/iptables](http://www.faqs.org/docs/iptables)
- HOWTO** *KernelAnalysis-HOWTO*  
*IP Masquerade HOWTO* (contains useful scripts)  
*Netfilter Extensions HOWTO* at [netfilter.org/documentation/HOWTO/netfilter-extensions-HOWTO.html](http://netfilter.org/documentation/HOWTO/netfilter-extensions-HOWTO.html)
- Book** *TCP Illustrated* by W. Richard Stevens, Addison-Wesley, December 1993

## PREREQUISITES

Install the following package:

- **iptables**

Run **chkconfig** to cause **iptables** to start when the system comes up:

```
# /sbin/chkconfig iptables on
```

To ensure maximum protection, the **iptables** init script starts packet filtering by running **iptables** very soon after the system enters runlevels 2–5; in contrast, this script does not stop packet filtering almost until the system leaves runlevels 0, 1, and 6. See page 426 for more information on init scripts.

## NOTES

The **iptables** utility differs from most other Linux utilities in its setup and use. Whereas other Linux utilities such as **Apache**, **vsftpd**, and **sshd** read the data that controls their operation from a configuration file, **iptables** requires you to give a series of **iptables** commands to build a set of packet filtering rules that are kept in the kernel.

There are two ways to set up the same set of rules each time you bring the system up. First, you can put **iptables** commands in a script and run that script each time the system boots. You can call this script from **/etc/rc.d/rc.local**.

Second, you can put the arguments to the **iptables** commands you want to execute in **/etc/sysconfig/iptables**. The **system-config-firewall** utility (page 833) and the **Anaconda** installer (page 57) both use this technique, building sets of rules and storing the corresponding **iptables** command arguments in **/etc/sysconfig/iptables**. The command **service iptables save** stores the **iptables** rules currently in effect to this file. If you use the **/etc/sysconfig/iptables** file in this manner, be aware that **system-config-firewall** and **service iptables save** overwrite this file.

For information on copying packet filtering rules to and from the kernel, refer to “Copying Rules to and from the Kernel” on page 832. You can run **iptables** with the **-L** option or you can run **service iptables status** to display the packet filtering rules the kernel is using.

The **iptables** init script executes the **/etc/sysconfig/iptables-config** file. Refer to the comments in this file for options you can set in it.

**Resetting iptables** If you encounter problems related to the firewall rules, you can return packet processing rules in the kernel to their default state without rebooting by giving the following commands:

```
# iptables --flush && iptables --delete-chain
```

These commands flush all chains and delete any user-defined chains, leaving the system without a firewall. In an emergency you can give the following command to unload all **iptables** modules from the kernel and set a policy of DROP for all tables:

```
# /sbin/service iptables panic
```

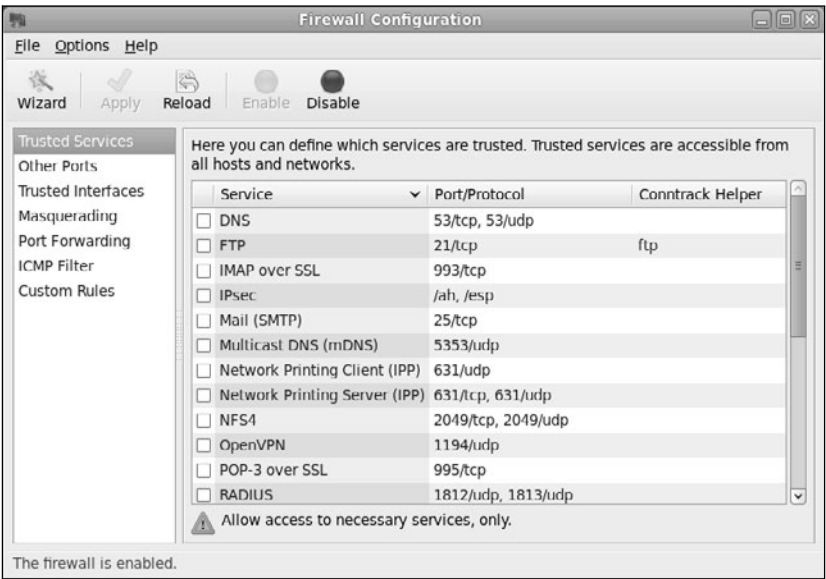


Figure 25-3 Firewall Configuration window

# JUMPSTART: BUILDING A FIREWALL USING system-config-firewall

To run this utility, enter `system-config-firewall` (*FEDORA*) or `system-config-securitylevel` (*RHEL*) on a command line or select **System: Administration**⇒**Firewall** (*FEDORA*) or **System: Administration**⇒**Security Level and Firewall** (*RHEL*). The `system-config-firewall` and `system-config-securitylevel` utilities build a extremely simple firewalls but struggle with complex setups. The `system-config-securitylevel` utility displays a simpler window that contains a subset of the features of `system-config-firewall`. This section describes the `system-config-firewall` utility, which displays the Firewall Configuration window (Figure 25-3).

To enable the firewall, click **Enable** on the toolbar. The firewall automatically allows packets that originate locally through to the outside (generally the Internet) and allows responses to those packets back in.

Opening Trusted services

Click the check boxes next to the services that the local system provides. These boxes set up a firewall that allows the local system to function as one or more types of servers, including FTP, Mail (SMTP), Samba, Secure WWW (HTTPS), SSH, and WWW (HTTP).

Opening Other ports Enter other ports you want to open by clicking **Other ports** on the left side of the window and then clicking **Add** to open the Port and Protocol window. This window allows you to select from a list or, if you put a check mark in the box labeled **User Defined**, specify a port to open and the protocol that that port uses (TCP or UDP).

Click **Apply** and **Yes**, and system-config-firewall sets up the firewall. Click **Enable** if necessary. For more information refer to “system-config-firewall: Generates a Set of Rules” on page 833.

## ANATOMY OF AN iptables COMMAND

Command line This section lists the components of an iptables command line that follow the name of the utility, iptables. Except as noted, the iptables utility is not sensitive to the position of arguments on the command line. The examples in this chapter reflect a generally accepted syntax that allows commands to be easily read, understood, and maintained. Not all commands have all components.

Many tokens on an iptables command line have two forms: a short form, consisting of a single letter preceded by a single hyphen, and a long form, consisting of a word preceded by two hyphens. Most scripts use the short forms for brevity; lines using the long forms can get unwieldy. The following iptables command lines are equivalent and are used as examples in this section:

```
# iptables --append FORWARD --in-interface eth1 --out-interface eth0 --jump ACCEPT
# iptables -A FORWARD -i eth1 -o eth0 -j ACCEPT
```

- Table Specifies the name of the table the command operates on: Filter, NAT, or Mangle. You can specify a table name in any iptables command. When you do not specify a table name, the command operates on the Filter table. Most of the examples in this chapter do not specify table names and, therefore, work on the Filter table. Specify a table as **-t *tablename*** or **--table *tablename***.
  - Command Tells iptables what to do with the rest of the command line—for example, add or delete a rule, display rules, or add a chain. The example commands, **-A** and **--append**, append the rule specified by the command line to the specified table and chain. See page 827 for a list of commands.
  - Chain Specifies the name of the chain that this rule belongs to or that this command works on. The chain is INPUT, OUTPUT, FORWARD, PREROUTING, POSTROUTING, or the name of a user-defined chain. Specify a chain by putting the name of the chain on the command line without any preceding hyphens. The examples at the beginning of this section work with the FORWARD chain.
- There are two kinds of match criteria: *packet match* criteria, which match a network packet, and *rule match* criteria, which match an existing rule.

**Rule specifications** Packet match criteria identify network packets and implement rules that take action on packets that match the criteria. The combination of packet match criteria and an action is called a *rule specification*. Rule specifications form the basis for packet filtering. The first example at the beginning of this section uses the **--in-interface eth1 --out-interface eth0** rule match criteria. The second example uses the short form of the same criteria: **-i eth1 -o eth0**. Both of these rules forward packets that come in on device **eth1** and go out on device **eth0**.

**Rule match criteria** Rule match criteria identify existing rules. An **iptables** command can modify, remove, or position a new rule adjacent to a rule specified by a rule match criterion. There are two ways to identify an existing rule: You can use the same rule specification that was used to create the rule or you can use the rule's ordinal number, called a *rule number*. Rule numbers begin with 1, signifying the first rule in a chain, and can be displayed with **iptables -L** (or **--line-numbers**). The first command below deletes the rule listed at the beginning of this section; the second replaces rule number 3 in the INPUT chain with a rule that rejects all packets from IP address 192.168.0.10:

```
# iptables --delete -A FORWARD -i eth1 -o eth0 -j ACCEPT
# iptables -R INPUT 3 --source 192.168.0.10 --jump REJECT
```

A *jump* or *target* specifies what action the kernel takes on packets that match all match criteria for a rule. Specify a jump or target as **-j target** or **--jump target**. The examples at the beginning of this section specify the **ACCEPT** target using the following commands: **--jump ACCEPT** and **-j ACCEPT**.

**Jumps** A jump transfers control to a different chain within the same table. The following command adds (**--append**) a rule to the INPUT chain that transfers packets that use the TCP protocol (**--protocol tcp**) to a user-defined chain named **tcp\_rules** (**--jump tcp\_rules**):

```
# iptables --append INPUT --protocol tcp --jump tcp_rules
```

When the packet finishes traversing the **tcp\_rules** chain, assuming it has not been dropped or rejected, it continues traversing the INPUT chain from the rule following the one it jumped from.

**Targets** A target specifies an action the kernel takes on the packet; the simplest actions are **ACCEPT**, **DROP**, and **REJECT**. The following command adds a rule to the FORWARD chain that rejects packets coming from the FTP port (**/etc/services**, the file **iptables** consults to determine which port to use, shows that FTP uses port 21):

```
# iptables --append FORWARD --sport ftp --jump REJECT
```

Some targets, such as **LOG**, are *nonterminating*: Control passes to the next rule after the target is executed. See page 831 for information on how to use targets.

---

## BUILDING A SET OF RULES

To specify a table, it is common practice to put the table declaration on the command line immediately following **iptables**. For example, the following command flushes (deletes all the rules from) the NAT table:

```
# iptables -t NAT -F
```

## COMMANDS

Following is a list of iptables commands:

- append** **-A** Adds rule(s) specified by *rule-specifications* to the end of *chain*. When a packet matches one of the *rule-specifications*, *target* processes it.

*iptables -A chain rule-specifications --jump target*

- delete** **-D** Removes one or more rules from *chain*, as specified by the *rule-numbers* or *rule-specifications*.

*iptables -D chain rule-numbers | rule-specifications*

- insert** **-I** Adds rule(s) specified by *rule-specifications* and *target* to the location in *chain* specified by *rule-number*. If you do not specify *rule-number*, it defaults to 1, the head of the chain.

*iptables -I chain rule-number rule-specifications --jump target*

- replace** **-R** Replaces rule number *rule-number* in *chain* with *rule-specification* and *target*. The command fails if *rule-number* or *rule-specification* resolves to more than one address.

*iptables -R chain rule-number rule-specification --jump target*

- list** **-L** Displays the rules in *chain*. Omit *chain* to display rules for all chains. Use **--line-numbers** to display rule numbers or select other display criteria from the list on page 828.

*iptables -L [chain] display-criteria*

- flush** **-F** Deletes all rules from *chain*. Omit *chain* to delete all rules from all chains.

*iptables -F [chain]*

- zero** **-Z** Change to zero the value of all packet and byte counters in *chain* or in all chains when you do not specify *chain*. Use with **-L** to display the counters before clearing them.

*iptables -Z [-L] [chain]*

- delete-chain** **-X** Removes the user-defined chain named *chain*. If you do not specify *chain*, removes all user-defined chains. You cannot delete a chain that a target points to.

*iptables -X chain*

- policy** **-P** Sets the default target or policy *builtin-target* for the builtin chain *builtin-chain*. This policy is applied to packets that do not match any rule in the chain. If a chain does not have a policy, unmatched packets are ACCEPTed.

*iptables -P builtin-chain builtin-target*

- rename-chain** **-E** Changes the name of the chain *old* to *new*.

*iptables -E old new*

**--help -h** Displays a summary of iptables command syntax.

*iptables -h*

Follow a match extension protocol with **-h** to display options you can use with that protocol. For more information refer to “Help with extensions” on page 829.

## PACKET MATCH CRITERIA

The following criteria match network packets. When you precede a criterion with an exclamation point (!), the rule matches packets that do not match the criterion.

**--protocol [!] *proto***

**-p** Matches if the packet uses the *proto* protocol. This criterion is a match extension (page 829).

**--source [!] *address[/mask]***

**-s** or **--src** Matches if the packet came from *address*. The *address* can be a name or IP address. See page 443 for formats of the optional *mask* (only with an IP address).

**--destination [!] *address[/mask]***

**-d** or **--dst** Matches if the packet is going to *address*. The *address* can be a name or IP address. See page 443 for formats of the optional *mask* (only with an IP address).

**--in-interface [!] *iface*[+]**

**-i** For the INPUT, FORWARD, and PREROUTING chains, matches if *iface* is the name of the interface the packet was received from. Append a plus sign (+) to *iface* to match any interface whose name begins with *iface*. When you do not specify **in-interface**, the rule matches packets coming from any interface.

**--out-interface [!] *iface*[+]**

**-o** For the FORWARD, OUTPUT, and POSTROUTING chains, matches if *iface* is the interface the packet will be sent to. Append a plus sign (+) to *iface* to match any interface whose name begins with *iface*. When you do not specify **out-interface**, the rule matches packets going to any interface.

**[!] --fragment -f** Matches the second and subsequent fragments of fragmented packets. Because these packets do not contain source or destination information, they do not match any other rules.

## DISPLAY CRITERIA

The following criteria display information. All packets match these criteria.

**--verbose -v** Displays additional output.

**--numeric -n** Displays IP addresses and port numbers as numbers, not names.

**--exact -x** Use with **-L** to display exact packet and byte counts instead of rounded values.

**--line-numbers** Display line numbers when listing rules. The line numbers are also the rule numbers that you can use in rule match criteria (page 826).



## MATCH EXTENSIONS

Rule specification (packet match criteria) extensions, called *match extensions*, add matches based on protocols and state to the matches described previously. Each of the protocol extensions is kept in a module that must be loaded before that match extension can be used. The command that loads the module must appear in the same rule specification as, and to the left of, the command that uses the module. There are two types of match extensions: implicit and explicit.

### IMPLICIT MATCH EXTENSIONS

Help with  
extensions

Implicit extensions are loaded (somewhat) automatically when you use a **--protocol** command (following). Each protocol has its own extensions. Follow the protocol with **-h** to display extensions you can use with that protocol. For example, the following command displays TCP extensions *at the end* of the Help output:

```
# iptables -p tcp -h
...
tcp match options:
[!] --tcp-flags mask comp      match when TCP flags & mask == comp
                                (Flags: SYN ACK FIN RST URG PSH ALL NONE)
[!] --syn                      match when only SYN flag set
                                (equivalent to --tcp-flags SYN,RST,ACK,FIN
SYN)
[!] --source-port port[:port]
    --sport ...                match source port(s)
[!] --destination-port port[:port]
    --dport ...                match destination port(s)
[!] --tcp-option number        match if TCP option set
```

This section does not describe all extensions. Use **-h**, as described in the preceding example, to display a complete list.

**--protocol [!] *proto***

**-p** Loads the *proto* module and matches if the packet uses the *proto* protocol. The *proto* can be a name or number from **/etc/protocols**, including **tcp**, **udp**, and **icmp** (page 1087). Specifying **all** or **0** (zero) matches any of all protocols and is the same as not including this match in a rule.

The following criteria load the TCP module and match TCP protocol packets coming from port 22 (ssh packets):

```
--protocol tcp --source-port 22
```

The following command expands the preceding match to cause the kernel to drop all incoming ssh packets. This command uses **ssh**, which **iptables** looks up in **/etc/services**, in place of **22**:

```
# iptables --protocol tcp --source-port ssh --jump DROP
```

## TCP

The extensions in this section are loaded when you specify **--protocol tcp**.

**--destination-port** [!] [*port*][:*port*]]

**--dport** Matches a destination port number or service name (see */etc/services*). You can also specify a range of port numbers. Specifically, *:port* specifies ports 0 through *port*, and *port:* specifies ports *port* through 65535.

**--source-port** [!] [*port*][:*port*]]

**--sport** Matches a source port number or service name (see */etc/services*). You can also specify a range of port numbers. Specifically, *:port* specifies ports 0 through *port*, and *port:* specifies ports *port* through 65535.

[!] **--syn** Matches packets with the SYN bit set and the ACK and FIN bits cleared. This match extension is shorthand for **--tcp-flags SYN,RST,ACK SYN**.

**--tcp-flags** [!] *mask comp*

Defines TCP flag settings that constitute a match. Valid flags are SYN, ACK, FIN, RST, URG, PSH, ALL, and NONE. The *mask* is a comma-separated list of flags to be examined; *comp* is a comma-separated subset of *mask* that specifies the flags that must be set for a match to occur. Flags not specified in *mask* must be unset.

**--tcp-option** [!] *n* Matches a TCP option with a decimal value of *n*.

## UDP

When you specify **--protocol udp**, you can specify a source and/or destination port in the same manner as described earlier under “TCP.”

## ICMP

The extension in this section is loaded when you specify **--protocol icmp**. ICMP (page 1087) packets carry messages only.

**--icmp-type** [!] *name*

Matches when the packet is an ICMP packet of type *name*. The *name* can be a numeric ICMP type or one of the names returned by

```
# iptables -p icmp -h
```

## EXPLICIT MATCH EXTENSIONS

Explicit match extensions differ from implicit match extensions in that you must use a **-m** or **--match** option to specify a module before you can use the extension. Many explicit match extension modules are available; this section covers **state**, one of the most important.

## STATE

The **state** extension matches criteria based on the state of the connection the packet is part of (page 822).

**--state** *state* Matches a packet whose state is defined by *state*, a comma-separated list of states from the following list:

- **ESTABLISHED**—Any packet, within a specific connection, following the exchange of packets in both directions for that connection.
- **INVALID**—A stateless or unidentifiable packet.
- **NEW**—The first packet within a specific connection, typically a SYN packet.
- **RELATED**—Any packets exchanged in a connection spawned from an ESTABLISHED connection. For example, an FTP data connection might be related to the FTP control connection. (You need the `ip_conntrack_ftp` module for FTP connection tracking.)

The following command loads the `state` extension and establishes a rule that matches and drops both invalid packets and packets from new connections:

```
# iptables --match state --state INVALID,NEW --jump DROP
```

## TARGETS

All targets are built in; there are no user-defined targets. This section lists some of the targets available with `iptables`. Applicable target options are listed following each target.

**ACCEPT** Continues processing the packet.

**DNAT** (**D**estination **N**etwork **A**ddress **T**ranslation) Rewrites the destination address of the packet (page 821).

`--to-destination` *ip[-ip][:port-port]*

Same as SNAT with `to-source`, except that it changes the destination addresses of packets to the specified address(es) and port(s) and is valid only in the PREROUTING or OUTPUT chains of the NAT table and any user-defined chains called from those chains. The following command adds to the PREROUTING chain of the NAT table a rule that changes the destination in the headers of TCP packets with a destination of 66.187.232.50 to 192.168.0.10:

```
# iptables -t NAT -A PREROUTING -p tcp -d 66.187.232.50 -j DNAT --to-destination 192.168.0.10
```

**DROP** Ends the packet's life without notice.

**LOG** Turns on logging for the packet being processed. The kernel uses `rsyslogd` (page 582) to process output generated by this target. LOG is a nonterminating target; processing continues with the next rule. Use two rules to LOG packets that you REJECT, one each with the targets LOG and REJECT, with the same matching criteria.

`--log-level` *n* Specifies logging level *n* as per `rsyslog.conf` (page 583).

`--log-prefix` *string*

Prefixes log entries with *string*, which can be up to 14 characters long.

`--log-tcp-options` Logs options from the TCP packet header.

`--log-ip-options` Logs options from the IP packet header.

**MASQUERADE** Similar to SNAT with `--to-source`, except that the IP information is grabbed from the interface on the specified port. For use on systems with dynamically assigned IP addresses, such as those that use DHCP, including most dial-up lines. Valid only in rules in the POSTROUTING chain of the NAT table.

`--to-ports port[-port]`

Specifies the port for the interface you want to masquerade. Forgets connections when the interface goes down, as is appropriate for dial-up lines. You must specify the TCP or UDP protocol (`--protocol tcp` or `udp`) with this target.

**REJECT** Similar to DROP, except that it notifies the sending system that the packet was blocked.

`--reject-with type` Returns the error *type* to the originating system. The *type* can be any of the following, all of which return the appropriate ICMP (page 1087) error: **icmp-net-unreachable**, **icmp-host-unreachable**, **icmp-port-unreachable**, **icmp-proto-unreachable**, **icmp-net-prohibited**, or **icmp-host-prohibited**. You can specify *type* as **echo-reply** from rules that require an ICMP ping (page 379) packet to return a ping reply. You can specify **tcp-reset** from rules in or called from the INPUT chain to return a TCP RST packet. This parameter is valid in the INPUT, FORWARD, and OUTPUT chains and user-defined chains called from these chains.

**RETURN** Stops traversing this chain and returns the packet to the calling chain.

**SNAT Source Network Address Translation**—Rewrites the source address of the packet. Appropriate for hosts on a LAN that share an Internet connection.

`--to-source ip[-ip][:port-port]`

Alters the source IP address of an outbound packet, and the source IP addresses of all future packets in this connection, to *ip*. Skips additional rules, if any. Returning packets are automatically de-SNATed so they return to the originating host. Valid only in the POSTROUTING chain of the NAT table.

When you specify a range of IP addresses (*ip-ip*) or use multiple **to-source** targets, iptables assigns the addresses in a round-robin fashion, cycling through the addresses, one for each new connection.

When the rule specifies the TCP or UDP protocol (`-p tcp` or `-p udp`), you can specify a range of ports. When you do not specify a range of ports, the rule matches all ports. Every connection on a NATed subnet must have a unique IP address and port combination. If two computers on a NATed subnet try to use the same port, the kernel maps one of the ports to another (unused) one. Ports less than 512 are mapped to other ports less than 512, ports from 512 to 1024 are mapped to other ports from 512 to 1024, and ports above 1024 are mapped to other ports above 1024.

## COPYING RULES TO AND FROM THE KERNEL

The `iptables-save` utility copies packet filtering rules from the kernel to standard output so you can save them in a file. The `iptables-restore` utility copies rules from standard input, as written by `iptables-save`, to the kernel. Sample output from `iptables-save` follows:

```
# iptables-save
# Generated by iptables-save v1.4.5 on Tue Oct 13 12:31:13 2009
*filter
:INPUT ACCEPT [0:0]
:FORWARD ACCEPT [0:0]
:OUTPUT ACCEPT [184321:10675620]
-A INPUT -m state --state RELATED,ESTABLISHED -j ACCEPT
-A INPUT -p icmp -j ACCEPT
-A INPUT -i lo -j ACCEPT
-A INPUT -p tcp -m state --state NEW -m tcp --dport 22 -j ACCEPT
-A INPUT -j REJECT --reject-with icmp-host-prohibited
-A FORWARD -j REJECT --reject-with icmp-host-prohibited
COMMIT
```

Most of the lines that `iptables-save` writes are `iptables` command lines without the `iptables` at the beginning. Lines that begin with a pound sign (#) are comments. Lines that begin with an asterisk are names of tables that the following commands work on; all of the commands in the preceding example work on the Filter table. The COMMIT line must appear at the end of all commands for a table; it executes the preceding commands. Lines that begin with colons specify chains in the following format:

```
:chain policy [packets:bytes]
```

where *chain* is the name of the chain, *policy* is the policy (default target) for the chain, and *packets* and *bytes* are the packet and byte counters, respectively. The square brackets must appear in the line; they do not indicate optional parameters. Refer to the next section and visit [www.faqs.org/docs/iptables/iptables-save.html](http://www.faqs.org/docs/iptables/iptables-save.html) for more information.

---

## system-config-firewall: GENERATES A SET OF RULES

This section describes the set of rules generated by `system-config-firewall` (page 824) when you ask it to create a firewall with only `ssh` running as a trusted service and no other ports specified. The `system-config-firewall` utility writes the rules in the format used by `iptables-save` (see the preceding section) to the `/etc/sysconfig/iptables` file, which is read by the `iptables` init script so that the firewall is implemented each time the system boots.

In the following listing, `*filter` indicates that the commands appearing after it work on the Filter table. The first line that begins with a colon specifies that the policy for the INPUT chain in the Filter table is ACCEPT. FORWARD and OUTPUT chains are specified similarly. Because the counters for all the chains are zero, the counters will be reset to zero each time the system boots and initializes `iptables` from this file.

The `system-config-firewall` utility works mostly with the INPUT chain.

```
# cat /etc/sysconfig/iptables
# Firewall configuration written by system-config-firewall
# Manual customization of this file is not recommended.
*filter
:INPUT ACCEPT [0:0]
:FORWARD ACCEPT [0:0]
:OUTPUT ACCEPT [0:0]
-A INPUT -m state --state ESTABLISHED,RELATED -j ACCEPT
-A INPUT -p icmp -j ACCEPT
-A INPUT -i lo -j ACCEPT
-A INPUT -m state --state NEW -m tcp -p tcp --dport 22 -j ACCEPT
-A INPUT -j REJECT --reject-with icmp-host-prohibited
-A FORWARD -j REJECT --reject-with icmp-host-prohibited
COMMIT
```

Most of the lines append rules to the INPUT chain. Following is a description of what these lines do.

This line uses **-m** to specify the **state** module and accepts ESTABLISHED and RELATED packets:

```
-A INPUT -m state --state ESTABLISHED,RELATED -j ACCEPT
```

This line accepts all ICMP packets:

```
-A INPUT -p icmp -j ACCEPT
```

This line accepts packets from the local interface:

```
-A INPUT -i lo -j ACCEPT
```

This line allows TCP packets through on port 22 (ssh):

```
-A INPUT -m state --state NEW -m tcp -p tcp --dport 22 -j ACCEPT
```

These lines reject all packets that have not been accepted and return ICMP error **icmp-host-prohibited** to the system that sent the packet:

```
-A INPUT -j REJECT --reject-with icmp-host-prohibited
-A FORWARD -j REJECT --reject-with icmp-host-prohibited
```

COMMIT executes the preceding commands. With the preceding rules loaded, you can use iptables to list the rules and see the defaults that iptables puts in place:

```
# iptables -L
Chain INPUT (policy ACCEPT)
target    prot opt source                destination           state
ACCEPT    all  --  anywhere              anywhere              state RELATED,ESTABLISHED
ACCEPT    icmp --  anywhere              anywhere
ACCEPT    all  --  anywhere              anywhere
ACCEPT    tcp  --  anywhere              anywhere              state NEW tcp dpt:ssh
REJECT    all  --  anywhere              anywhere              reject-with icmp-host-prohibited
```

Chain FORWARD (policy ACCEPT)

target	prot	opt	source	destination	
REJECT	all	--	anywhere	anywhere	reject-with icmp-host-prohibited

Chain OUTPUT (policy ACCEPT)

target	prot	opt	source	destination
--------	------	-----	--------	-------------

## SHARING AN INTERNET CONNECTION USING NAT

On the Internet there are many scripts available that set up Internet connection sharing using `iptables`. Each of these scripts boils down to the same few basic `iptables` commands, albeit with minor differences. This section discusses those few statements to explain how a connection can be shared. You can use the statements presented in this section or refer to the *Linux IP Masquerade HOWTO* for complete scripts. The [tldp.org/HOWTO/IP-Masquerade-HOWTO/firewall-examples.html](http://tldp.org/HOWTO/IP-Masquerade-HOWTO/firewall-examples.html) Web page holds the simplest of these scripts.

There are two ways you can share a single connection to the Internet (one IP address). Both involve setting up NAT to alter addresses in packets and then forward them. The first allows clients (browsers, mail readers, and so on) on several systems on a LAN to share a single IP address to connect to servers on the Internet. The second allows servers (mail, Web, FTP, and so on) on different systems on a LAN to provide their services over a single connection to the Internet. You can use `iptables` to set up one or both of these configurations. In both cases, you need to set up a system that is a router: It must have two network connections—one connected to the Internet and the other to the LAN.

For optimal security, use a dedicated system as a router. Because data transmission over a connection to the Internet—even over a broadband connection—is relatively slow, using a slower, older system as a router does not generally slow down a LAN. This setup also gives you some defense against intrusion from the Internet. A workstation on the LAN can also function as a router, but this setup means that you maintain data on a system that is directly connected to the Internet. The following sections discuss the security of each setup.

The examples in this section assume that the device named `eth0` connects to the Internet on 10.255.255.255 and that `eth1` connects to the LAN on 192.168.0.1. Substitute the devices and IP addresses that your systems use. If you use a modem to connect to the Internet, you need to substitute `ppp0` (or another device) for `eth0` in the examples.

For the examples in this section to work, you must turn on IP forwarding. First give the following command and make sure everything is working:

```
# /sbin/sysctl -w net.ipv4.ip_forward=1
net.ipv4.ip_forward = 1
```

Once you know that `iptables` is working correctly, change the `0` to a `1` in the following line in `/etc/sysctl.conf` to make the kernel always perform IP forwarding:

```
net.ipv4.ip_forward = 0
```

After making this change, give the command `/sbin/sysctl -p` to apply the change and to make sure that there are no typographical errors in the configuration file.

## CONNECTING SEVERAL CLIENTS TO A SINGLE INTERNET CONNECTION

Configuring the kernel of the router system to allow clients on multiple local systems on the LAN to connect to the Internet requires you to set up *IP masquerading*, or *SNAT* (source NAT). IP masquerading translates the source and destination addresses in the headers of network packets that originate on local systems and the packets that remote servers send in response to those packets. These packets are part of connections that originate on a local system. The example in this section does nothing to packets that are part of connections that originate on the remote systems (on the Internet): These packets cannot get past the router system, which provides some degree of security.

The point of rewriting the packet headers is to allow systems with different local IP addresses to share a single IP address on the Internet. The router system translates the source or origin address of packets from local systems to that of the Internet connection, so that all packets passing from the router to the Internet appear to come from a single system—`10.255.255.255` in the example. All packets sent in response by remote systems on the Internet to the router system have the address of the Internet connection—`10.255.255.255` in the example—as their destination address. The router system remembers each connection and alters the destination address of each response packet to become that of the local, originating system.

The router system is established by four `iptables` commands, one of which sets up a log of masqueraded connections. The first command puts the first rule in the `FORWARD` chain of the Filter (default) table (`-A FORWARD`):

```
# iptables -A FORWARD -i eth0 -o eth1 -m state --state ESTABLISHED,RELATED -j ACCEPT
```

To match this rule, a packet must be

1. Received on `eth0` (coming in from the Internet): `-i eth0`.
2. Going to be sent out on `eth1` (going out to the LAN): `-o eth1`.
3. Part of an established connection or a connection that is related to an established connection: `--state ESTABLISHED,RELATED`.

The kernel accepts (`-j ACCEPT`) packets that meet these three criteria. Accepted packets pass to the next appropriate chain or table. Packets from the Internet that attempt to create a new connection are not matched and therefore not



accepted by this rule. Packets that are not accepted pass to the next rule in the FORWARD chain.

The second command puts the second rule in the FORWARD chain of the Filter table:

```
# iptables -A FORWARD -i eth1 -o eth0 -j ACCEPT
```

To match this rule, a packet must be

1. Received on **eth1** (coming in from the LAN): **-i eth1**.
2. Going to be sent out on **eth0** (going out to the Internet): **-o eth0**.

The kernel accepts packets that meet these two criteria, which means that all packets that originate locally and are going to the Internet are accepted. Accepted packets pass to the next appropriate chain/table. Packets that are not accepted pass to the next rule in the FORWARD chain.

The third command puts the third rule in the FORWARD chain of the Filter table:

```
# iptables -A FORWARD -j LOG
```

Because this rule has no match criteria, it acts on all packets it processes. This rule's action is to log packets—that is, it logs packets from the Internet that attempt to create a new connection.

Packets that get to the end of the FORWARD chain of the Filter table are done with the rules set up by **iptables** and are handled by the local TCP stack. Packets from the Internet that attempt to create a new connection on the router system are accepted or returned, depending on whether the service they are trying to connect to is available on the router system.

The fourth command puts the first rule in the POSTROUTING chain of the NAT table. Only packets that are establishing a new connection are passed to the NAT table. Once a connection has been set up for SNAT or MASQUERADE, the headers on all subsequent ESTABLISHED and RELATED packets are altered the same way as the first packet. Packets that are sent in response to these packets automatically have their headers adjusted so that they return to the originating local system.

```
# iptables -t NAT -A POSTROUTING -o eth0 -j MASQUERADE
```

To match this rule, a packet must be

1. Establishing a new connection (otherwise it would not have come to the NAT table).
2. Going to be sent out on **eth0** (going out to the Internet): **-o eth0**.

The kernel MASQUERADES all packets that meet these criteria. In other words, all locally originating packets that are establishing new connections have their source address changed to the address that is associated with **eth0** (10.255.255.255 in the example).

Following are the four commands together:

```
# iptables -A FORWARD -i eth0 -o eth1 -m state --state ESTABLISHED,RELATED -j ACCEPT
# iptables -A FORWARD -i eth1 -o eth0 -j ACCEPT
# iptables -A FORWARD -j LOG
# iptables -t NAT -A POSTROUTING -o eth0 -j MASQUERADE
```

You can put these commands in `/etc/rc.local` or in a script called by this file on the router system to have them executed each time the system boots. Alternatively, you can put them in `/etc/sysconfig/iptables`, leaving off the `iptables` command at the beginning of each line and adding a final line with the word **COMMIT** on it. When you put the commands in the `iptables` file, they are executed by the `iptables` init script each time it is called. For more information refer to “Copying Rules to and from the Kernel” on page 832.

To limit the local systems that can connect to the Internet, you can add a `-s` (source) match criterion to the last command:

```
# iptables -t NAT -A POSTROUTING -o eth0 -s 192.168.0.0-192.168.0.32 -j MASQUERADE
```

In the preceding command, `-s 192.168.0.0-192.168.0.32` causes only packets from an IP address in the specified range to be MASQUERADED.

## CONNECTING SEVERAL SERVERS TO A SINGLE INTERNET CONNECTION

DNAT (destination NAT) can set up rules to allow clients from the Internet to send packets to servers on the LAN. This example sets up an SMTP mail server on 192.168.1.33 and an HTTP (Web) server on 192.168.1.34. Both protocols use TCP. SMTP uses port 25 and HTTP uses port 80, so the rules match TCP packets with destination ports of 25 and 80. The example assumes the mail server does not make outgoing connections and uses another server on the LAN for DNS and mail relaying. Both commands put rules in the PREROUTING chain of the NAT table (`-A PREROUTING -t NAT`):

```
# iptables -A PREROUTING -t NAT -p tcp --dport 25 --to-source 192.168.0.33:25 -j DNAT
# iptables -A PREROUTING -t NAT -p tcp --dport 80 --to-source 192.168.0.34:80 -j DNAT
```

To match these rules, the packet must use the TCP protocol (`-p tcp`) and have a destination port of 25 (first rule, `--dport 25`) or 80 (second rule, `--dport 80`).

The `--to-source` is a target specific to the PREROUTING and OUTPUT chains of the NAT table; it alters the destination address and port of matched packets as specified. As with MASQUERADE and SNAT, subsequent packets in the same and related connections are altered appropriately.

The fact that the servers cannot originate connections means that neither server can be exploited to participate in a *DDoS attack* (page 1078) on systems on the Internet and cannot send private data from the local system back to a malicious user’s system.

## CHAPTER SUMMARY

The `iptables` utility creates firewalls intended to prevent unauthorized access to a system or network. An `iptables` command sets up or maintains in the kernel rules that control the flow of network packets; rules are stored in chains. Each rule has a criteria part and an action part, called a target. When the criteria part matches a network packet, the kernel applies the action from the rule to the packet.

Chains are collected in three tables: Filter, NAT, and Mangle. Filter, the default table, DROPS or ACCEPTs packets based on their content. NAT, the Network Address Translation table, translates the source or destination field of packets. Mangle is used exclusively to alter TOS (type of service), TTL (time to live), and MARK fields in a packet. The connection tracking machine, which is handled by the `conntrack` module, defines rules that match criteria based on the state of the connection a packet is part of.

In an emergency you can give the following command to unload all `iptables` modules from the kernel and set a policy of DROP for all tables:

```
# /sbin/service iptables panic
```

## EXERCISES

1. How would you remove all `iptables` rules and chains?
2. How would you list all current `iptables` rules?
3. How is configuring `iptables` different from configuring most Linux services?
4. Define an `iptables` rule that will reject incoming connections on the TELNET port.
5. What does NAT stand for? What does the NAT table do?

## ADVANCED EXERCISES

6. What does the `conntrack` module do?
7. What do rule match criteria do? What are they used for?
8. What do packet match criteria do? What are they used for?
9. Which utilities copy packet filtering rules to and from the kernel? How do they work?
10. Define a rule that will silently block incoming SMTP connections from `spmr.com`.

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# APACHE (httpd): SETTING UP A WEB SERVER

## IN THIS CHAPTER

JumpStart I: Getting Apache Up and Running . . . . .	844
JumpStart II: Setting Up Apache Using system-config-httpd . . . .	846
Filesystem Layout . . . . .	848
Directives I: Directives You May Want to Modify as You Get Started . . . . .	850
Contexts and Containers . . . . .	854
The Fedora/RHEL httpd.conf File . . . . .	870
Redirects . . . . .	873
Multiviews . . . . .	874
Virtual Hosts . . . . .	874
Troubleshooting . . . . .	875

The World Wide Web (WWW or Web for short), is a collection of servers that hold material, called *content*, that Web browsers (or just browsers) can display. Each of the servers on the Web is connected to the Internet, a network of networks (an *internet-work*). Much of the content on the Web is coded in HTML (Hypertext Markup Language, page 1086). *Hypertext*, the code behind the links that you click on a Web page, allows browsers to display and react to links that point to other Web pages on the Internet.

Apache is the most popular Web server on the Internet today. It is both robust and extensible. The ease with which you can install, configure, and run it in the Linux environment makes it an obvious choice for publishing content on the World Wide Web. The Apache server and related projects are developed and maintained by the Apache Software Foundation (ASF), a not-for-profit corporation formed in June 1999. The ASF grew out of the Apache Group, which was established in 1995 to develop the Apache server.

This chapter starts by providing introductory information about Apache. This information is followed by the first JumpStart section, which describes the minimum steps needed to get Apache up and running. The second JumpStart section covers the use of the Fedora/RHEL `system-config-httpd` configuration script. Following these sections is “Filesystem Layout,” which tells you where the various Apache files are located.

Configuration directives, a key part of Apache, are discussed starting on page 850. This section includes coverage of contexts and containers, two features/concepts that are critical to understanding Apache. The next section explains the main Apache configuration file, `/etc/httpd/conf/httpd.conf`, as modified by Fedora/RHEL. The final pages of the chapter cover virtual hosts, troubleshooting, and modules you can use with Apache, including CGI and SSL.

---

## INTRODUCTION

Apache is a server that responds to requests from Web browsers, or *clients*, such as Firefox, Netscape, lynx, and Internet Explorer. When you enter the address of a Web page (a *URI*, page 1113) in a Web browser’s location bar, the browser sends a request over the Internet to the (Apache) server at that address. In response, the server sends the requested content back to the browser. The browser then displays or plays the content, which might be a song, picture, video clip, or other information.

**Content** Aside from add-on modules that can interact with the content, Apache remains oblivious to the content itself. Server administration and content creation are two different aspects of bringing up a Web site. This chapter concentrates on setting up and running an Apache server; it spends little time discussing content creation.

**Modules** Apache, like the Linux kernel, uses external modules to increase load-time flexibility and allow parts of its code to be recompiled without recompiling the whole program. Rather than being part of the Apache binary, modules are stored as separate files that can be loaded when Apache is started.

Apache uses external modules, called dynamic shared objects (DSOs), for basic and advanced functions; there is not much to Apache without these modules. Apache also uses modules to extend its functionality: Modules can process scripts written in Perl, PHP, Python, and other languages; use several different methods to authenticate users; facilitate publishing content; and process nontextual content, such as audio. The list of modules written by the Apache Group and third-party developers is always growing. For more information refer to “Modules” on page 876.

---

## ABOUT APACHE

This section describes the packages you need to install and provides references for the programs covered in this chapter. The “Notes” section on page 844 introduces terminology and other topics that will help you make better sense of this chapter. “JumpStart I” (page 844) gets Apache up and running as quickly as possible.

## PREREQUISITES

Minimal installation Install the following packages:

- **httpd**
- **apr** (Apache portable runtime)
- **apr-util**

Starting Apache Run **chkconfig** to cause **httpd** to start when the system enters multiuser mode:

```
# /sbin/chkconfig httpd on
```

After you configure Apache, use **service** to start **httpd**:

```
# /sbin/service httpd start
```

After changing the Apache configuration, restart **httpd** with the following command, which will not disturb clients connected to the server:

```
# /sbin/service httpd graceful
```

Optional packages You can install the following optional packages:

- **httpd-manual**—The Apache manual
- **system-config-httpd**—GUI configuration tool
- **webalizer**—Web server log analyzer (page 881)
- **mod\_perl**—Embedded Perl scripting language
- **mod\_python**—Embedded Python scripting language
- **mod\_ssl**—Secure Sockets Layer extension (page 877)
- **php**—Embedded PHP scripting language, including IMAP & LDAP support
- **mrtg**—MRTG traffic monitor (page 882)
- **net-snmp** and **net-snmp-utils**—SNMP, required for MRTG (page 882).

## MORE INFORMATION

Local The Apache *Reference Manual* and *Users' Guide*: Point a browser at **http://localhost/manual** if **httpd** is running or at **/var/www/manual/index.html** if **httpd** is not running. The manual is available online only if the **httpd-manual** package is installed.

Web Apache documentation: [httpd.apache.org/docs/2.2](http://httpd.apache.org/docs/2.2)  
 Apache directives list: [httpd.apache.org/docs/2.2/mod/directives.html](http://httpd.apache.org/docs/2.2/mod/directives.html)  
 Apache Software Foundation (newsletters, mailing lists, projects, module registry, and more): [www.apache.org](http://www.apache.org)  
**mod\_perl**: [perl.apache.org](http://perl.apache.org)  
**mod\_php**: [www.php.net](http://www.php.net)  
**mod\_python**: [www.modpython.org](http://www.modpython.org)  
**mod\_ssl**: [www.modssl.org](http://www.modssl.org)  
 MRTG: [mrtg.hdl.com/mrtg](http://mrtg.hdl.com/mrtg)  
 SNMP: [net-snmp.sourceforge.net](http://net-snmp.sourceforge.net)  
 SSI: [httpd.apache.org/docs/2.2/howto/ssi.html](http://httpd.apache.org/docs/2.2/howto/ssi.html)  
 webalizer: [www.mrunix.net/webalizer](http://www.mrunix.net/webalizer)

## NOTES

- Terms:** Apache is the name of a server that serves HTTP and other content. The Apache daemon is named **httpd** because it is an HTTP server daemon. This chapter uses the terms *Apache* and *httpd* interchangeably.
- Apache and httpd**
- Terms: server and process** An Apache *server* is the same thing as an Apache *process*. An Apache child process exists to handle incoming client requests, hence it is referred to as a server.
- Firewall** An Apache server normally uses TCP port 80; a secure server uses TCP port 443. If the Apache server system is running a firewall, you need to open one or both of these ports. To get started you just need to open port 80 (HTTP). Using the Fedora/RHEL graphical firewall tool (page 824), select **WWW (HTTPD)** and/or **Secure WWW (HTTPS)** from the Trusted services frame to open these ports. For more general information, see Chapter 25, which details iptables.
- SELinux** When SELinux is set to use a targeted policy, **httpd** is protected by SELinux. You can disable this protection if necessary. For more information refer to “Setting the Targeted Policy with system-config-selinux” on page 416.
- Running as root** Because Apache serves content on privileged ports, you must start it as **root**. For security reasons, the processes that Apache spawns run as the user and group **apache**.
- Locale** The **httpd** daemon is started using the C locale by default. You can modify this behavior, for example, to use the configured system locale, by setting the **HTTPD\_LANG** variable in the **/etc/sysconfig/httpd** file.
- Document root** The root of the directory hierarchy that Apache serves content from is called the *document root*. As shipped by Fedora/RHEL, the document root is **/var/www/html**. You can use the DocumentRoot directive (page 852) to change the location of the document root.
- Modifying content** As shipped by Fedora/RHEL, only **root** can add or modify content in **/var/www/html**. To avoid having people work as **root** when they are manipulating content, create a group (**webwork**, for example), put people who need to work with Web content in this group, and make the directory hierarchy starting at **/var/www/html** (or another document root) writable by that group. In addition, if you make the directory hierarchy setgid (**chmod g+s filename**), all new files created within this hierarchy will belong to the group, which facilitates sharing files. See page 557 for more information about working with groups.
- Versions** Fedora/RHEL runs Apache version 2.2.

---

## JUMPSTART I: GETTING APACHE UP AND RUNNING

To get Apache up and running, modify the **/etc/httpd/conf/httpd.conf** configuration file. “Directives I: Directives You May Want to Modify as You Get Started” on



page 850 explains more about this file and explores other changes you may want to make to it.

## MODIFYING THE `httpd.conf` CONFIGURATION FILE

Apache runs as installed, but it is a good idea to add the three lines described in this section to the `/etc/httpd/conf/httpd.conf` configuration file before starting Apache. If you do not add these lines, Apache assigns values that may not work for you.

The `ServerName` line establishes a name for the server. Add one of the following lines to `httpd.conf` to set the name of the server to the domain name of the server or, if you do not have a domain name, to the IP address of the server:

*`ServerName example.com`*

or

*`ServerName IP_address`*

where *`example.com`* is the domain name of the server and *`IP_address`* is the IP address of the server. If you are not connected to a network, you can use the **localhost** address, 127.0.0.1, so that you can start the server and experiment with it.

When a client has trouble getting information from a server, the server frequently displays an error page that identifies the problem. For example, when Apache cannot find a requested page, it displays a page that says **Error 404: Not Found**. Each error page has a link that the user can click to send mail to the server's administrator. `ServerSignature` can specify that you want an email link on error pages and `ServerAdmin` specifies the email address that the server displays on error pages. Change these two lines in `httpd.conf`:

*`ServerAdmin email_address`*  
*`ServerSignature EMail`*

where *`email_address`* is the email address of the person who needs to know if people are having trouble using the server. Make sure that someone checks this email account frequently.

After making the changes to `httpd.conf`, start or restart **httpd** as explained on page 843.

## TESTING APACHE

Once you start the **httpd** daemon, you can confirm that Apache is working correctly by pointing a browser on the local system to **http://localhost/**. From a remote system, point a browser to **http://** followed by the `ServerName` you specified in `httpd.conf`. For example, you might use either of these URI formats: **http://192.168.0.16** or

<http://example.org>. The browser should display the Fedora/RHEL/Apache test page. This test page is actually an error page that says there is no content. For more information refer to “Fedora/RHEL test page” on page 872.

If the server is behind a firewall, open TCP port 80 (page 844). If you are having problems getting Apache to work, see “Troubleshooting” on page 875.

## PUTTING YOUR CONTENT IN PLACE

Place the content you want Apache to serve in `/var/www/html`. Apache automatically displays the file named `index.html` in this directory. Working as `root` (or as a member of the group you set up for this purpose [e.g., `webwork`]), give the following command to create such a page:

```
# cat > /var/www/html/index.html
<html><body><p>This is my test page.</p></body></html>
CONTROL-D
```

After creating this file, either refresh the browser if it is still running or start it again and point it at the server. The browser should display the page you just created.

---

## JUMPSTART II: SETTING UP APACHE

### USING `system-config-httpd`

#### Make a copy of `httpd.conf`

**tip** As installed, the `/etc/httpd/conf/httpd.conf` file contains extensive comments and is set up as explained in this chapter. The `system-config-httpd` utility overwrites this file. Make a copy of `httpd.conf` for safekeeping before you run this utility for the first time.

---

You can use the `system-config-httpd` utility to display the HTTP window, which allows you to edit the `/etc/httpd/conf/httpd.conf` file to set up Apache. To run this utility, enter `system-config-httpd` on a command line or select **Main menu: System**⇒[Server Settings⇒]Administration⇒HTTP.

The HTTP window has four tabs: Main, Virtual Hosts, Server, and Performance Tuning. Each field in these tabs/windows corresponds to a directive in the `/etc/httpd/conf/httpd.conf` file. This section discusses some of the basic directives you can change with `system-config-httpd`. For more information click **Help** at the bottom of the HTTP window.

**Main tab** The Main tab (Figure 26-1) allows you to establish an *FQDN* (page 1083) as the name of the server (`ServerName`, page 852), an email address for the server administrator (`ServerAdmin`, page 851), and the ports and addresses that Apache listens on for requests (`Listen`, page 851). Highlight an entry in the Available Addresses subwindow, and click **Edit** to edit that entry or **Add** to add a new entry. Both

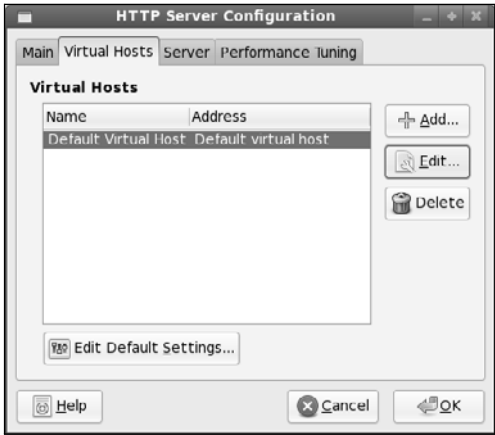


Figure 26-1 HTTP window, Main tab

actions bring up a window that allows you to specify a port and select whether you want to listen to all IP addresses on that port or listen to a specific address. To get started, set up Apache to listen to all available addresses on port 80.

**Virtual Hosts** The Virtual Hosts tab allows you to establish default settings for Apache and set up virtual hosts (page 874). Click the Virtual Hosts tab, and then click **Edit** to edit the settings for the highlighted virtual host or **Add** to add a new virtual host. Both actions open the Virtual Host Properties window, General Options tab (Figure 26-2).



Figure 26-2 Virtual Host Properties window, General Options tab



**Figure 26-3** Virtual Host Properties window, Page Options tab

The other tabs in the Virtual Host Properties window are Page Options (Figure 26-3), SSL, Logging, Environment, and Performance. This window is similar to the one you used to establish default settings, except that it pertains to a specific virtual host and has more tabs. You do not have to change most of the values in this window. Click **OK** when you are done making changes.

- Server tab
- Usually you do not need to change the values in the Server tab. You can specify the pathname of the lock file (LockFile directive), the PID file (PidFile directive), and the directory that Apache stores core dumps in (CoreDumpDirectory). The lower portion of the tab allows you to specify the user (User, page 868) and group (Group, page 866) that Apache runs as.
- Performance Tuning tab
- The selections in the Performance Tuning tab control the maximum number of connections that Apache allows (MaxClients, page 858), the number of seconds after which a connection will disconnect (Timeout, page 860), the maximum number of requests Apache allows per connection (MaxRequestsPerChild, page 859), and whether to allow persistent connections (KeepAlive directive). Initially, the values in this tab do not need to be changed. Click **OK** when you are done making changes and restart **httpd** as discussed on page 843.

## FILESYSTEM LAYOUT

This section tells you where you can find many of the files you may need to work with as you set up and modify an Apache server.

- p>Binaries, scripts, and modules
- The Apache server and related binary files are kept in several directories:
- `/usr/sbin/httpd`—The Apache server (daemon).
  - `/usr/sbin/apachectl`—Starts and stops Apache. The `httpd` init script calls `apachectl`.
  - `/usr/bin/htpasswd`—Creates and maintains password files used by the Apache authentication module (page 880).
  - `/usr/sbin/rotatelogs`—Rotates Apache log files so the files do not get too large. See `logrotate` (page 579) for more information about rotating log files.
  - `/etc/httpd/modules`—Holds module binaries. Two of the most frequently used module binary files are `mod_perl.so` and `pw.so`. This directory is a symbolic link to `/usr/lib/httpd/modules` (page 876).
- Configuration files
- Apache configuration files are kept in the `/etc/httpd/conf` and `/etc/httpd/conf.d` directories.
- `/etc/httpd/conf/httpd.conf`—Holds configuration directives. This file is the main Apache configuration file. The discussion of configuration directives starts on page 850. Refer to “The Fedora/RHEL `httpd.conf` File” on page 870 for a description of the `httpd.conf` file.
  - `/etc/httpd/conf/magic`—Provides *MIME* (page 1094) file type identification (the MIME hints file). It is not normally changed. See *magic number* (page 1092) for more information.
  - `/etc/pki/tls/certs`—Holds files and directories used by `mod_ssl` (page 877).
  - `/etc/httpd/conf.d`—Holds configuration files for modules, including `php` and `mod_perl`.
- Logs
- Logs are kept in `/var/log/httpd` (there is a symbolic link at `/etc/httpd/logs`):
- `/var/log/httpd/access_log`—Logs requests made to the server.
  - `/var/log/httpd/error_log`—Logs request and runtime server errors.
  - `/var/log/httpd/ssl_*_log`—Holds `mod_ssl` logs.
- Web documents
- Web documents (including the Web pages displayed by client browsers), custom error messages, and CGI scripts are kept in `/var/www` by default:
- `/var/www/cgi-bin`—Holds CGI scripts (page 877).
  - `/var/www/error`—Holds default error documents. You can modify these documents to conform to the style of your Web site. See *ErrorDocument* (page 863).
  - `/var/www/icons`—Holds icons used to display directory entries.
  - `/var/www/manual`—Holds the Apache *Reference Manual* and *Users’ Guide*. Present only if the `httpd-manual` package is installed.
- Document root
- By default, the document root (page 844) is `/var/www/html`. You can change this location with the `DocumentRoot` directive (page 852). In addition to content for the

Web pages that Apache serves, this directory can house the **usage** directory, which holds **webalizer** (page 881) output.

**.htaccess files** A **.htaccess** file contains configuration directives and can appear in any directory in the document root hierarchy. The location of a **.htaccess** file is critical: The directives in a **.htaccess** file apply to all files in the hierarchy rooted at the directory that holds the **.htaccess** file. You must use the **AllowOverride** directive (page 869) to cause Apache to examine **.htaccess** files. Based on the Fedora/RHEL **httpd.conf** file, Apache does not answer requests for files whose names start with **.ht**, so clients cannot read **.htaccess** files.

---

## CONFIGURATION DIRECTIVES

*Configuration directives*, or simply *directives*, are lines in a configuration file that control some aspect of how Apache functions. A configuration directive is composed of a keyword followed by one or more arguments (values) separated by **SPACES**. For example, the following configuration directive sets **Timeout** to 300 (seconds):

```
Timeout 300
```

You must enclose arguments that contain **SPACES** within double quotation marks. Keywords are not case sensitive, but arguments (pathnames, filenames, and so on) often are.

**httpd.conf** The most important file that holds Apache configuration directives is, by default, **/etc/httpd/conf/httpd.conf**. This file holds global directives that affect all content served by Apache. An **Include** directive (page 866) within **httpd.conf** can incorporate the contents of another file as though it were part of **httpd.conf**.

**.htaccess** Local directives can appear in **.htaccess** files (above). A **.htaccess** file can appear in any directory within the document root hierarchy; it affects files in the directory hierarchy rooted at the directory the **.htaccess** file appears in.

**Pathnames** When you specify an absolute pathname in a configuration directive, the directive uses that pathname without modifying it. When you specify a relative pathname, such as a simple filename or the name of a directory, Apache prepends to the name the value specified by the **ServerRoot** (page 865) directive (**/etc/httpd** by default).

## DIRECTIVES I: DIRECTIVES YOU MAY WANT TO MODIFY AS YOU GET STARTED

When it starts, Apache reads the **/etc/httpd/conf/httpd.conf** configuration file (by default) for instructions governing every aspect of how Apache runs and delivers content. The **httpd.conf** file shipped by Fedora/RHEL is almost 1,000 lines long. This section details some lines you may want to change as you are getting started with Apache. You can use each of the following directives in **httpd.conf**; the Context line in each explanation shows which other files the directives can appear in. Context is explained on page 854. The section titled “Directives II: Advanced Directives” on page 858 describes more directives.

**Listen** *Specifies the port(s) that Apache listens for requests on.*

*Listen [IP-address:]portnumber*

where *IP-address* is the IP address that Apache listens on and *portnumber* is the number of the port that Apache listens on for the given *IP-address*. When *IP-address* is absent or is set to 0.0.0.0, Apache listens on all network interfaces. At least one Listen directive must appear in **httpd.conf** or Apache will not work.

The following minimal directive from the **httpd.conf** file listens for requests on all interfaces on port 80:

```
Listen 80
```

The next directive changes the port from the default value of 80 to 8080:

```
Listen 8080
```

When you specify a port other than 80, each request to the server must include a port number (as in **www.example.org:8080**) or the kernel will return a **Connection Refused** message. Use multiple Listen directives to cause Apache to listen on multiple IP addresses and ports. For example,

```
Listen 80
Listen 192.168.1.1:8080
Listen 192.168.1.2:443
```

accepts connections on all network interfaces on port 80, on 192.168.1.1 on port 8080, and on 192.168.1.2 on port 443.

Context: **server config**

Default: none (Apache will not start without this directive)

Fedora/RHEL: Listen 80

**ServerAdmin** *Sets the email address displayed on error pages.*

*ServerAdmin email-address*

where *email-address* is the email address of the person responsible for managing the Web content. Under most versions of Apache, this address appears on Apache-generated error pages. However, Fedora/RHEL sets **ServerSignature** (page 866) to **On** which causes Apache to display information about the server, not an email address, on error pages. If you want to display an email address on error pages set **ServerSignature** to **EMail**. Make sure *email-address* points to an email account that someone checks frequently. Users can use this address to get help with the Web site or to inform the administrator of problems. There is no default value for **ServerAdmin**; if you do not use this directive, the value is undefined and no email address appears on error pages.

Because **webmaster** is a common name, you can use **webmaster** at your domain and use the `/etc/aliases` file (page 675) to forward mail that is sent to **webmaster** to the person who is responsible for maintaining the Web site.

Contexts: **server config, virtual host**

Default: none

Fedora/RHEL: **root@localhost**

**ServerName** *Specifies the server's name and the port it listens on.*

*ServerName FQDN [:port]*

where **FQDN** is the fully qualified domain name or IP address of the server and *port* is the optional port number Apache listens on. The domain name of the server must be able to be resolved by DNS and may differ from the hostname of the system running the server. If you do not specify a **ServerName**, Apache performs a DNS reverse name resolution (page 783) on the system's IP address and assigns that value to **ServerName**. If the reverse lookup fails, Apache assigns the system's IP address to **ServerName**.

Fedora/RHEL provides the following **ServerName** template in the **httpd.conf** file:

```
#ServerName www.example.com:80
```

Copy this line, remove the **#**, and substitute the **FQDN** or IP address of the server in place of **www.example.com**. Change the **80** to the port number Apache listens on if it is not port 80.

The ports specified by **ServerName** and **Listen** (page 851) must be the same if you want the **FQDN** specified by **ServerName** tied to the IP address specified by the **Listen** directive.

Apache uses **ServerName** to construct a URI when it redirects a client (page 873).

Contexts: **server config, virtual host**

Default: none

Fedora/RHEL: none

**DocumentRoot** *Points to the root of the directory hierarchy that holds the server's content.*

*DocumentRoot dirname*

where *dirname* is the absolute pathname of the directory at the root of the directory hierarchy that holds the content Apache serves. Do not use a trailing slash. You can put the document root wherever you like, as long as the user **apache** has read access to the ordinary files and execute access to the directory files in the directory hierarchy. The FHS (page 198) specifies **/srv** as the top-level directory for this purpose. The following directive puts the document root at **/home/www**:

```
DocumentRoot /home/www
```

Contexts: **server config, virtual host**

Default: **/usr/local/apache/htdocs**

Fedora/RHEL: **/var/www/html**



**UserDir** *Allows users to publish content from their home directories.*

*UserDir* **dirname** | *disabled* | *enabled* **user-list**

where **dirname** is the name of a directory that, if it appears in a local user's home directory, Apache publishes to the Web. The *disabled* keyword prevents content from being published from users' home directories; *enabled* causes content to be published from the home directories of users specified in the SPACE-separated **user-list**. When you do not specify a **dirname**, Apache publishes content to **~/public\_html**.

Apache can combine the effects of multiple UserDir directives. Suppose you have the following directives:

```
UserDir disabled
UserDir enabled user1 user2 user3
UserDir web
```

The first directive turns off user publishing for all users. The second directive enables user publishing for three users. The third directive makes **web** the name of the directory that, if it appears in one of the specified users' home directories, Apache publishes to the Web.

To cause a browser to display the content published by a user, specify in the location bar the name of the Web site followed by a **/~** and the user's username. For example, if Sam published content in the **public\_html** directory in his home directory and the URI of the Web site was **www.example.com**, you would enter **http://www.example.com/~sam** to display Sam's Web page. To display a user's Web page, Apache must have execute permission (as user **apache**) for the user's home directory and the directory holding the content, and read permission for the content files.

Fedora/RHEL provides the following ServerName directive and template in the **httpd.conf** file:

```
UserDir disable
#UserDir public_html
```

Put a pound sign (**#**) in front of the first line and remove the pound sign from the second line to allow users to publish content from directories named **public\_html** in their home directories.

Contexts: **server config, virtual host**

Default: none

Fedora/RHEL: disabled

**DirectoryIndex** *Specifies which file to display when a user asks for a directory.*

*DirectoryIndex* **filename** [**filename** ...]

where **filename** is the name of the file that Apache serves.

This directive specifies a list of filenames. When a client requests a directory, Apache attempts to find a file in the specified directory whose name matches a file in the list. When Apache finds a match, it returns that file. When this directive is

absent or when none of the files specified by this directive exists in the specified directory, Apache displays a directory listing as specified by the `IndexOptions` directive (page 863).

For example, you could provide the following `DirectoryIndex` directive:

```
DirectoryIndex index.php index.html index.htm index.shtml
```

This directive would cause Apache to return from the specified directory the file named `index.php`, `index.html`, `index.htm`, or `index.shtml`.

The `index.php` is the name of a PHP document; `index.html` and `index.htm` are the names of the standard, default HTML documents; and `index.shtml` is a secure HTML document. If you supply CGI documents, you may want to add the `index.cgi` value to this directive. The name `index` is standard but arbitrary.

A `.var` filename extension denotes a content-negotiated document that allows Apache to serve the Apache manual and other documents in one of several languages as specified by the client. If you are not providing content in different languages, you can omit this filename extension from the `DirectoryIndex` directive.

Contexts: `server config`, `virtual host`  
Default: `index.html`  
Fedora/RHEL: `index.html index.html.var`

## CONTEXTS AND CONTAINERS

To make it flexible and easy to customize, Apache uses configuration directives, contexts, and containers. Configuration directives were covered in the previous section. This section discusses contexts and containers, which are critical to managing an Apache server.

### CONTEXTS

Four locations, called *contexts*, define where a configuration directive can appear. This chapter marks each configuration directive to indicate which context(s) it can appear in. Table 26-1 describes each of these contexts.

**Table 26-1**    Contexts

Context	Location(s) directives can appear in
<b>server config</b>	Directive can appear in the <b>httpd.conf</b> file only, but not inside <code>&lt;VirtualHost&gt;</code> or <code>&lt;Directory&gt;</code> containers (next section) unless so marked
<b>virtual host</b>	Directive can appear inside <code>&lt;VirtualHost&gt;</code> containers in the <b>httpd.conf</b> file only
<b>directory</b>	Directive can appear inside <code>&lt;Directory&gt;</code> , <code>&lt;Location&gt;</code> , and <code>&lt;Files&gt;</code> containers in the <b>httpd.conf</b> file only
<b>.htaccess</b>	Directive can appear in <b>.htaccess</b> files (page 850) only

Directives in files incorporated by means of the Include directive (page 866) are part of the context they are included in and must be allowed in that context.

Putting a directive in the wrong context generates a configuration error and can cause Apache not to serve content correctly or not to start.

## CONTAINERS

*Containers*, or *special directives*, are directives that group other directives. Containers are delimited by XML-style tags. Three examples are shown here:

```
<Directory> ... </Directory>

<Location> ... </Location>

<VirtualHost> ... </VirtualHost>
```

Look in **httpd.conf** for examples of containers. Like other directives, containers are limited to use within specified contexts. This section describes some of the more frequently used containers.

**<Directory>** *Applies directives to directories within specified directory hierarchies.*

```
<Directory directory> ... </Directory>
```

where *directory* is an absolute pathname specifying the root of the directory hierarchy that holds the directories the directives in the container apply to. The *directory* can include wildcards; a *\** does not match a */*.

A **<Directory>** container provides the same functionality as a **.htaccess** file. While an administrator can use a **<Directory>** container in the **httpd.conf** file, regular users cannot. Regular users can use **.htaccess** files to control access to their own directories.

The directives in the **<Directory>** container shown in the following example apply to the **/var/www/html/corp** directory hierarchy: The **Deny** directive denies access to all clients, the **Allow** directive grants clients from the 192.168.10. subnet access, and the **AllowOverride** directive (page 869) enables the use of **.htaccess** files in the hierarchy:

```
<Directory /var/www/html/corp>
    Deny from all
    Allow from 192.168.10.
    AllowOverride All
</Directory>
```

Contexts: **server config**, **virtual host**

**<Files>** *Applies directives to specified ordinary files.*

```
<Files directory> ... </Files>
```

where *directory* is an absolute pathname specifying the root of the directory hierarchy that holds the ordinary files the directives in the container apply to. The *directory*

can include wildcards; a `*` does not match a `/`. This container is similar to `<Directory>` but applies to ordinary files and not to directories.

The following directive, from the Fedora/RHEL `httpd.conf` file, denies access to all files whose filenames start with `.ht`. The tilde (`~`) changes how Apache interprets the following string. Without a tilde, the string is a simple shell match that interprets shell special characters (page 243). With a tilde, Apache interprets the string as a regular expression (page 1023):

```
<Files ~ "^\.ht">
    Order allow,deny
    Deny from all
</Files>
```

Contexts: **server config, virtual host, directory, .htaccess**

**<IfModule>** *Applies directives if a specified module is loaded.*

```
<IfModule [!]module-name> ... </IfModule>
```

where *module-name* is the name of the module (page 876) that is tested for. Apache executes the directives in this container if *module-name* is loaded or with `!` if *module-name* is not loaded.

Apache will not start if you specify a configuration directive that is specific to a module that is not loaded.

The following `<IfModule>` container from the Fedora/RHEL `httpd.conf` file depends on the `mod_mime_magic.c` module being loaded. If this module is loaded, Apache runs the `MIMEMagicFile` directive, which tells the `mod_mime_magic.c` module where its hints file is located.

```
<IfModule mod_mime_magic.c>
    MIMEMagicFile conf/magic
</IfModule>
```

See page 871 for another example of the `<IfModule>` container.

Contexts: **server config, virtual host, directory, .htaccess**

**<Limit>** *Limits access-control directives to specified HTTP methods.*

```
<Limit method [method] ... > ... </Limit>
```

where *method* is an HTTP method. An HTTP method specifies which action is to be performed on a URI. The most frequently used methods are GET, PUT, POST, and OPTIONS; method names are case sensitive. GET, the default method, sends any data indicated by the URI. PUT stores data from the body section of the communication at the specified URI. POST creates a new document containing the body of the request at the specified URI. OPTIONS requests information about the capability of the server.

This container binds a group of access-control directives to specified HTTP methods: Only methods named by the `<Limit>` container are affected by this group of directives.

The following example disables HTTP uploads (PUTs) from systems that are not in a subdomain of **example.com**:

```
<Limit PUT>
order deny,allow
deny from all
allow from .example.com
</Limit>
```

### Use `<LimitExcept>` instead of `<Limit>`

**caution** It is safer to use the `<LimitExcept>` container instead of the `<Limit>` container, as the former protects against arbitrary methods. When you use `<Limit>`, you must be careful to name explicitly all possible methods that the group of directives could affect.

It is safer still not to put access-control directives in any container.

Contexts: server config, virtual host, directory, .htaccess

**<LimitExcept>** *Limits access-control directives to all except specified HTTP methods.*

```
<LimitExcept method [method] ... > ... </LimitExcept>
```

where *method* is an HTTP method. See `<Limit>` for a discussion of methods.

This container causes a group of access-control directives *not* to be bound to specified HTTP methods: Methods *not* named in `<LimitExcept>` are affected by this group of directives.

The access-control directives within the following `<LimitExcept>` container affect HTTP methods other than GET and POST. You could put this container in a `<Directory>` container to limit its scope:

```
<LimitExcept GET POST OPTIONS>
Order deny,allow
Deny from all
</LimitExcept>
```

Contexts: server config, virtual host, directory, .htaccess

**<Location>** *Applies directives to specified URIs.*

```
<Location URI> ... </Location>
```

where *URI* points to content and specifies a file or the root of the directory hierarchy that the directives in the container apply to. While the `<Directory>` container points within the local filesystem, `<Location>` points outside the local filesystem. The *URI* can include wildcards; a `*` does not match a `/`.

The following `<Location>` container limits access to **http://server/pop** to clients from the **example.net** domain, where *server* is the FQDN of the server:

```
<Location /pop>
    Order deny,allow
    Deny from all
    Allow from .example.net
</Location>
```

Contexts: server config, virtual host

### Use `<Location>` with care

---

**caution** Use this powerful container with care. Do not use it to replace the `<Directory>` container: When several URIs point to the same location in a filesystem, a client may be able to circumvent the desired access control by using a URI not specified by this container.

---

`<LocationMatch>` *Applies directives to matched URIs.*

```
<LocationMatch regex> ... </LocationMatch>
```

where *regex* is a regular expression that matches one or more URIs. This container works the same way as `<Location>`, except that it applies to any URIs that *regex* matches:

```
# Disable autoindex for the root directory and present a
# default welcome page if no other index page is present.
#
<LocationMatch "^/$">
Options -Indexes
ErrorDocument 403 /error/noindex.html
</LocationMatch>
```

Contexts: server config, virtual host

`<VirtualHost>` *Applies directives to a specified virtual host.*

```
<VirtualHost addr[:port] [addr[:port]] ... > ... </VirtualHost>
```

where *addr* is an FQDN or IP address of the virtual host and *port* is the port that Apache listens on for the virtual host. This container holds commands that Apache applies to a virtual host. For an example and more information, refer to “Virtual Hosts” on page 874.

Context: server config

## DIRECTIVES II: ADVANCED DIRECTIVES

This section discusses configuration directives that you may want to use after you have gained some experience with Apache.

### DIRECTIVES THAT CONTROL PROCESSES

**MaxClients** *Specifies the maximum number of child processes.*

*MaxClients* **num**

where *num* is the maximum number of child processes (servers) Apache runs at one time, including idle processes and those serving requests. When Apache is running *num* processes and there are no idle processes, Apache issues **Server too busy** errors to new connections; it does not start new child processes. A value of 150 is usually sufficient, even for moderately busy sites.

Context: **server config**

Default: 256

Fedora/RHEL: 256

#### **MaxRequestsPerChild**

*Specifies the maximum number of requests a child process can serve.*

*MaxRequestsPerChild num*

where *num* is the maximum number of requests a child process (server) can serve during its lifetime. After a child process serves *num* requests, it does not process any more requests but dies after it finishes processing its current requests. At this point additional requests are processed by other processes from the server pool.

Set *num* to 0 to not set a limit on the number of requests a child can process, except for the effects of `MinSpareServers`. By limiting the life of processes, this directive can prevent memory leaks from consuming too much system memory. However, setting `MaxRequestsPerChild` to a small value can hurt performance by causing Apache to create new child servers constantly.

Context: **server config**

Default: 10000

Fedora/RHEL: 4000

#### **MaxSpareServers** *Specifies the maximum number of idle processes.*

*MaxSpareServers num*

where *num* is the maximum number of idle processes (servers) Apache keeps running to serve requests as they come in. Do not set this number too high, as each process consumes system resources.

Context: **server config**

Default: 10

Fedora/RHEL: 20

#### **MinSpareServers** *Specifies the minimum number of idle processes.*

*MinSpareServers num*

where *num* is the minimum number of idle processes (servers) Apache keeps running to serve requests as they come in. More idle processes occupy more computer resources; increase this value for busy sites only.

Context: **server config**

Default: 5

Fedora/RHEL: 5

**StartServers** *Specifies the number of child processes that Apache starts with.*

*StartServers* **num**

where **num** is the number of child processes, or servers, that Apache starts when it is brought up. This value is significant only when Apache starts; `MinSpareServers` and `MaxSpareServers` control the number of idle processes once Apache is up and running. Starting Apache with multiple servers ensures that a pool of servers is waiting to serve requests immediately.

Context: **server config**

Default: 5

Fedora/RHEL: 8

## NETWORKING DIRECTIVES

**HostnameLookups**

*Specifies whether Apache puts a client's hostname or its IP address in the logs.*

*HostnameLookups* **On | Off | Double**

**On:** Performs DNS reverse name resolution (page 783) to determine the hostname of each client for logging purposes.

**Off:** Logs each client's IP address.

**Double:** To provide greater security, performs DNS reverse name resolution (page 783) to determine the hostname of each client, performs a forward DNS lookup to verify the original IP address, and logs the hostname.

Contexts: **server config, virtual host, directory**

Default: Off

Fedora/RHEL: Off

### Lookups can consume a lot of system resources

---

**tip** Use the **On** and **Double** options with caution: They can consume a lot of resources on a busy system. You can use a program such as `logresolve` to perform reverse name resolution offline for statistical purposes.

If you perform hostname resolution offline, you run the risk that the name may have changed; you usually want the name that was current at the time of the request. To minimize this problem, perform the hostname resolution as soon as possible after writing the log.

---

**Timeout** *Specifies the time Apache waits for network operations to complete.*

*Timeout* **num**

where **num** is the number of seconds that Apache waits for network operations to finish. You can usually set this directive to a lower value; five minutes is a long time to wait on a busy server. The Apache documentation says that the default is not



lower “because there may still be odd places in the code where the timer is not reset when a packet is sent.”

Context: **server config**

Default: 300

Fedora/RHEL: 120

#### UseCanonicalName

*Specifies the method the server uses to identify itself.*

*UseCanonicalName On | Off | DNS*

**On:** Apache uses the value of the `ServerName` directive (page 852) as its identity.

**Off:** Apache uses the name and port from the incoming request as its identity.

**DNS:** Apache performs a DNS reverse name resolution (page 783) on the IP address from the incoming request and uses the result as its identity. Rarely used.

This directive is important when a server has more than one name and needs to perform a redirect. Fedora/RHEL sets this directive to `Off` because the `ServerName` directive (page 852) is commented out. Once you set `ServerName`, change `UseCanonicalName` to `On`. See page 873 for a discussion of redirects and this directive.

Contexts: **server config, virtual host, directory**

Default: `Off`

Fedora/RHEL: `Off`

## LOGGING DIRECTIVES

**ErrorLog** *Specifies where Apache sends error messages.*

*ErrorLog **filename** | syslog[:**facility**]*

where **filename** specifies the name of the file, relative to `ServerRoot` (page 865), that Apache sends error messages to; **syslog** specifies that Apache send errors to **rsyslogd** (page 582); and **facility** specifies which **rsyslogd** facility to use. The default facility is `local7`.

Contexts: **server config, virtual host**

Default: `logs/error_log`

Fedora/RHEL: `logs/error_log`

**LogLevel** *Specifies the level of error messages that Apache logs.*

*LogLevel **level***

where **level** specifies that Apache log errors of that level and higher (more urgent). Choose **level** from the following list, which is presented here in order of decreasing urgency and increasing verbosity:

<b>emerg</b>	System unusable messages
<b>alert</b>	Need for immediate action messages

<b>crit</b>	Critical condition messages
<b>error</b>	Error condition messages
<b>warn</b>	Nonfatal warning messages
<b>notice</b>	Normal but significant messages
<b>info</b>	Operational messages and recommendations
<b>debug</b>	Messages for finding and solving problems

Contexts: **server config, virtual host**

Default: **warn**

Fedora/RHEL: **warn**

## DIRECTIVES THAT CONTROL CONTENT

**AddHandler** *Creates a mapping between filename extensions and a builtin Apache handler.*

*AddHandler handler extension [extension] ...*

where *handler* is the name of a builtin handler and *extension* is a filename extension that maps to the *handler*. Handlers are actions that are built in to Apache and are directly related to loaded modules. Apache uses a handler when a client requests a file with a specified filename extension.

For example, the following AddHandler directive causes Apache to process files that have a filename extension of **.cgi** with the **cgi-script** handler:

```
AddHandler cgi-script .cgi
```

Contexts: **server config, virtual host, directory, .htaccess**

Default: **none**

Fedora/RHEL: **type-map var**

**Alias** *Maps a URI to a directory or file.*

*Alias alias pathname*

where *alias* must match part of the URI that the client requested to invoke the alias and *pathname* is the absolute pathname of the target of the alias, usually a directory.

For example, the following alias causes Apache to serve **/usr/local/pix/milk.jpg** when a client requests **http://www.example.com/pix/milk.jpg**:

```
Alias /pix /usr/local/pix
```

In some cases, you need to use a **<Directory>** container (page 855) to grant access to aliased content.

Contexts: **server config, virtual host**

Default: **None**

Fedora/RHEL: provides two aliases, one for **/icons/** and one for **/error/**

**ErrorDocument** *Specifies the action Apache takes when the specified error occurs.*

*ErrorDocument code action*

where **code** is the error code (page 882) that this directive defines a response for and **action** is one of the following:

**string:** Defines the message that Apache returns to the client.

**absolute pathname:** Points to a local script or other content that Apache redirects the client to.

**URI:** Points to an external script or other content that Apache redirects the client to.

When you do not specify this directive for a given error code, Apache returns a hardcoded error message when that error occurs. See page 872 for an explanation of how an ErrorDocument directive returns the Fedora/RHEL test page when the system is first installed.

Some examples of ErrorDocument directives follow:

```
ErrorDocument 403 "Sorry, access is forbidden."
ErrorDocument 403 /cgi-bin/uh-uh.pl
ErrorDocument 403 http://errors.example.com/not_allowed.html
```

Contexts: **server config, virtual host, directory, .htaccess**

Default: none; Apache returns hardcoded error messages

Fedora/RHEL: 403 /error/noindex.html; refer to “Fedora/RHEL test page” on page 872.

**IndexOptions** *Specifies how Apache displays directory listings.*

*IndexOptions [±]option [[±]option] ...*

where **option** can be any combination of the following:

**DescriptionWidth=*n*:** Sets the width of the description column to *n* characters. Use \* in place of *n* to accommodate the widest description.

**FancyIndexing:** In directory listings, displays column headers that are links. When you click one of these links, Apache sorts the display based on the content of the column. Clicking a second time reverses the order.

**FoldersFirst:** Sorts the listing so that directories come before plain files. Use only with FancyIndexing.

**HTMLTable:** Displays a directory listing in a table.

**IconsAreLinks:** Makes the icons clickable. Use only with FancyIndexing.

**IconHeight=*n*:** Sets the height of icons to *n* pixels. Use only with IconWidth.

**IconWidth=*n*:** Sets the width of icons to *n* pixels. Use only with IconHeight.

**IgnoreCase:** Ignores case when sorting names.

**IgnoreClient:** Ignores options the client supplied in the URI.

**NameWidth=*n*:** Sets the width of the filename column to *n* characters. Use \* in place of *n* to accommodate the widest filename.

**ScanHTMLTitles:** Extracts and displays titles from HTML documents. Use only with FancyIndexing. Not normally used because it is CPU and disk intensive.

**SuppressColumnSorting:** Suppresses clickable column headings that can be used for sorting columns. Use only with FancyIndexing.

**SuppressDescription:** Suppresses file descriptions. Use only with FancyIndexing.

**SuppressHTMLPreamble:** Suppresses the contents of the file specified by the HeaderName directive, even if that file exists.

**SuppressIcon:** Suppresses icons. Use only with FancyIndexing.

**SuppressLastModified:** Suppresses the modification date. Use only with FancyIndexing.

**SuppressRules:** Suppresses horizontal lines. Use only with FancyIndexing.

**SuppressSize:** Suppresses file sizes. Use only with FancyIndexing.

**VersionSort:** Sorts version numbers (in filenames) in a natural way; character strings, except for substrings of digits, are not affected.

As an example, suppose a client requests a URI that points to a directory (such as <http://www.example.com/support/>) and none of the files specified by the DirectoryIndex directive (page 853) is present in that directory. If the directory hierarchy is controlled by a **.htaccess** file and AllowOverride (page 869) has been set to allow indexing, then Apache displays a directory listing according to the options specified by this directive.

When this directive appears more than once within a directory, Apache merges the options from the directives. Use + and – to merge options with options from higher-level directories. (Unless you use + or – with all options, Apache discards any options set in higher-level directories.) For example, the following directives and containers set the options for **/custsup/download** to VersionSort; Apache discards FancyIndexing and IgnoreCase in the **download** directory because there is no + or – before VersionSort in the second <Directory> container:

```
<Directory /custsup>
    IndexOptions FancyIndexing
    IndexOptions IgnoreCase
</Directory>

<Directory /custsup/download>
    IndexOptions VersionSort
</Directory>
```

Because + appears before VersionSort, the next directives and containers set the options for **/custsup/download** to FancyIndexing, IgnoreCase, and VersionSort:

```

<Directory /custsup>
    IndexOptions FancyIndexing
    IndexOptions IgnoreCase
</Directory>

<Directory /custsup/download>
    IndexOptions +VersionSort
</Directory>

```

Contexts: **server config**, **virtual host**, **directory**, **.htaccess**

Default: none; lists only filenames

Fedora/RHEL: FancyIndexing VersionSort NameWidth=\* HTMLTable

Fedora only: Charset=UTF-8

**ServerRoot** *Specifies the root directory for server files (not content).*

*ServerRoot* **directory**

where *directory* specifies the pathname of the root directory for files that make up the server. Apache prepends *directory* to relative pathnames in **httpd.conf**. This directive does not specify the location of the content that Apache serves; the DocumentRoot directive (page 852) performs that function. Do not change this value unless you move the server files.

Context: **server config**

Default: **/usr/local/apache**

Fedora/RHEL: **/etc/httpd**

**ServerTokens** *Specifies the server information that Apache returns to a client.*

*ServerTokens* **Prod | Major | Minor | Min | OS | Full**

**Prod**: Returns the product name (**Apache**). Also **ProductOnly**.

**Major**: Returns the major release number of the server (**Apache/2**).

**Minor**: Returns the major and minor release numbers of the server (**Apache/2.2**).

**Minimal**: Returns the complete version (**Apache/2.2.8**). Also **Min**.

**OS**: Returns the name of the operating system and the complete version (**Apache/2.2.8 (Fedora)**). Provides less information that might help a malicious user than **Full** does.

**Full**: Same as **OS**, plus sends the names and versions of non-Apache group modules (**Apache/2.2.8 (Fedora) PHP/5.2.4**).

Unless you want clients to know the details of the software you are running for some reason, set ServerTokens to reveal as little as possible.

Context: **server config**

Default: **Full**

Fedora/RHEL: **OS**

**ServerSignature** *Adds a line to server-generated pages.*

*ServerSignature On | Off | EMail*

**On:** Turns the signature line on. The signature line contains the server version as specified by the `ServerTokens` directive (page 865) and the name specified by the `<VirtualHost>` container (page 858).

**Off:** Turns the signature line off.

**EMail:** To the signature line, adds a **mailto:** link to the server email address. This option produces output that can attract spam. See `ServerAdmin` (page 851) for information on specifying an email address.

Contexts: **server config, virtual host, directory, .htaccess**

Default: `Off`

Fedora/RHEL: `On`

## CONFIGURATION DIRECTIVES

**Group** *Sets the GID of the processes that run the servers.*

*Group #groupid | groupname*

where **groupid** is a GID value, preceded by a `#`, and **groupname** is the name of a group. The processes (servers) that Apache spawns are run as the group specified by this directive. See the `User` directive (page 868) for more information.

Context: **server config**

Default: `#-1`

Fedora/RHEL: `apache`

**Include** *Loads directives from files.*

*Include filename | directory*

where **filename** is the relative pathname of a file that contains directives. Apache prepends `ServerRoot` (page 865) to **filename**. The directives in **filename** are included in the file holding this directive at the location of the directive. Because **filename** can include wildcards, it can specify more than one file.

The **directory** is the relative pathname that specifies the root of a directory hierarchy that holds files containing directives. Apache prepends `ServerRoot` to **directory**. The directives in ordinary files in this hierarchy are included in the file holding this directive at the location of the directive. The **directory** can include wildcards.

When you install Apache and its modules, `rpm` puts configuration files, which have a filename extension of **conf**, in the `conf.d` directory within the `ServerRoot` directory. The `Include` directive in the Fedora/RHEL `httpd.conf` file incorporates module configuration files for whichever modules are installed.

Contexts: **server config, virtual host, directory**

Default: `none`

Fedora/RHEL: `conf.d/*.conf`

**LoadModule** *Loads a module.*

*LoadModule module filename*

where **module** is the name of an external DSO module and **filename** is the relative pathname of the named module. Apache prepends `ServerRoot` (page 865) to **filename**. Apache loads the external module specified by this directive. For more information refer to “Modules” on page 876.

Context: **server config**

Default: none; nothing is loaded by default if this directive is omitted

Fedora/RHEL: loads more than 40 modules; refer to **httpd.conf** for the list

**Options** *Controls server features by directory.*

*Options [**±**]option [[**±**]option ...]*

This directive controls which server features are enabled for a directory hierarchy. The directory hierarchy is specified by the container this directive appears in. A **+** or the absence of a **–** turns an option on and a **–** turns it off.

The **option** may be one of the following:

**None:** None of the features this directive can control are enabled.

**All:** All of the features this directive can control are enabled, except for MultiViews, which you must explicitly enable.

**ExecCGI:** Apache can execute CGI scripts (page 877).

**FollowSymLinks:** Apache follows symbolic links.

**Includes:** Permits SSIs (server-side includes). SSIs are containers embedded in HTML pages that are evaluated on the server before the content is passed to the client.

**IncludesNOEXEC:** The same as Includes but disables the **#exec** and **#exec cgi** commands that are part of SSIs. Does *not* prevent the **#include** command from referencing CGI scripts.

**Indexes:** Generates a directory listing if `DirectoryIndex` (page 853) is not set.

**MultiViews:** Allows multiviews (page 874).

**SymLinksIfOwnerMatch:** The same as FollowSymLinks but follows the link only if the file or directory being pointed to has the same owner as the link.

The following Options directive from the Fedora/RHEL **httpd.conf** file sets the Indexes and FollowSymLinks options and, because the `<Directory>` container specifies the `/var/www/html` directory hierarchy (the document root), affects all content:

```
<Directory "/var/www/html">
    Options Indexes FollowSymLinks
    ...
</Directory>
```

Context: **directory**

Default: All

Fedora/RHEL: Indexes FollowSymLinks

**ScriptAlias** *Maps a URI to a directory or file and declares the target to be a server (CGI) script.*

*ScriptAlias alias pathname*

where *alias* must match part of the URI the client requested to invoke the ScriptAlias and *pathname* is the absolute pathname of the target of the alias, usually a directory. Similar to the Alias directive, this directive specifies that the target is a CGI script (page 877).

The following ScriptAlias directive from the Fedora/RHEL **httpd.conf** file maps client requests that include **/cgi-bin/** to the **/var/www/cgi-bin** directory (and indicates that these requests will be treated as CGI requests):

```
ScriptAlias /cgi-bin/ "/var/www/cgi-bin/"
```

Contexts: **server config, virtual host**

Default: none

Fedora/RHEL: **/cgi-bin/ "/var/www/cgi-bin"**

**User** *Sets the UID of the processes that run the servers.*

*User #userid | username*

where *userid* is a UID value, preceded by a #, and *username* is the name of a local user. The processes (servers) that Apache spawns are run as the user specified by this directive.

Apache must start as **root** to listen on a privileged port. For reasons of security, Apache's child processes (servers) run as nonprivileged users. The default UID of -1 does not map to a user under Fedora/RHEL. Instead, Fedora/RHEL's **httpd** package creates a user named **apache** during installation and sets User to that user.

Context: **server config**

Default: **#-1**

Fedora/RHEL: **apache**

### **Do not set User to root or 0**

---

**security** For a more secure system, do not set User to **root** or **0** (zero) and do not allow the **apache** user to have write access to the DocumentRoot directory hierarchy (except as needed for storing data), especially not to configuration files.

---

## **SECURITY DIRECTIVES**

**Allow** *Specifies which clients can access specified content.*

*Allow from All | host [host ...] | env=var [env=var ...]*

This directive, which must be written as **Allow from**, grants access to a directory hierarchy to the specified clients. The directory hierarchy is specified by the container or **.htaccess** file this directive appears in.



*All*: Serves content to any client.

*host*: Serves content to the client(s) specified by *host*, which can take several forms: *host* can be an FQDN, a partial domain name (such as **example.com**), an IP address, a partial IP address, or a network/netmask pair.

*var*: Serves content when the environment variable named *var* is set. You can set a variable with the SetEnvIf directive. See the Order directive (page 870) for an example.

Contexts: **directory**, **.htaccess**

Default: none; default behavior depends on the Order directive

Fedora/RHEL: All

**AllowOverride** *Specifies the classes of directives that are allowed in .htaccess files.*

*AllowOverride All | None | directive-class [directive-class ...]*

This directive specifies whether Apache read **.htaccess** files in the directory hierarchy specified by its container. If Apache does reads **.htaccess** files, this directive specifies which kinds of directives are valid within **.htaccess** files.

*None*: Ignores **.htaccess** files.

*All*: Allows all classes of directives in **.htaccess** files.

The *directive-class* is one of the following directive class identifiers:

**AuthConfig**: Class of directives that control authorization (AuthName, AuthType, Require, and so on). This class is used mostly in **.htaccess** files to require a username and password to access the content. For more information refer to “Authentication Modules and **.htaccess**” on page 880.

**FileInfo**: Class of directives that controls document types (DefaultType, ErrorDocument, SetHandler, and so on).

**Indexes**: Class of directives relating to directory indexing (DirectoryIndex, FancyIndexing, IndexOptions, and so on).

**Limit**: Class of client access directives (Allow, Deny, and Order).

**Options**: Class of directives controlling directory features.

Context: **directory**

Default: All

Fedora/RHEL: None

**Deny** *Specifies which clients are not allowed to access specified content.*

*Deny from All | host [host ...] | env=var [env=var ...]*

This directive, which must be written as **Deny from**, denies access to a directory hierarchy to the specified clients. The directory hierarchy is specified by the container or **.htaccess** file this directive appears in. See the Order directive (page 870) for an example.

**All:** Denies content to all clients.

**host:** Denies content to the client(s) specified by **host**, which can take several forms: **host** can be an FQDN, a partial domain name (such as **example.com**), an IP address, a partial IP address, or a network/netmask pair.

**var:** Denies content when the environment variable named **var** is set. You can set a variable with the `SetEnvIf` directive.

Contexts: **directory**, **.htaccess**

Default: none

Fedora/RHEL: none

**Order** *Specifies default access and the order in which Allow and Deny directives are evaluated.*

*Order Deny,Allow | Allow,Deny*

**Deny,Allow:** Allows access by default; denies access only to clients specified in Deny directives. (First evaluates Deny directives, then evaluates Allow directives.)

**Allow,Deny:** Denies access by default; allows access only to clients specified in Allow directives. (First evaluates Allow directives, then evaluates Deny directives.)

Access granted or denied by this directive applies to the directory hierarchy specified by the container or **.htaccess** file this directive appears in.

There must not be SPACES on either side of the comma. Although Fedora/RHEL has a default of **Allow,Deny**, which denies access to all clients not specified by Allow directives, the next directive in **httpd.conf**, **Allow from all**, grants access to all clients:

```
Order allow,deny
Allow from all
```

You can restrict access by specifying **Deny,Allow** to deny all access and then specifying only those clients you want to grant access to in an Allow directive. The following directives grant access to clients from the **example.net** domain only and would typically appear within a `<Directory>` container (page 855):

```
Order deny,allow
Deny from all
Allow from .example.net
```

Contexts: **directory**, **.htaccess**

Default: **Deny,Allow**

Fedora/RHEL: **Allow,Deny**

---

## THE FEDORA/RHEL httpd.conf FILE

This section highlights some of the important features of the Fedora/RHEL **httpd.conf** file, which is based on the **httpd.conf** file distributed by Apache. This heavily commented file is broken into the following parts (as is this section):

1. **Global Environment**—Controls the overall functioning of the Apache server.
2. **Main Server Configuration**—Configures the default server (as opposed to virtual hosts) and provides default configuration information for virtual hosts.
3. **Virtual Hosts**—Configures virtual hosts. For more information refer to “Virtual Hosts” on page 874.

## SECTION 1: GLOBAL ENVIRONMENT

**ServerTokens** The `ServerTokens` directive (page 865) is set to `OS`, which causes Apache, when queried, to return the name of the operating system and the complete version number of Apache:

```
ServerTokens OS
```

**ServerRoot** The `ServerRoot` directive (page 865) is set to `/etc/httpd`, which is the pathname that Apache prepends to relative pathnames in `httpd.conf`:

```
ServerRoot "/etc/httpd"
```

**<IfModule>** Multiprocessing modules (MPMs) allow you to change the way Apache works by changing the modules it uses. The `<IfModule>` containers (page 856) allow you to use the same `httpd.conf` file with different modules: The directives in an `<IfModule>` container are executed only if the specified module is loaded.

The section of `httpd.conf` that starts with the comment

```
## Server-Pool Size Regulation (MPM specific)
```

holds two `<IfModule>` containers (page 856) that configure Apache, depending on which module, `prefork` or `worker`, is loaded. Fedora/RHEL ships Apache with the `prefork` module loaded; this section does not discuss the `<IfModule>` container for the `worker` module. (See the comments in the `/etc/sysconfig/httpd` file if you want to load the `worker` module.)

The `prefork` `<IfModule>` container, shown below, holds directives that control the functioning of Apache when it starts and as it runs:

```
<IfModule prefork.c>
StartServers      8
MinSpareServers   5
MaxSpareServers   20
ServerLimit       256
MaxClients        256
MaxRequestsPerChild 4000
</IfModule>
```

**Listen** *FEDORA* The `Listen` directive (page 851) does not specify an IP address.

*RHEL* The `Listen` directive specifies an IP address of 0.0.0.0, which is the same as not specifying an IP address, so Apache listens on all network interfaces.

```
Listen 80
```

**LoadModule** There are quite a few **LoadModule** directives (page 867); these directives load the Apache DSO modules (page 876).

**Include** The **Include** directive (page 866) includes the files that match **\*.conf** in the **/etc/httpd/conf.d** directory, as though they were part of **httpd.conf**:

```
Include conf.d/*.conf
```

**Fedora/RHEL test page** When you first install Apache, there is no **index.html** file in **/var/www/html**; when you point a browser at the local Web server, Apache generates error 403, which returns the Fedora/RHEL test page. The mechanism by which this page is returned is convoluted: The Fedora/RHEL **httpd.conf** file holds an **Include** directive that includes all files in the **conf.d** directory that is in the **ServerRoot** directory (page 865). The **welcome.conf** file in this directory contains an **ErrorDocument 403** directive (page 863) that redirects users who receive this error to **error/noindex.html** in the **DocumentRoot** directory (page 852). The **noindex.html** file is the Fedora/RHEL test page that confirms the server is working but there is no content to display.

## SECTION 2: MAIN SERVER CONFIGURATION

**ServerAdmin, ServerName** As Fedora/RHEL is shipped, the **ServerAdmin** and **ServerName** directives are commented out. Change them to useful values as suggested in the **ServerAdmin** (page 851) and **ServerName** (page 852) sections.

**DocumentRoot** The **DocumentRoot** directive (page 852) appears as follows:

```
DocumentRoot "/var/www/html"
```

You need to modify this directive only if you want to put your content somewhere other than **/var/www/html**.

**<Directory>** The following **<Directory>** container (page 855) sets up a restrictive environment for the entire local filesystem (specified by **/**):

```
<Directory />
    Options FollowSymLinks
    AllowOverride None
</Directory>
```

The **Options** directive (page 867) allows Apache to follow symbolic links but disallows many options. The **AllowOverride** directive (page 869) causes Apache to ignore **.htaccess** files. You must explicitly enable less restrictive options if you want them, but be aware that doing so can expose the root filesystem and compromise system security.

Next another **<Directory>** container sets up less restrictive options for the **DocumentRoot** (**/var/www/html**). The code in **httpd.conf** is interspersed with many comments. Without the comments it looks like this:

```
<Directory "/var/www/html">
    Options Indexes FollowSymLinks
    AllowOverride None
    Order allow,deny
    Allow from all
</Directory>
```

The `Indexes` option in the `Options` directive allows Apache to display directory listings. The `Order` (page 870) and `Allow` (page 868) directives combine to allow requests from all clients. This container is slightly less restrictive than the preceding one, although it still does not allow Apache to follow directives in `.htaccess` files.

**DirectoryIndex** As explained on page 853, the `DirectoryIndex` directive causes Apache to return the file named `index.php`, `index.html`, `index.htm`, or `index.shtml` from a requested directory. Because `Options Indexes` is specified in the preceding `<Directory>` container, if none of these files exists in a queried directory, Apache returns a directory listing:

```
DirectoryIndex index.html index.html.var
```

There are many more directives in this part of the `httpd.conf` file. The comments in the file provide a guide as to what they do. There is nothing here you need to change as you get started using Apache.

## SECTION 3: VIRTUAL HOSTS

All lines in this section are comments or commented-out directives. If you want to set up virtual hosts, see page 874.

---

## REDIRECTS

Apache can respond to a request for a URI by asking the client to request a different URI. This response is called a *redirect*. A redirect works because redirection is part of the HTTP implementation: Apache sends the appropriate response code and the new URI, and a compliant browser requests the new location.

The `Redirect` directive can establish an explicit redirect that sends a client to a different page when a Web site is moved. Or, when a user enters the URI of a directory in a browser but leaves off the trailing slash, Apache can automatically redirect the client to the same URI terminated with a slash.

**UseCanonicalName** The `ServerName` directive (page 852), which establishes the name of the server, and the `UseCanonicalName` directive (page 861) are both important when a server has more than one name and needs to perform an automatic redirect. For example, assume the server with the name `zach.example.com` and the alias `www.example.com` has `ServerName` set to `www.example.com`. When a client specifies a URI of a directory but leaves off the trailing slash (`zach.example.com/dir`), Apache has to perform a redirect to determine the URI of the requested directory. When `UseCanonicalName` is set to `On`, Apache uses the value of `ServerName` and returns `www.example.com/dir/`. With `UseCanonicalName` set to `Off`, Apache uses the name from the incoming request and returns `zach.example.com/dir/`.

## MULTIVIEWS

Multiviews is a way to represent a page in different ways, most commonly in different languages. Using request headers, a browser can request a specific language from a server. Servers that cannot handle these requests ignore them.

## SERVER-GENERATED DIRECTORY LISTINGS (INDEXING)

When a client requests a directory, the Apache configuration determines what is returned to the client. Apache can return a file as specified by the `DirectoryIndex` directive (page 853), a directory listing if no file matches `DirectoryIndex` and the `Options Indexes` directive (page 867) is set, or an error message if no file matches `DirectoryIndex` and `Options Indexes` is not set.

## VIRTUAL HOSTS

Apache supports *virtual hosts*, which means that one instance of Apache can respond to requests directed to multiple IP addresses or hostnames as though it were multiple servers. Each IP address or hostname can then provide different content and be configured differently.

There are two types of virtual hosts: *host-by-name* and *host-by-IP*. Host-by-name relies on the FQDN the client uses in its request to Apache—for example, **www.example.com** versus **www2.example.com**. Host-by-IP examines the IP address the host resolves as and responds according to that match.

Host-by-name is handy if there is only one IP address, but Apache must support multiple FQDNs. Although you can use host-by-IP if a given Web server has aliases, Apache should serve the same content regardless of which name is used.

Virtual hosts inherit their configurations from **httpd.conf** Section 1 (page 871) and Section 2 (page 872). In Section 3, `<VirtualHost>` containers create the virtual hosts and specify directives that override inherited and default values. You can specify many virtual hosts for a single instance of Apache.

The following `<VirtualHost>` container sets up a host-by-name for the site named **intranet.example.com**. This virtual host handles requests that are directed to **intranet.example.com**.

```
<VirtualHost intranet.example.com>
    ServerName intranet.example.com
    DocumentRoot /usr/local/www
    ErrorLog /var/log/httpd/intra.error_log
```

```

CustomLog /var/log/httpd/intra.server_log
<Directory /usr/local/www>
    Order deny,allow
    Deny from all
    Allow from 192.168. # allow from private subnet only
</Directory>
</VirtualHost>

```

## TROUBLESHOOTING

You can use `service` and the `httpd` init script to check the syntax of the Apache configuration files:

```

# service httpd configtest
Syntax OK

```

Once you start the `httpd` daemon, you can confirm that Apache is working correctly by pointing a browser on the local system at `http://localhost/`. From a remote system, use `http://server/`, substituting the hostname of the server for *server*. In response, Apache displays the Fedora/RHEL test page.

If the browser does not display the test page, it will display one of two errors: **Connection refused** or an error page. If you get a **Connection refused** error, make sure that port 80 is not blocked by a firewall (page 844) and check that the server is running:

```

# /sbin/service httpd status
httpd (pid 21406 21405 21404 21403 21402 21401 13622) is running...

```

If the server is running, check that you did not specify a port other than 80 in a `Listen` directive. If you did, the URI you specify in the browser must reflect this port number (`http://localhost:port` specifies port *port*). Otherwise, check the error log (`/var/log/httpd/error_log`) for information on what is not working.

To verify that the browser is not at fault, use `telnet` to try to connect to port 80 of the server:

```

$ telnet www.example.com 80
Trying 192.0.34.166...
Connected to www.example.com.
Escape character is '^['.
CONTROL-]
telnet> quit
Connection closed.

```

If **Connection refused** is displayed, you have verified that you cannot get through to the server.

## MODULES

Apache is a skeletal program that relies on external modules, called dynamic shared objects (DSOs), to provide most of its functionality. This section lists these modules and discusses some of the more important ones. In addition to the modules included with Fedora/RHEL, many other modules are available. See [httpd.apache.org/modules](http://httpd.apache.org/modules) for more information.

## MODULE LIST

Following is a list of some of the modules that are available under Apache:

- access** (mod\_access.so) Controls access based on client characteristics.
- actions** (mod\_actions.so) Allows execution of CGI scripts based on the request method.
- alias** (mod\_alias.so) Allows outside directories to be mapped to DocumentRoot.
- asis** (mod\_asis.so) Allows sending files that contain their own headers.
- auth** (mod\_auth.so) Provides user authentication via **.htaccess**.
- auth\_anon** (mod\_auth\_anon.so) Provides anonymous user access to restricted areas.
- auth\_dbm** (mod\_auth\_dbm.so) Uses DBM files for authentication.
- auth\_digest** (mod\_auth\_digest.so) Uses MD5 digest for authentication.
- autoindex** (mod\_autoindex.so) Allows directory indexes to be generated.
- cern\_meta** (mod\_cern\_meta.so) Allows the use of CERN **httpd** metafile semantics.
- cgi** (mod\_cgi.so) Allows the execution of CGI scripts.
- dav** (mod\_dav.so) Allows Distributed Authoring and Versioning.
- dav\_fs** (mod\_dav\_fs.so) Provides a filesystem for mod\_dav.
- dir** (mod\_dir.so) Allows directory redirects and listings as index files.
- env** (mod\_env.so) Allows CGI scripts to access environment variables.
- expires** (mod\_expires.so) Allows generation of Expires HTTP headers.
- headers** (mod\_headers.so) Allows customization of request and response headers.
- imap** (mod\_imap.so) Allows image maps to be processed on the server side.
- include** (mod\_include.so) Provides server-side includes (SSIs).
- info** (mod\_info.so) Allows the server configuration to be viewed.
- log\_config** (mod\_log\_config.so) Allows logging of requests made to the server.
- mime** (mod\_mime.so) Allows association of file extensions with content.
- mime\_magic** (mod\_mime\_magic.so) Determines MIME types of files.
- negotiation** (mod\_negotiation.so) Allows content negotiation.
- proxy** (mod\_proxy.so) Allows Apache to act as a proxy server.
- proxy\_connect** (mod\_proxy\_connect.so) Allows connect request handling.
- proxy\_ftp** (mod\_proxy\_ftp.so) Provides an FTP extension proxy.
- proxy\_http** (mod\_proxy\_http.so) Provides an HTTP extension proxy.
- rewrite** (mod\_rewrite.so) Allows on-the-fly URI rewriting based on rules.
- setenvif** (mod\_setenvif.so) Sets environment variables based on a request.
- speling** (mod\_speling.so) Auto-corrects spelling if the requested URI has incorrect capitalization and one spelling mistake.
- status** (mod\_status.so) Allows the server status to be queried and viewed.



**unique\_id** (mod\_unique\_id.so) Generates a unique ID for each request.  
**userdir** (mod\_userdir.so) Allows users to have content directories (public\_html).  
**usertrack** (mod\_usertrack.so) Allows tracking of user activity on a site.  
**vhost\_alias** (mod\_vhost\_alias.so) Allows the configuration of virtual hosting.

## mod\_cgi AND CGI SCRIPTS

The CGI (Common Gateway Interface) allows external application programs to interface with Web servers. Any program can be a CGI program if it runs in real time (at the time of the request) and relays its output to the requesting client. Various kinds of scripts, including shell, Perl, Python, and PHP, are the most commonly encountered CGI programs because a script can call a program and reformat its output in HTML for a client.

Apache can handle requests for CGI programs in several different ways. The most common method is to put a CGI program in the **cgi-bin** directory and then enable its execution from that directory only. The location of the **cgi-bin** directory, as specified by the ScriptAlias directive (page 868), is **/var/www/cgi-bin**. Alternatively, an AddHandler directive (page 862) can identify filename extensions of scripts, such as **.cgi** or **.pl**, within the regular content (for example, **AddHandler cgi-script .cgi**). If you use AddHandler, you must also specify the ExecCGI option in an Options directive within the appropriate <Directory> container. The **mod\_cgi** module must be loaded to access and execute CGI scripts.

The following Perl CGI script displays the Apache environment. This script should be used for debugging only because it presents a security risk if outside clients can access it:

```
#!/usr/bin/perl
##
## printenv -- demo CGI program that prints its environment
##

print "Content-type: text/plain\n\n";
foreach $var (sort(keys(%ENV))) {
    $val = $ENV{$var};
    $val =~ s|\n|\\n|g;
    $val =~ s|\"|\\\"|g;
    print "${var}=\"${val}\"\\n";
}
```

## mod\_ssl

SSL (Secure Sockets Layer), which is implemented by the **mod\_ssl** module, has two functions: It allows a client to verify the identity of a server and it enables secure two-way communication between a client and a server. SSL is used on Web pages with forms that require passwords, credit card numbers, or other sensitive data.

Apache uses the HTTPS protocol—not HTTP—for SSL communication. When Apache uses SSL, it listens on a second port (443 by default) for a connection and performs a handshaking sequence before sending the requested content to the client.

Server verification is critical for financial transactions. After all, you do not want to give your credit card number to a fraudulent Web site posing as a known company. SSL uses a certificate to positively identify a server. Over a public network such as the Internet, the identification is reliable only if the certificate contains a digital signature from an authoritative source such as VeriSign or Thawte. SSL Web pages are denoted by a URI beginning with **https://**.

Data encryption prevents malicious users from eavesdropping on Internet connections and copying personal information. To encrypt communication, SSL sits between the network and an application and encrypts communication between the server and the client.

## SETTING UP `mod_ssl`

The `/etc/httpd/conf.d/ssl.conf` file configures `mod_ssl`. The first few directives in this file load the `mod_ssl` module, instruct Apache to listen on port 443, and set various parameters for SSL operation. About a third of the way through the file is a section labeled **SSL Virtual Host Context** that sets up virtual hosts (page 874).

A `<VirtualHost>` container in `ssl.conf` is similar to one in `httpd.conf`. As with any `<VirtualHost>` container, it holds directives such as `ServerName` and `ServerAdmin` that need to be configured. In addition, it holds some SSL-related directives.

## USING A SELF-SIGNED CERTIFICATE FOR ENCRYPTION

If you require SSL for encryption and not verification—that is, if the client already trusts the server—you can generate and use a self-signed certificate, bypassing the time and expense involved in obtaining a digitally signed certificate. Self-signed certificates generate a warning when you connect to the server: Most browsers display a dialog box that allows you to examine and accept the certificate. The `sendmail` daemon also uses certificates (page 690).

The self-signed certificate depends on two files: a private key and the certificate. The location of each file is specified in `/etc/httpd/conf.d/ssl.conf`.

```
# grep '^SSLCertificate' /etc/httpd/conf.d/ssl.conf
SSLCertificateFile /etc/pki/tls/certs/localhost.crt
SSLCertificateKeyFile /etc/pki/tls/private/localhost.key
```

To generate the private key that the encryption relies on, `cd` to `/etc/pki/tls/certs` and enter a `make` command:

```
# cd /etc/pki/tls/certs
# make localhost.key
umask 77 ; \
    /usr/bin/openssl genrsa -aes128 2048 > localhost.key
Generating RSA private key, 2048 bit long modulus
.....+++
.....+++
e is 65537 (0x10001)
Enter pass phrase:
Verifying - Enter pass phrase:
```

The preceding command generates a file named **localhost.key** that is protected by the pass phrase you entered: *You will need this pass phrase to start the server.* Keep the **server.key** file secret.

The next command generates the certificate. This process uses the private key you just created. You need to supply the same pass phrase you entered when you created the private key.

```
# make localhost.crt
umask 77 ; \
/usr/bin/openssl req -utf8 -new -key localhost.key -x509 -days 365 -out
localhost.crt -set_serial 0
Enter pass phrase for localhost.key:
You are about to be asked to enter information that will be incorporated
into your certificate request.
What you are about to enter is what is called a Distinguished Name or a DN.
There are quite a few fields but you can leave some blank
For some fields there will be a default value,
If you enter '.', the field will be left blank.
-----
Country Name (2 letter code) [GB]:US
State or Province Name (full name) [Berkshire]:California
Locality Name (eg, city) [Newbury]:San Francisco
Organization Name (eg, company) [My Company Ltd]:Sobell Associates Inc.
Organizational Unit Name (eg, section) []:
Common Name (eg, your name or your server's hostname) []:www.sobell.com
Email Address []:mgs@sobell.com
```

The answers to the first five questions are arbitrary: They can help clients identify a site when they examine the certificate. The answer to the sixth question (**Common Name**) is critical. Because certificates are tied to the name of the server, you must enter the server's FQDN accurately. If you mistype this information, the server name and that of the certificate will not match. The browser will then generate a warning message each time a connection is made.

As specified by **ssl.conf**, Apache looks for the files in the directory that you created them in. Do not move these files. After you restart Apache, the new certificate will be in use.

## NOTES ON CERTIFICATES

- Although the server name is part of the certificate, the SSL connection is tied to the IP address of the server: You can have only one certificate per IP address. For multiple virtual hosts to have separate certificates, you must specify host-by-IP rather than host-by-name virtual hosts (page 874).
- As long as the server is identified by the name for which the certificate was issued, you can use the certificate on another server and/or IP address.
- A root certificate (root CA) is the certificate that signs the server certificate. Every browser contains a database of the public keys for the root certificates of the major signing authorities, including VeriSign and Thawte.

- It is possible to generate a root certificate (root CA) and sign all your server certificates with this root CA. Regular clients can import the public key of the root CA so that they recognize every certificate signed by that root CA. This setup is convenient for a server with multiple SSL-enabled virtual hosts and no commercial certificates. For more information see [www.modssl.org/docs/2.8/ssl\\_faq.html#ToC29](http://www.modssl.org/docs/2.8/ssl_faq.html#ToC29).
- You cannot use a self-signed certificate if clients need to verify the identity of the server.

## AUTHENTICATION MODULES AND .htaccess

To restrict access to a Web page, Apache and third parties provide authentication modules and methods that can verify a user's credentials, such as a username and password. Some modules enable authentication against various databases, including NIS (page 695) and LDAP (page 710).

User authentication directives are commonly placed in a **.htaccess** file. A basic **.htaccess** file that uses the Apache default authentication module (**mod\_auth**) follows. Substitute appropriate values for the local server.

```
# cat .htaccess
AuthUserFile /var/www/.htpasswd
AuthGroupFile /dev/null
AuthName "Browser dialog box query"
AuthType Basic
require valid-user
```

The **/var/www/.htpasswd** is a typical absolute pathname of a **.htpasswd** file and **Browser dialog box query** is the string that the user will see as part of the dialog box that requests a username and password.

The second line of the preceding **.htaccess** file turns off the group function. The fourth line specifies the user authentication type **Basic**, which is implemented by the default **mod\_auth** module. The last line tells Apache which users can access the protected directory. The entry **valid-user** grants access to the directory to any user who is in the Apache password file and who enters the correct password. You can also specify Apache usernames separated by SPACES.

You can put the Apache password file anywhere on the system, as long as Apache can read it. It is safe to put this file in the same directory as the **.htaccess** file because, by default, Apache will not answer any requests for files whose names start with **.ht**.

The following command creates a **.htpasswd** file for Sam:

```
$ htpasswd -c .htpasswd sam
New password:
```

```
Re-type new password:  
Adding password for user sam
```

Omit the `-c` option to add a user or to change a password in an existing `.htpasswd` file. Remember to use an `AllowOverride` directive (page 869) to permit Apache to read the `.htaccess` file.

## SCRIPTING MODULES

Apache can process content before serving it to a client. In earlier versions of Apache, only CGI scripts could process content. In the current version, *scripting modules* can work with scripts that are embedded in HTML documents.

Scripting modules manipulate content before Apache serves it to a client. Because they are built into Apache, they are fast. Scripting modules are especially efficient at working with external data sources such as relational databases. Clients can pass data to a scripting module that modifies the information that Apache serves.

Contrast scripting modules with CGI scripts that are run externally to Apache: CGI scripts do not allow client interaction and are slow because they must make external calls.

Fedora/RHEL provides packages that allow you to embed Perl, Python, and PHP code in HTML content. Perl and Python, which are general-purpose scripting languages, are encapsulated for use directly in Apache and are implemented in the `mod_perl` and `mod_python` modules, respectively.

PHP, which was developed for manipulating Web content, outputs HTML by default. Implemented in the `mod_php` module, this language is easy to set up, has a syntax similar to Perl and C, and comes with a large number of Web-related functions.

---

## webalizer: ANALYZES WEB TRAFFIC

The `webalizer` package, which is typically installed as part of Apache, creates a directory at `/var/www/usage` and a cron file (page 565) at `/etc/cron.daily/00webalizer`. Once a day, the cron file generates usage data and puts it in the `usage` directory; you can view this data by pointing a browser at `http://server/usage/`, where *server* is the hostname of the server.

The `/etc/webalizer.conf` file controls the behavior of the `webalizer` utility. If you change the location of the `DocumentRoot` or log files, you must edit this file to reflect those changes. For more information on `webalizer`, refer to the `webalizer` man page and the sites listed under “More Information” on page 843.

---

## MRTG: MONITORS TRAFFIC LOADS

Multi Router Traffic Grapher (MRTG) is an open-source application that graphs statistics available through SNMP (Simple Network Management Protocol). SNMP information is available on all high-end routers and switches, as well as on some other networked equipment, such as printers and wireless access points. You can use the **net-snmp** and **net-snmp-utils** packages supplied by Fedora/RHEL to install SNMP on a system. You also need to install the **mrtg** package.

Once MRTG and SNMP are installed and running, you can view the reports at **<http://server/mrtg>**, where *server* is the FQDN of the server. For more information see the mrtg man page and the sites listed under “More Information” on page 843.

---

## ERROR CODES

Following is a list of Apache error codes:

- 100 Continue
- 101 Switching Protocols
- 200 OK
- 201 Created
- 202 Accepted
- 203 Non-Authoritative Information
- 204 No Content
- 205 Reset Content
- 206 Partial Content
- 300 Multiple Choices
- 301 Moved Permanently
- 302 Moved Temporarily
- 303 See Other
- 304 Not Modified
- 305 Use Proxy
- 400 Bad Request
- 401 Unauthorized
- 402 Payment Required
- 403 Forbidden
- 404 Not Found
- 405 Method Not Allowed
- 406 Not Acceptable
- 407 Proxy Authentication Required
- 408 Request Time-out
- 409 Conflict
- 410 Gone
- 411 Length Required
- 412 Precondition Failed

- 413 Request Entity Too Large
- 414 Request-URI Too Large
- 415 Unsupported Media Type
- 500 Internal Server Error
- 501 Not Implemented
- 502 Bad Gateway
- 503 Service Unavailable
- 504 Gateway Time-out
- 505 HTTP Version not supported

---

## CHAPTER SUMMARY

Apache is the most popular Web server on the Internet today. It is both robust and extensible. The `/etc/httpd/conf/httpd.conf` configuration file controls many aspects of how Apache runs. The Fedora/RHEL `httpd.conf` file, which is based on the `httpd.conf` file distributed by Apache, is heavily commented and broken into three parts: Global Environment, Main Server Configuration, and Virtual Hosts. You can use the `system-config-httpd` utility to modify `httpd.conf`.

Content to be served must be placed in `/var/www/html`, called the document root. Apache automatically displays the file named `index.html` in this directory.

Configuration directives, or simply directives, are lines in a configuration file that control some aspect of how Apache functions. Four locations, called contexts, define where a configuration directive can appear: **server config**, **virtual host**, **directory**, and **.htaccess**. Containers, or special directives, are directives that group other directives.

To restrict access to a Web page, Apache and third parties provide authentication modules and methods that can verify a user's credentials, such as a username and password. Some modules enable authentication against various databases, including LDAP and NIS.

Apache can respond to a request for a URI by asking the client to request a different URI. This response is called a redirect. Apache can also process content before serving it to a client using scripting modules that work with scripts embedded in HTML documents.

Apache supports virtual hosts, which means that one instance of Apache can respond to requests directed to multiple IP addresses or hostnames as though it were multiple servers. Each IP address or hostname can provide different content and be configured differently.

The CGI (Common Gateway Interface) allows external application programs to interface with Web servers. Any program can be a CGI program if it runs in real time and relays its output to the requesting client.

SSL (Secure Sockets Layer) has two functions: It allows a client to verify the identity of a server and it enables secure two-way communication between a client and server.

## EXERCISES

1. How would you tell Apache that your content is in `/usr/local/www`?
2. How would you instruct an Apache server to listen on port 81 instead of port 80?
3. How would you enable Sam to publish Web pages from his `~/website` directory but not allow anyone else to publish to the Web?
4. Apache must be started as **root**. Why? Why does this action not present a security risk?

---

## ADVANCED EXERCISES

5. If you are running Apache on a firewall system, perhaps to display a Web front end for firewall configuration, how would you make sure that it is accessible only from inside the local network?
6. Why is it more efficient to run scripts using **mod\_php** or **mod\_perl** than through CGI?
7. What two things does SSL provide and how does this differ if the certificate is self-signed?
8. Some Web sites generate content by retrieving data from a database and inserting it into a template using PHP or CGI each time the site is accessed. Why is this practice often a poor idea?
9. Assume you want to provide Webmail access for employees on the same server that hosts the corporate Web site. The Web site address is `example.com`, you want to use `mail.example.com` for Webmail, and the Webmail application is located in `/var/www/webmail`. Describe two ways you can set this up this configuration.
10. Part of a Web site is a private intranet and is accessed as `http://example.com/intranet`. Describe how you would prevent people outside the company from accessing this site. Assume the company uses the `192.168.0.0/16` subnet internally.



# PART VI

---

## PROGRAMMING TOOLS

### CHAPTER 27

PROGRAMMING THE BOURNE AGAIN SHELL 887

### CHAPTER 28

THE PERL SCRIPTING LANGUAGE 975

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# 27

## PROGRAMMING THE BOURNE AGAIN SHELL

### IN THIS CHAPTER

Control Structures.....	888
File Descriptors.....	921
Parameters and Variables .....	924
Array Variables .....	924
Locality of Variables .....	926
Special Parameters.....	928
Positional Parameters.....	930
Builtin Commands .....	936
Expressions.....	950
Shell Programs .....	958
A Recursive Shell Script .....	959
The quiz Shell Script.....	962

Chapter 7 introduced the shells and Chapter 9 went into detail about the Bourne Again Shell. This chapter introduces additional Bourne Again Shell commands, builtins, and concepts that carry shell programming to a point where it can be useful. The first part of this chapter covers programming control structures, which are also known as control flow constructs. These structures allow you to write scripts that can loop over command-line arguments, make decisions based on the value of a variable, set up menus, and more. The Bourne Again Shell uses the same constructs found in such high-level programming languages as C.

The next part of this chapter discusses parameters and variables, going into detail about array variables, local versus global variables, special parameters, and positional parameters. The exploration of builtin commands covers `type`, which displays information about a command, and `read`, which allows you to accept user input in a shell script. The section on the `exec` builtin demonstrates how `exec` provides an efficient way to execute a command by replacing a process and explains how

you can use it to redirect input and output from within a script. The next section covers the `trap` builtin, which provides a way to detect and respond to operating system signals (such as that which is generated when you press `CONTROL-C`). The discussion of builtins concludes with a discussion of `kill`, which can abort a process, and `getopts`, which makes it easy to parse options for a shell script. (Table 27-6 on page 949 lists some of the more commonly used builtins.)

Next the chapter examines arithmetic and logical expressions and the operators that work with them. The final section walks through the design and implementation of two major shell scripts.

This chapter contains many examples of shell programs. Although they illustrate certain concepts, most use information from earlier examples as well. This overlap not only reinforces your overall knowledge of shell programming but also demonstrates how you can combine commands to solve complex tasks. Running, modifying, and experimenting with the examples in this book is a good way to become comfortable with the underlying concepts.

### Do not name a shell script `test`

---

**tip** You can unwittingly create a problem if you give a shell script the name **`test`** because a Linux utility has the same name. Depending on how the **`PATH`** variable is set up and how you call the program, you may run your script or the utility, leading to confusing results.

---

This chapter illustrates concepts with simple examples, which are followed by more complex ones in sections marked “Optional.” The more complex scripts illustrate traditional shell programming practices and introduce some Linux utilities often used in scripts. You can skip these sections without loss of continuity the first time you read the chapter. Return to them later when you feel comfortable with the basic concepts.

---

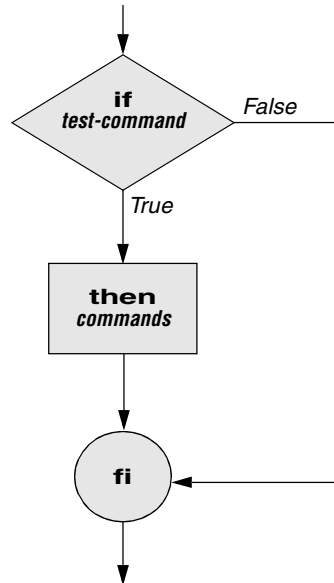
## CONTROL STRUCTURES

The *control flow* commands alter the order of execution of commands within a shell script. Control structures include the **`if...then`**, **`for...in`**, **`while`**, **`until`**, and **`case`** statements. In addition, the **`break`** and **`continue`** statements work in conjunction with the control structures to alter the order of execution of commands within a script.

### if...then

The **`if...then`** control structure has the following syntax:

```
if test-command
then
    commands
fi
```



**Figure 27-1** An if...then flowchart

The *bold* words in the syntax description are the items you supply to cause the structure to have the desired effect. The *nonbold* words are the keywords the shell uses to identify the control structure.

**test builtin** Figure 27-1 shows that the **if** statement tests the status returned by the *test-command* and transfers control based on this status. The end of the **if** structure is marked by a **fi** statement (*if* spelled backward). The following script prompts for two words, reads them, and then uses an **if** structure to execute commands based on the result returned by the **test** builtin when it compares the two words. (See the **test** info page for information on the **test** utility, which is similar to the **test** builtin.) The **test** builtin returns a status of *true* if the two words are the same and *false* if they are not. Double quotation marks around **\$word1** and **\$word2** make sure that **test** works properly if you enter a string that contains a **SPACE** or other special character:

```

$ cat if1
echo -n "word 1: "
read word1
echo -n "word 2: "
read word2

if test "$word1" = "$word2"
then
    echo "Match"
fi
echo "End of program."
  
```

```
$ if1
word 1: peach
word 2: peach
Match
End of program.
```

In the preceding example the *test-command* is `test "$word1" = "$word2"`. The test builtin returns a *true* status if its first and third arguments have the relationship specified by its second argument. If this command returns a *true* status (`= 0`), the shell executes the commands between the **then** and **fi** statements. If the command returns a *false* status (`not = 0`), the shell passes control to the statement following **fi** without executing the statements between **then** and **fi**. The effect of this **if** statement is to display **Match** if the two words are the same. The script always displays **End of program**.

**Builtins** In the Bourne Again Shell, `test` is a builtin—part of the shell. It is also a stand-alone utility kept in `/usr/bin/test`. This chapter discusses and demonstrates many Bourne Again Shell builtins. You usually use the builtin version if it is available and the utility if it is not. Each version of a command may vary slightly from one shell to the next and from the utility to any of the shell builtins. See page 936 for more information on shell builtins.

**Checking arguments** The next program uses an **if** structure at the beginning of a script to check that you have supplied at least one argument on the command line. The `-eq` test operator compares two integers, where the `$#` special parameter (page 931) takes on the value of the number of command-line arguments. This structure displays a message and exits from the script with an exit status of 1 if you do not supply at least one argument:

```
$ cat chkargs
if test $# -eq 0
then
    echo "You must supply at least one argument."
    exit 1
fi
echo "Program running."
$ chkargs
You must supply at least one argument.
$ chkargs abc
Program running.
```

A test like the one shown in `chkargs` is a key component of any script that requires arguments. To prevent the user from receiving meaningless or confusing information from the script, the script needs to check whether the user has supplied the appropriate arguments. Sometimes the script simply tests whether arguments exist (as in `chkargs`). Other scripts test for a specific number or specific kinds of arguments.

You can use `test` to ask a question about the status of a file argument or the relationship between two file arguments. After verifying that at least one argument has been given on the command line, the following script tests whether the argument is the

name of an ordinary file (not a directory or other type of file) in the working directory. The `test` builtin with the `-f` option and the first command-line argument (`$1`) check the file:

```
$ cat is_ordinaryfile
if test $# -eq 0
then
    echo "You must supply at least one argument."
    exit 1
fi
if test -f "$1"
then
    echo "$1 is an ordinary file in the working directory"
else
    echo "$1 is NOT an ordinary file in the working directory"
fi
```

You can test many other characteristics of a file with `test` and various options. Table 27-1 lists some of these options.

**Table 27-1** Options to the `test` builtin

Option	Tests file to see if it
<code>-d</code>	Exists and is a directory file
<code>-e</code>	Exists
<code>-f</code>	Exists and is an ordinary file (not a directory)
<code>-r</code>	Exists and is readable
<code>-s</code>	Exists and has a size greater than 0 bytes
<code>-w</code>	Exists and is writable
<code>-x</code>	Exists and is executable

Other `test` options provide ways to test relationships between two files, such as whether one file is newer than another. Refer to later examples in this chapter for more detailed information.

**Always test the arguments**

**tip** To keep the examples in this book short and focused on specific concepts, the code to verify arguments is often omitted or abbreviated. It is a good practice to test arguments in shell programs that other people will use. Doing so results in scripts that are easier to run and debug.

[] is a synonym for test The following example—another version of `chkargs`—checks for arguments in a way that is more traditional for Linux shell scripts. The example uses the bracket (`[]`) synonym for `test`. Rather than using the word `test` in scripts, you can surround the arguments to test with brackets. The brackets must be surrounded by white-space (SPACES or TABs).

```
$ cat chkargs2
if [ $# -eq 0 ]
then
    echo "Usage: chkargs2 argument..." 1>&2
    exit 1
fi
echo "Program running."
exit 0
$ chkargs2
Usage: chkargs2 arguments
$ chkargs2 abc
Program running.
```

Usage message The error message that **chkargs2** displays is called a *usage message* and uses the **1>&2** notation to redirect its output to standard error (page 284). After issuing the usage message, **chkargs2** exits with an exit status of 1, indicating that an error has occurred. The **exit 0** command at the end of the script causes **chkargs2** to exit with a 0 status after the program runs without an error. The Bourne Again Shell returns a 0 status if you omit the status code.

The usage message is commonly employed to specify the type and number of arguments the script takes. Many Linux utilities provide usage messages similar to the one in **chkargs2**. If you call a utility or other program with the wrong number or kind of arguments, you will often see a usage message. Following is the usage message that **cp** displays when you call it without any arguments:

```
$ cp
cp: missing file argument
Try 'cp --help' for more information.
```

## if...then...else

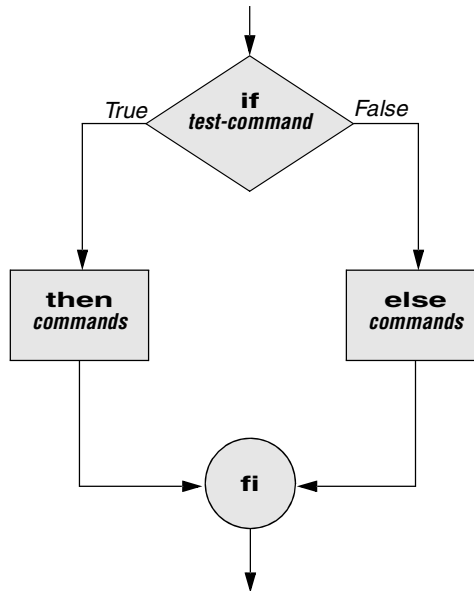
The introduction of an **else** statement turns the **if** structure into the two-way branch shown in Figure 27-2. The **if...then...else** control structure has the following syntax:

```
if test-command
then
    commands
else
    commands
fi
```

Because a semicolon (;) ends a command just as a **NEWLINE** does, you can place **then** on the same line as **if** by preceding it with a semicolon. (Because **if** and **then** are separate builtins, they require a command separator between them; a semicolon and **NEWLINE** work equally well.) Some people prefer this notation for aesthetic reasons, while others like it because it saves space:

```
if test-command; then
    commands
else
    commands
fi
```





**Figure 27-2** An if...then...else flowchart

If the *test-command* returns a *true* status, the *if* structure executes the commands between the *then* and *else* statements and then diverts control to the statement following *fi*. If the *test-command* returns a *false* status, the *if* structure executes the commands following the *else* statement.

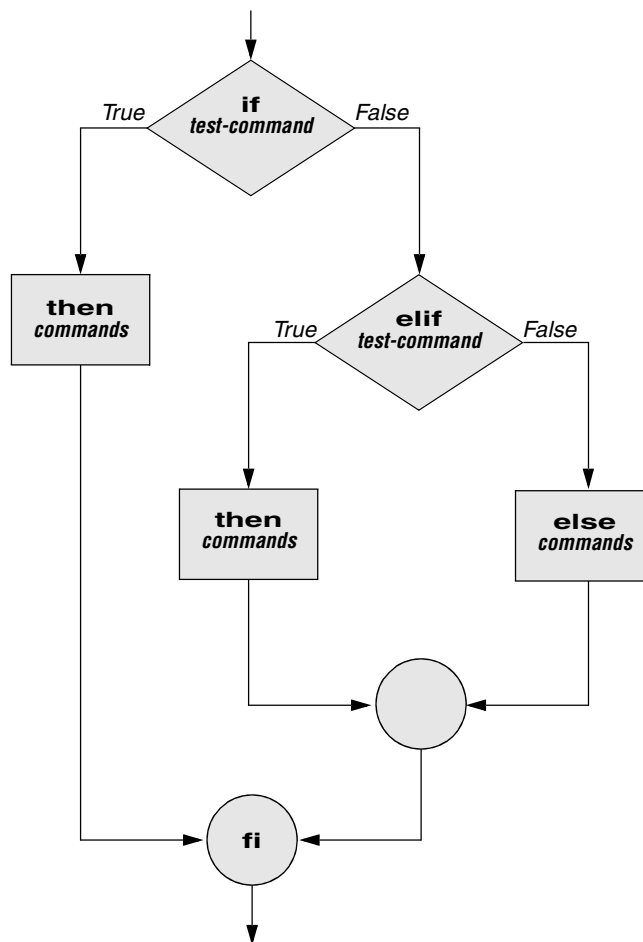
When you run the next script, named *out*, with arguments that are filenames, it displays the files on the terminal. If the first argument is *-v* (called an option in this case), *out* uses *less* (page 150) to display the files one page at a time. After determining that it was called with at least one argument, *out* tests its first argument to see whether it is *-v*. If the result of the test is *true* (if the first argument is *-v*), *out* uses the *shift* builtin to shift the arguments to get rid of the *-v* and displays the files using *less*. If the result of the test is *false* (if the first argument is *not -v*), the script uses *cat* to display the files:

```

$ cat out
if [ $# -eq 0 ]
then
    echo "Usage: out [-v] filenames..." 1>&2
    exit 1
fi
if [ "$1" = "-v" ]
then
    shift
    less -- "$@"
else
    cat -- "$@"
fi

```

**optional** In **out** the `--` argument to `cat` and `less` tells these utilities that no more options follow on the command line and not to consider leading hyphens (`-`) in the following list as indicating options. Thus `--` allows you to view a file with a name that starts with a hyphen. Although not common, filenames beginning with a hyphen do occasionally occur. (You can create such a file by using the command `cat > -fname.`) The `--` argument works with all Linux utilities that use the `getopts` builtin (page 946) to parse their options; it does not work with `more` and a few other utilities. This argument is particularly useful when used in conjunction with `rm` to remove a file whose name starts with a hyphen (`rm -- -fname`), including any that you create while experimenting with the `--` argument.



**Figure 27-3** An `if...then...elif` flowchart

## if...then...elif

The **if...then...elif** control structure (Figure 27-3) has the following syntax:

```

if test-command
then
    commands
elif test-command
then
    commands
...
else
    commands
fi

```

The **elif** statement combines the **else** statement and the **if** statement and allows you to construct a nested set of **if...then...else** structures (Figure 27-3). The difference between the **else** statement and the **elif** statement is that each **else** statement must be paired with a **fi** statement, whereas multiple nested **elif** statements require only a single closing **fi** statement.

The following example shows an **if...then...elif** control structure. This shell script compares three words that the user enters. The first **if** statement uses the Boolean operator AND (**-a**) as an argument to **test**. The **test** builtin returns a *true* status only if the first and second logical comparisons are *true* (that is, if **word1** matches **word2** and **word2** matches **word3**). If **test** returns a *true* status, the script executes the command following the next **then** statement, passes control to the statement following **fi**, and terminates:

```

$ cat if3
echo -n "word 1: "
read word1
echo -n "word 2: "
read word2
echo -n "word 3: "
read word3

if [ "$word1" = "$word2" -a "$word2" = "$word3" ]
then
    echo "Match: words 1, 2, & 3"
elif [ "$word1" = "$word2" ]
then
    echo "Match: words 1 & 2"
elif [ "$word1" = "$word3" ]
then
    echo "Match: words 1 & 3"
elif [ "$word2" = "$word3" ]
then
    echo "Match: words 2 & 3"
else
    echo "No match"
fi

```

```

$ if3
word 1: apple
word 2: orange
word 3: pear
No match
$ if3
word 1: apple
word 2: orange
word 3: apple
Match: words 1 & 3
$ if3
word 1: apple
word 2: apple
word 3: apple
Match: words 1, 2, & 3

```

If the three words are not the same, the structure passes control to the first **elif**, which begins a series of tests to see if any pair of words is the same. As the nesting continues, if any one of the **if** statements is satisfied, the structure passes control to the next **then** statement and subsequently to the statement following **fi**. Each time an **elif** statement is not satisfied, the structure passes control to the next **elif** statement. The double quotation marks around the arguments to **echo** that contain ampersands (&) prevent the shell from interpreting the ampersands as special characters.

### optional THE **lnks** SCRIPT

The following script, named **lnks**, demonstrates the **if...then** and **if...then...elif** control structures. This script finds hard links to its first argument, a filename. If you provide the name of a directory as the second argument, **lnks** searches for links in that directory and all subdirectories. If you do not specify a directory, **lnks** searches the working directory and its subdirectories. This script does not locate symbolic links.

```

$ cat lnks
#!/bin/bash
# Identify links to a file
# Usage: lnks file [directory]

if [ $# -eq 0 -o $# -gt 2 ]; then
    echo "Usage: lnks file [directory]" 1>&2
    exit 1
fi
if [ -d "$1" ]; then
    echo "First argument cannot be a directory." 1>&2
    echo "Usage: lnks file [directory]" 1>&2
    exit 1
else
    file="$1"
fi

```

```

if [ $# -eq 1 ]; then
    directory="."
elif [ -d "$2" ]; then
    directory="$2"
else
    echo "Optional second argument must be a directory." 1>&2
    echo "Usage: lnks file [directory]" 1>&2
    exit 1
fi

# Check that file exists and is an ordinary file:
if [ ! -f "$file" ]; then
    echo "lnks: $file not found or special file" 1>&2
    exit 1
fi
# Check link count on file
set -- $(ls -l "$file")
linkcnt=$2
if [ "$linkcnt" -eq 1 ]; then
    echo "lnks: no other hard links to $file" 1>&2
    exit 0
fi

# Get the inode of the given file
set $(ls -i "$file")

inode=$1

# Find and print the files with that inode number
echo "lnks: using find to search for links..." 1>&2
find "$directory" -xdev -inum $inode -print

```

Alex has a file named **letter** in his home directory. He wants to find links to this file in his and other users' home directory file trees. In the following example, Alex calls **lnks** from his home directory to perform the search. The second argument to **lnks**, **/home**, is the pathname of the directory he wants to start the search in. The **lnks** script reports that **/home/alex/letter** and **/home/jenny/draft** are links to the same file:

```

$ lnks letter /home
lnks: using find to search for links...
/home/alex/letter
/home/jenny/draft

```

In addition to the **if...then...elif** control structure, **lnks** introduces other features that are commonly used in shell programs. The following discussion describes **lnks** section by section.

Specify the shell The first line of the **lnks** script uses **#!** (page 288) to specify the shell that will execute the script:

```
#!/bin/bash
```

In this chapter the **#!** notation appears only in more complex examples. It ensures that the proper shell executes the script, even when the user is running a different shell or the script is called from another shell script.

**Comments** The second and third lines of **lnks** are comments; the shell ignores the text that follows a pound sign up to the next **NEWLINE** character. These comments in **lnks** briefly identify what the file does and how to use it:

```
# Identify links to a file
# Usage: lnks file [directory]
```

**Usage messages** The first **if** statement tests whether **lnks** was called with zero arguments or more than two arguments:

```
if [ $# -eq 0 -o $# -gt 2 ]; then
    echo "Usage: lnks file [directory]" 1>&2
    exit 1
fi
```

If either of these conditions is *true*, **lnks** sends a usage message to standard error and exits with a status of 1. The double quotation marks around the usage message prevent the shell from interpreting the brackets as special characters. The brackets in the usage message indicate that the **directory** argument is optional.

The second **if** statement tests whether the first command-line argument (**\$1**) is a directory (the **-d** argument to test returns a *true* value if the file exists and is a directory):

```
if [ -d "$1" ]; then
    echo "First argument cannot be a directory." 1>&2
    echo "Usage: lnks file [directory]" 1>&2
    exit 1
else
    file="$1"
fi
```

If the first argument is a directory, **lnks** displays a usage message and exits. If it is not a directory, **lnks** saves the value of **\$1** in the **file** variable because later in the script **set** resets the command-line arguments. If the value of **\$1** is not saved before the **set** command is issued, its value will be lost.

**Test the arguments** The next section of **lnks** is an **if...then...elif** statement:

```
if [ $# -eq 1 ]; then
    directory="."
elif [ -d "$2" ]; then
    directory="$2"
else
    echo "Optional second argument must be a directory." 1>&2
    echo "Usage: lnks file [directory]" 1>&2
    exit 1
fi
```

The first *test-command* determines whether the user specified a single argument on the command line. If the *test-command* returns 0 (*true*), the user-created variable named **directory** is assigned the value of the working directory (.). If the *test-command* returns *false*, the **elif** statement tests whether the second argument is a directory. If it is a directory, the **directory** variable is set equal to the second command-line argument, **\$2**. If **\$2** is not a directory, **lnks** sends a usage message to standard error and exits with a status of 1.

The next **if** statement in **lnks** tests whether **\$file** does not exist. This test keeps **lnks** from wasting time looking for links to a nonexistent file.

The **test** builtin with the three arguments **!**, **-f**, and **\$file** evaluates to *true* if the file **\$file** does *not* exist:

```
[ ! -f "$file" ]
```

The **!** operator preceding the **-f** argument to **test** negates its result, yielding *false* if the file **\$file** *does* exist and is an ordinary file.

Next **lnks** uses **set** and **ls -l** to check the number of links **\$file** has:

```
# Check link count on file
set -- $(ls -l "$file")
linkcnt=$2
if [ "$linkcnt" -eq 1 ]; then
    echo "lnks: no other hard links to $file" 1>&2
    exit 0
fi
```

The **set** builtin uses command substitution (page 348) to set the positional parameters to the output of **ls -l**. The second field in this output is the link count, so the user-created variable **linkcnt** is set equal to **\$2**. The **--** used with **set** prevents **set** from interpreting as an option the first argument produced by **ls -l** (the first argument is the access permissions for the file and typically begins with **-**). The **if** statement checks whether **\$linkcnt** is equal to 1; if it is, **lnks** displays a message and exits. Although this message is not truly an error message, it is redirected to standard error. The way **lnks** has been written, all informational messages are sent to standard error. Only the final product of **lnks**—the pathnames of links to the specified file—is sent to standard output, so you can redirect the output as you please.

If the link count is greater than one, **lnks** goes on to identify the *inode* (page 1087) for **\$file**. As explained on page 215, comparing the inodes associated with filenames is a good way to determine whether the filenames are links to the same file. The **lnks** script uses **set** to set the positional parameters to the output of **ls -li**. The first argument to **set** is the inode number for the file, so the user-created variable named **inode** is assigned the value of **\$1**:

```
# Get the inode of the given file
set $(ls -li "$file")

inode=$1
```

Finally **lnks** uses the **find** utility to search for files having inode numbers that match **\$inode**:

```
# Find and print the files with that inode number
echo "lnks: using find to search for links..." 1>&2
find "$directory" -xdev -inum $inode -print
```

The **find** utility searches for files that meet the criteria specified by its arguments, beginning its search with the directory specified by its first argument (**\$directory**) and searching all subdirectories. The remaining arguments specify that the filenames of files having inodes matching **\$inode** should be sent to standard output. Because files in different filesystems can have the same inode number and not be linked, **find** must search only directories in the same filesystem as **\$directory**. The **-xdev** argument prevents **find** from searching directories on other filesystems. Refer to page 212 for more information about filesystems and links.

The **echo** command preceding the **find** command in **lnks**, which tells the user that **find** is running, is included because **find** frequently takes a long time to run. Because **lnks** does not include a final exit statement, the exit status of **lnks** is that of the last command it runs, **find**.

## DEBUGGING SHELL SCRIPTS

When you are writing a script such as **lnks**, it is easy to make mistakes. You can use the shell's **-x** option to help debug a script. This option causes the shell to display each command before it runs the command. Tracing a script's execution in this way can give you information about where a problem lies.

You can run **lnks** as in the previous example and cause the shell to display each command before it is executed. Either set the **-x** option for the current shell (**set -x**) so that all scripts display commands as they are run or use the **-x** option to affect only the shell that is running the script called by the command line.

```
$ bash -x lnks letter /home
+ '[' 2 -eq 0 -o 2 -gt 2 -e ']'
+ '[' -d letter -e ']'
+ file=letter
+ '[' 2 -eq 1 -e ']'
+ '[' -d /home -e ']'
+ directory=/home
+ '[' '!' -f letter -e ']'
...
```

- PS4** Each command that the script executes is preceded by the value of the **PS4** variable—a plus sign (+) by default, so you can distinguish debugging output from script-produced output. You must export **PS4** if you set it in the shell that calls the script. The next command sets **PS4** to **>>>>** followed by a **SPACE** and exports it:

```
$ export PS4='>>>> '
```



You can also set the `-x` option of the shell running the script by putting the following `set` command at the top of the script:

```
set -x
```

Put `set -x` anywhere in the script you want to turn debugging on. Turn the debugging option off with a plus sign.

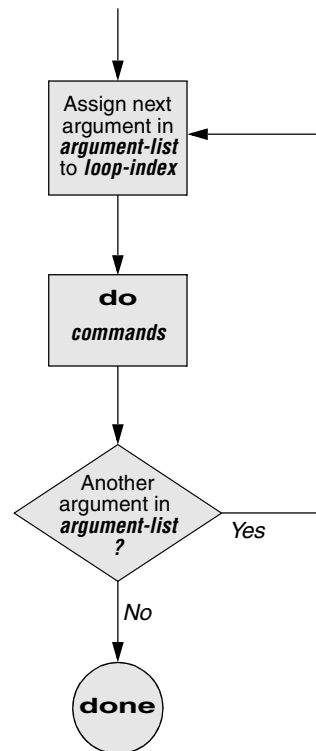
```
set +x
```

The `set -o xtrace` and `set +o xtrace` commands do the same things as `set -x` and `set +x`, respectively.

## for...in

The `for...in` control structure has the following syntax:

```
for loop-index in argument-list
do
    commands
done
```



**Figure 27-4** A `for...in` flowchart

The **for...in** structure (Figure 27-4, preceding page) assigns the value of the first argument in the *argument-list* to the *loop-index* and executes the *commands* between the **do** and **done** statements. The **do** and **done** statements mark the beginning and end of the **for** loop.

After it passes control to the **done** statement, the structure assigns the value of the second argument in the *argument-list* to the *loop-index* and repeats the *commands*. The structure repeats the *commands* between the **do** and **done** statements one time for each argument in the *argument-list*. When the structure exhausts the *argument-list*, it passes control to the statement following **done**.

The following **for...in** structure assigns **apples** to the user-created variable **fruit** and then displays the value of **fruit**, which is **apples**. Next the structure assigns **oranges** to **fruit** and repeats the process. When it exhausts the argument list, the structure transfers control to the statement following **done**, which displays a message.

```
$ cat fruit
for fruit in apples oranges pears bananas
do
    echo "$fruit"
done
echo "Task complete."

$ fruit
apples
oranges
pears
bananas
Task complete.
```

The next script lists the names of the directory files in the working directory by looping over all the files, using **test** to determine which files are directories:

```
$ cat dirfiles
for i in *
do
    if [ -d "$i" ]
    then
        echo "$i"
    fi
done
```

The ambiguous file reference character **\*** matches the names of all files (except hidden files) in the working directory. Prior to executing the **for** loop, the shell expands the **\*** and uses the resulting list to assign successive values to the index variable **i**.

## for

The **for** control structure has the following syntax:

```
for loop-index
do
    commands
done
```

In the **for** structure the *loop-index* takes on the value of each of the command-line arguments, one at a time. It is the same as the **for...in** structure (Figure 27-4, page 901) except for where it gets values for the *loop-index*. The **for** structure performs a sequence of commands, usually involving each argument in turn.

The following shell script shows a **for** structure displaying each command-line argument. The first line of the script, **for arg**, implies **for arg in "\$@"**, where the shell expands **"\$@"** into a list of quoted command-line arguments **"\$1"** **"\$2"** **"\$3"** and so on. The balance of the script corresponds to the **for...in** structure.

```
$ cat for_test
for arg
do
    echo "$arg"
done
$ for_test candy gum chocolate
candy
gum
chocolate
```

### optional THE whos SCRIPT

The following script, named **whos**, demonstrates the usefulness of the implied **"\$@"** in the **for** structure. You give **whos** one or more users' full names or usernames as arguments, and **whos** displays information about the users. The **whos** script gets the information it displays from the first and fifth fields in the **/etc/passwd** file. The first field always contains a username, and the fifth field typically contains the user's full name. You can provide a username as an argument to **whos** to identify the user's name or provide a name as an argument to identify the username. The **whos** script is similar to the **finger** utility, although **whos** delivers less information.

```
$ cat whos
#!/bin/bash
# adapted from finger.sh by Lee Sailer
# UNIX/WORLD, III:11, p. 67, Fig. 2

if [ $# -eq 0 ]
then
    echo "Usage: whos id..." 1>&2
    exit 1
fi
for id
do
    gawk -F: '{print $1, $5}' /etc/passwd |
    grep -i "$id"
done
```

Below **whos** identifies the user whose username is **chas** and the user whose name is **Marilou Smith**:

```
$ whos chas "Marilou Smith"
chas Charles Casey
msmith Marilou Smith
```

Use of "\$@" The **whos** script uses a **for** statement to loop through the command-line arguments. In this script the implied use of "\$@" in the **for** loop is particularly beneficial because it causes the **for** loop to treat an argument that contains a SPACE as a single argument. This example quotes **Marilou Smith**, which causes the shell to pass it to the script as a single argument. Then the implied "\$@" in the **for** statement causes the shell to regenerate the quoted argument **Marilou Smith** so that it is again treated as a single argument.

**gawk** For each command-line argument, **whos** searches the **/etc/passwd** file. Inside the **for** loop the **gawk** utility extracts the first (\$1) and fifth (\$5) fields from the lines in **/etc/passwd**. The **-F:** option causes **gawk** to use a colon (:) as a field separator when it reads **/etc/passwd**, allowing it to break each line into fields. The **gawk** command sets and uses the \$1 and \$5 arguments; they are included within single quotation marks and are not interpreted by the shell. Do not confuse these arguments with positional parameters, which correspond to command-line arguments. The first and fifth fields are sent to **grep** (page 153) via a pipe. The **grep** utility searches for \$id (which has taken on the value of a command-line argument) in its input. The **-i** option causes **grep** to ignore case as it searches; **grep** displays each line in its input that contains \$id.

| at the end of a line An interesting syntactical exception that **bash** gives the pipe symbol (|) appears on the line with the **gawk** command: You do not have to quote a NEWLINE that immediately follows a pipe symbol (that is, a pipe symbol that is the last thing on a line) to keep the NEWLINE from executing a command. Try giving the command **who |** and pressing RETURN. The shell displays a secondary prompt. If you then enter **sort** followed by another RETURN, you see a sorted **who** list. The pipe works even though a NEWLINE follows the pipe symbol.

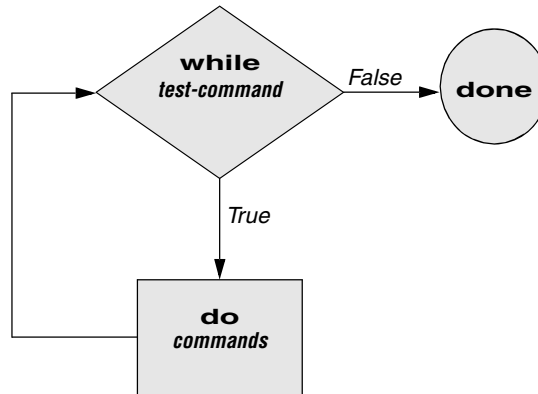
## while

The **while** control structure has the following syntax:

```
while test-command
do
    commands
done
```

As long as the *test-command* (Figure 27-5) returns a *true* exit status, the **while** structure continues to execute the series of *commands* delimited by the **do** and **done** statements. Before each loop through the *commands*, the structure executes the *test-command*. When the exit status of the *test-command* is *false*, the structure passes control to the statement after the **done** statement.

**test builtin** The following shell script first initializes the **number** variable to zero. The **test** builtin then determines whether **number** is less than 10. The script uses **test** with the **-lt** argument to perform a numerical test. For numerical comparisons, you must use **-ne** (not equal), **-eq** (equal), **-gt** (greater than), **-ge** (greater than or equal to), **-lt** (less than), or **-le** (less than or equal to). For string comparisons use **=** (equal) or **!=** (not equal) when you are working with **test**. In this example, **test** has an exit status



**Figure 27-5** A while flowchart

of 0 (*true*) as long as **number** is less than 10. As long as **test** returns *true*, the structure executes the commands between the **do** and **done** statements. See page 889 for information on the **test** utility, which is very similar to the **test** builtin.

```

$ cat count
#!/bin/bash
number=0
while [ "$number" -lt 10 ]
do
    echo -n "$number"
    ((number +=1))
done
echo
$ count
0123456789
$
  
```

The **echo** command following **do** displays **number**. The **-n** prevents **echo** from issuing a **NEWLINE** following its output. The next command uses arithmetic evaluation [((...)); page 950] to increment the value of **number** by 1. The **done** statement terminates the loop and returns control to the **while** statement to start the loop over again. The final **echo** causes **count** to send a **NEWLINE** character to standard output, so that the next prompt occurs in the leftmost column on the display (rather than immediately following 9).

### optional THE spell\_check SCRIPT

The **aspell** utility checks the words in a file against a dictionary of correctly spelled words. With the **list** command, **aspell** runs in list mode: Input comes from standard input and **aspell** sends each potentially misspelled word to standard output. The following command produces a list of possible misspellings in the file **letter.txt**:

```

$ aspell list < letter.txt
quikly
portible
frendly
  
```

The next shell script, named **spell\_check**, shows another use of a **while** structure. To find the incorrect spellings in a file, you can use **spell\_check**, which calls **aspell** to check a file against a system dictionary but goes a step further: It enables you to specify a list of correctly spelled words and removes these words from the output of **aspell**. This script is useful for removing words that you use frequently, such as names and technical terms, that are not in a standard dictionary. Although you can duplicate the functionality of **spell\_check** by using additional **aspell** dictionaries, the script is included here for its instructive value.

The **spell\_check** script requires two filename arguments: a file containing the list of correctly spelled words and a file that you want to check. The first **if** statement verifies that the user specified two arguments. The next two **if** statements verify that both arguments are readable files. (The exclamation point negates the sense of the following operator; the **-r** operator causes **test** to determine whether a file is readable. The result is a test that determines whether a file is *not readable*.)

```
$ cat spell_check
#!/bin/bash
# remove correct spellings from aspell output
if [ $# -ne 2 ]
then
    echo "Usage: spell_check file1 file2" 1>&2
    echo "file1: list of correct spellings" 1>&2
    echo "file2: file to be checked" 1>&2
    exit 1
fi

if [ ! -r "$1" ]
then
    echo "spell_check: $1 is not readable" 1>&2
    exit 1
fi

if [ ! -r "$2" ]
then
    echo "spell_check: $2 is not readable" 1>&2
    exit 1
fi

aspell -l < "$2" |
while read line
do
    if ! grep "^$line$" "$1" > /dev/null
    then
        echo $line
    fi
done
```

The **spell\_check** script sends the output from **aspell** (with the **-l** option so that it produces a list of misspelled words on standard output) through a pipe to standard input of a **while** structure, which reads one line at a time (each line has one word on

it) from standard input. The *test-command* (that is, *read line*) returns a *true* exit status as long as it receives a line from standard input.

Inside the **while** loop an **if** statement<sup>1</sup> monitors the return value of **grep**, which determines whether the line that was read is in the user's list of correctly spelled words. The pattern that **grep** searches for (the value of **\$line**) is preceded and followed by special characters that specify the beginning and end of a line (^ and \$, respectively). These special characters ensure that **grep** finds a match only if the **\$line** variable matches an entire line in the file of correctly spelled words. (Otherwise, **grep** would match a string, such as **paul**, in the output of **aspell** if the file of correctly spelled words contained the word **paulson**.) These special characters, together with the value of the **\$line** variable, form a regular expression (Appendix A).

The output of **grep** is redirected to **/dev/null** (page 237) because the output is not needed; only the exit code is important. The **if** statement checks the negated exit status of **grep** (the leading exclamation point negates or changes the sense of the exit status—*true* becomes *false*, and vice versa), which is 0 or *true* (*false* when negated) when a matching line is found. If the exit status is *not* 0 or *false* (*true* when negated), the word was *not* in the file of correctly spelled words. The **echo** builtin sends a list of words that are not in the file of correctly spelled words to standard output.

Once it detects the EOF (end of file), the **read** builtin returns a *false* exit status. Control then passes out of the **while** structure, and the script terminates.

Before you use **spell\_check**, create a file of correct spellings containing words that you use frequently but that are not in a standard dictionary. For example, if you work for a company named **Blinkenship and Klimowski, Attorneys**, you would put **Blinkenship** and **Klimowski** into the file. The following example shows how **spell\_check** checks the spelling in a file named **memo** and removes **Blinkenship** and **Klimowski** from the output list of incorrectly spelled words:

```
$ aspell -l < memo
Blinkenship
Klimowski
targat
hte
$ cat word_list
Blinkenship
Klimowski
$ spell_check word_list memo
targat
hte
```

Refer to the **aspell** manual (in the **/usr/share/doc/aspell** directory or at [aspell.net](http://aspell.net)) for more information.

---

1. This **if** statement can also be written as

```
if ! grep -qw "$line" "$1"
```

The **-q** option suppresses the output from **grep** so that only an exit code is returned. The **-w** option causes **grep** to match only a whole word.

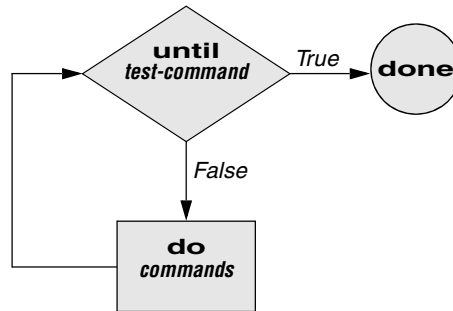


Figure 27-6 An until flowchart

## until

The **until** and **while** structures are very similar, differing only in the sense of the test performed at the top of the loop. Figure 27-6 shows that **until** continues to loop *until* the *test-command* returns a *true* exit status. The **while** structure loops *while* the *test-command* continues to return a *true* or nonerror condition. The **until** control structure has the following syntax:

```

until test-command
do
    commands
done

```

The following script demonstrates an **until** structure that includes **read**. When the user enters the correct string of characters, the *test-command* is satisfied and the structure passes control out of the loop.

```

$ cat untill
secretname=jenny
name=noname
echo "Try to guess the secret name!"
echo
until [ "$name" = "$secretname" ]
do
    echo -n "Your guess: "
    read name
done
echo "Very good."

$ untill
Try to guess the secret name!

Your guess: helen
Your guess: barbara
Your guess: rachael
Your guess: jenny
Very good

```



The following **locktty** script is similar to the **lock** command on Berkeley UNIX and the **Lock Screen** menu selection in GNOME. The script prompts you for a key (password) and uses an **until** control structure to lock the terminal. The **until** statement causes the system to ignore any characters typed at the keyboard until the user types in the key on a line by itself, which unlocks the terminal. The **locktty** script can keep people from using your terminal while you are away from it for short periods of time. It saves you from having to log out if you are concerned about other users using your login.

```
$ cat locktty
#!/bin/bash
# UNIX/WORLD, III:4

trap '' 1 2 3 18
stty -echo
echo -n "Key: "
read key_1
echo
echo -n "Again: "
read key_2
echo
key_3=
if [ "$key_1" = "$key_2" ]
then
    tput clear
    until [ "$key_3" = "$key_2" ]
    do
        read key_3
    done
else
    echo "locktty: keys do not match" 1>&2
fi
stty echo
```

### Forget your password for locktty?

**tip** If you forget your key (password), you will need to log in from another (virtual) terminal and kill the process running **locktty**.

**trap builtin** The **trap** builtin (page 943) at the beginning of the **locktty** script stops a user from being able to terminate the script by sending it a signal (for example, by pressing the interrupt key). Trapping signal 18 means that no one can use **CONTROL-Z** (job control, a stop from a tty) to defeat the lock. (See Table 27-5 on page 943 for a list of signals.) The **stty -echo** command causes the terminal not to display characters typed at the keyboard, thereby preventing the key that the user enters from appearing on the screen. After turning off keyboard echo, the script prompts the user for a key, reads it into the user-created variable **key\_1**, prompts the user to enter the same key again, and saves it in **key\_2**. The statement **key\_3=** creates a variable with a **NULL** value. If **key\_1** and **key\_2** match, **locktty** clears the screen (with the **tput** command) and starts an **until** loop. The **until** loop keeps attempting to read from the terminal and

assigning the input to the **key\_3** variable. Once the user types in a string that matches one of the original keys (**key\_2**), the **until** loop terminates and keyboard echo is turned on again.

## break AND continue

You can interrupt a **for**, **while**, or **until** loop by using a **break** or **continue** statement. The **break** statement transfers control to the statement after the **done** statement, which terminates execution of the loop. The **continue** command transfers control to the **done** statement, which continues execution of the loop.

The following script demonstrates the use of these two statements. The **for...in** structure loops through the values 1–10. The first **if** statement executes its commands when the value of the index is less than or equal to 3 (**\$index -le 3**). The second **if** statement executes its commands when the value of the index is greater than or equal to 8 (**\$index -ge 8**). In between the two **ifs**, **echo** displays the value of the index. For all values up to and including 3, the first **if** statement displays **continue** and executes a **continue** statement that skips **echo \$index** and the second **if** statement and continues with the next **for** statement. For the value of 8, the second **if** statement displays **break** and executes a **break** statement that exits from the **for** loop:

```
$ cat brk
for index in 1 2 3 4 5 6 7 8 9 10
do
    if [ $index -le 3 ] ; then
        echo "continue"
        continue
    fi
#
    echo $index
#
    if [ $index -ge 8 ] ; then
        echo "break"
        break
    fi
done

$ brk
continue
continue
continue
4
5
6
7
8
break
```

## case

The **case** structure (Figure 27-7, page 912) is a multiple-branch decision mechanism. The path taken through the structure depends on a match or lack of a match between the *test-string* and one of the *patterns*. The **case** control structure has the following syntax:

```

case test-string in
    pattern-1)
        commands-1
        ;;
    pattern-2)
        commands-2
        ;;
    pattern-3)
        commands-3
        ;;
    ...
esac

```

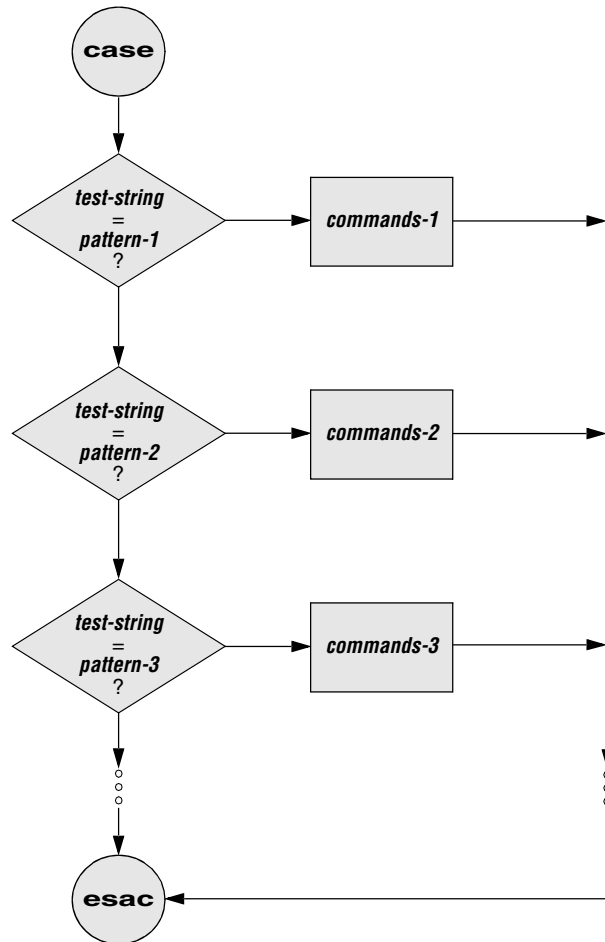
The following **case** structure examines the character that the user enters as the *test-string*. This value is held in the variable **letter**. If the *test-string* has a value of **A**, the structure executes the command following the *pattern* **A**. The right parenthesis is part of the **case** control structure, not part of the *pattern*. If the *test-string* has a value of **B** or **C**, the structure executes the command following the matching *pattern*. The asterisk (\*) indicates *any string of characters* and serves as a catchall in case there is no match. If no *pattern* matches the *test-string* and if there is no catchall (\*) *pattern*, control passes to the command following the **esac** statement, without the **case** structure taking any action.

```

$ cat case1
echo -n "Enter A, B, or C: "
read letter
case "$letter" in
    A)
        echo "You entered A"
        ;;
    B)
        echo "You entered B"
        ;;
    C)
        echo "You entered C"
        ;;
    *)
        echo "You did not enter A, B, or C"
        ;;
esac

$ case1
Enter A, B, or C: B
You entered B

```



**Figure 27-7** A case flowchart

The next execution of `case1` shows the user entering a lowercase `b`. Because the *test-string* `b` does not match the uppercase `B` *pattern* (or any other *pattern* in the `case` statement), the program executes the commands following the catchall *pattern* and displays a message:

```
$ case1
Enter A, B, or C: b
You did not enter A, B, or C
```

The *pattern* in the `case` structure is analogous to an ambiguous file reference. It can include any of the special characters and strings shown in Table 27-2.

The next script accepts both uppercase and lowercase letters:

```
$ cat case2
echo -n "Enter A, B, or C: "
read letter
case "$letter" in
    a|A)
        echo "You entered A"
        ;;
    b|B)
        echo "You entered B"
        ;;
    c|C)
        echo "You entered C"
        ;;
    *)
        echo "You did not enter A, B, or C"
        ;;
esac

$ case2
Enter A, B, or C: b
You entered B
```

Table 27-2 Patterns

Pattern	Function
*	Matches any string of characters. Use for the default case.
?	Matches any single character.
[...]	Defines a character class. Any characters enclosed within brackets are tried, one at a time, in an attempt to match a single character. A hyphen between two characters specifies a range of characters.
	Separates alternative choices that satisfy a particular branch of the <b>case</b> structure.

**optional** The following example shows how you can use the **case** structure to create a simple menu. The **command\_menu** script uses **echo** to present menu items and prompt the user for a selection. (The **select** control structure [page 917] makes it much easier to code a menu.) The **case** structure then executes the appropriate utility depending on the user's selection.

```
$ cat command_menu
#!/bin/bash
# menu interface to simple commands

echo -e "\n      COMMAND MENU\n"
echo "  a.  Current date and time"
echo "  b.  Users currently logged in"
echo "  c.  Name of the working directory"
echo -e "  d.  Contents of the working directory\n"
echo -n "Enter a, b, c, or d: "
read answer
echo
```

```
#
case "$answer" in
a)
    date
    ;;
b)
    who
    ;;
c)
    pwd
    ;;
d)
    ls
    ;;
*)
    echo "There is no selection: $answer"
    ;;
esac

$ command_menu

COMMAND MENU

a. Current date and time
b. Users currently logged in
c. Name of the working directory
d. Contents of the working directory

Enter a, b, c, or d: a

Wed Jan  9 12:31:12 PST 2008
```

**echo -e** The `-e` option causes `echo` to interpret `\n` as a NEWLINE character. If you do not include this option, `echo` does not output the extra blank lines that make the menu easy to read but instead outputs the (literal) two-character sequence `\n`. The `-e` option causes `echo` to interpret several other backslash-quoted characters (Table 27-3). Remember to quote (i.e., place double quotation marks around the string) the backslash-quoted character so that the shell does not interpret it but passes the backslash and the character to `echo`. See `xpg_echo` (page 341) for a way to avoid using the `-e` option.

**Table 27-3** Special characters in `echo` (must use `-e`)

Quoted character	echo displays
<code>\a</code>	Alert (bell)
<code>\b</code>	BACKSPACE
<code>\c</code>	Suppress trailing NEWLINE
<code>\f</code>	FORMFEED
<code>\n</code>	NEWLINE
<code>\r</code>	RETURN

**Table 27-3** Special characters in `echo` (must use `-e`) (continued)

<code>\t</code>	Horizontal TAB
<code>\v</code>	Vertical TAB
<code>\\</code>	Backslash
<code>\nnn</code>	The character with the ASCII octal code <i>nnn</i> ; if <i>nnn</i> is not valid, <code>echo</code> displays the string literally

You can also use the `case` control structure to take various actions in a script, depending on how many arguments the script is called with. The following script, named `safedit`, uses a `case` structure that branches based on the number of command-line arguments (`$#`). It saves a backup copy of a file you are editing with `vim`.

```
$ cat safedit
#!/bin/bash
# UNIX/WORLD, IV:11

PATH=/bin:/usr/bin
script=$(basename $0)
case $# in
    0)
        vim
        exit 0
        ;;
    1)
        if [ ! -f "$1" ]
        then
            vim "$1"
            exit 0
        fi
        if [ ! -r "$1" -o ! -w "$1" ]
        then
            echo "$script: check permissions on $1" 1>&2
            exit 1
        else
            editfile=$1
        fi
        if [ ! -w "." ]
        then
            echo "$script: backup cannot be " \
                "created in the working directory" 1>&2
            exit 1
        fi
        ;;
    *)
        echo "Usage: $script [file-to-edit]" 1>&2
        exit 1
        ;;
esac
```

```

tempfile=/tmp/$$. $script
cp $editfile $tempfile
if vim $editfile
then
    mv $tempfile bak.$(basename $editfile)
    echo "$script: backup file created"
else
    mv $tempfile editerr
    echo "$script: edit error--copy of " \
        "original file is in editerr" 1>&2
fi

```

If you call **safedit** without any arguments, the **case** structure executes its first branch and calls **vim** without a filename argument. Because an existing file is not being edited, **safedit** does not create a backup file. If you call **safedit** with one argument, it runs the commands in the second branch of the **case** structure and verifies that the file specified by **\$1** does not yet exist or is the name of a file for which the user has read and write permission. The **safedit** script also verifies that the user has write permission for the working directory. If the user calls **safedit** with more than one argument, the third branch of the **case** structure presents a usage message and exits with a status of 1.

**Set PATH** In addition to using a **case** structure for branching based on the number of command-line arguments, the **safedit** script introduces several other features. First, at the beginning of the script, the **PATH** variable is set to search **/bin** and **/usr/bin**. Setting **PATH** in this way ensures that the commands executed by the script are standard utilities, which are kept in those directories. By setting **PATH** inside a script, you can avoid the problems that might occur if users have set **PATH** to search their own directories first and have scripts or programs with the same names as the utilities the script calls. You can also include absolute pathnames within a script to achieve this end, but this practice can make a script less portable.

**Name of the program** In a second **safedit** feature, the following line creates a variable named **script** and assigns the simple filename of the script to it:

```
script=$(basename $0)
```

The **basename** utility sends the simple filename component of its argument to standard output, which is assigned to the **script** variable, using command substitution. The **\$0** holds the command the script was called with (page 931). No matter which of the following commands the user calls the script with, the output of **basename** is the simple filename **safedit**:

```

$ /home/alex/bin/safedit memo
$ ./safedit memo
$ safedit memo

```

After the **script** variable is set, it replaces the filename of the script in usage and error messages. By using a variable that is derived from the command that invoked the script rather than a filename that is hardcoded into the script, you can create



#### Naming temporary files

links to the script or rename it, and the usage and error messages will still provide accurate information.

A third significant feature of **safedit** relates to the use of the **\$\$** variable in the name of a temporary file. The statement following the **esac** statement creates and assigns a value to the **tempfile** variable. This variable contains the name of a temporary file that is stored in the **/tmp** directory, as are many temporary files. The temporary filename begins with the PID number of the shell and ends with the name of the script. Use of the PID number ensures that the filename is unique, and **safedit** will not attempt to overwrite an existing file, as might happen if two people were using **safedit** at the same time. The name of the script is appended so that, should the file be left in **/tmp** for some reason, you can figure out where it came from.

The PID number is used in front of—rather than after—**\$script** in the filename because of the 14-character limit placed on filenames by some older versions of UNIX. Linux systems do not have this limitation. Because the PID number ensures the uniqueness of the filename, it is placed first so that it cannot be truncated. (If the **\$script** component is truncated, the filename is still unique.) For the same reason, when a backup file is created inside the **if** control structure a few lines down in the script, the filename is composed of the string **bak.** followed by the name of the file being edited. On an older system, if **bak** were used as a suffix rather than a prefix and the original filename were 14 characters long, **.bak** might be lost and the original file would be overwritten. The **basename** utility extracts the simple filename of **\$editfile** before it is prefixed with **bak.**

Fourth, **safedit** uses an unusual *test-command* in the **if** structure: **vim \$editfile**. The *test-command* calls **vim** to edit **\$editfile**. When you finish editing the file and exit from **vim**, **vim** returns an exit code. The **if** control structure uses that exit code to determine which branch to take. If the editing session completed successfully, **vim** returns **0** and the statements following the **then** statement are executed. If **vim** does not terminate normally (as would occur if the user killed [page 409] the **vim** process), **vim** returns a nonzero exit status and the script executes the statements following **else**.

## select

The **select** control structure is based on the one found in the Korn Shell. It displays a menu, assigns a value to a variable based on the user's choice of items, and executes a series of commands. The **select** control structure has the following syntax:

```
select varname [in arg . . . ]
do
    commands
done
```

The **select** structure displays a menu of the *arg* items. If you omit the keyword **in** and the list of arguments, **select** uses the positional parameters in place of the *arg*

items. The menu is formatted with numbers before each item. For example, a **select** structure that begins with

```
select fruit in apple banana blueberry kiwi orange watermelon STOP
```

displays the following menu:

```
1) apple      3) blueberry  5) orange      7) STOP
2) banana     4) kiwi       6) watermelon
```

The **select** structure uses the values of the **LINES** and **COLUMNS** variables to determine the size of the display. (**LINES** has a default value of 24; **COLUMNS** has a default value of 80.) With **COLUMNS** set to 20, the menu looks like this:

```
1) apple
2) banana
3) blueberry
4) kiwi
5) orange
6) watermelon
7) STOP
```

**PS3** After displaying the menu, **select** displays the value of **PS3**, the special **select** prompt. The default value of **PS3** is **?#** but you typically set **PS3** to a more meaningful value. When you enter a valid number (one in the menu range) in response to the **PS3** prompt, **select** sets *varname* to the argument corresponding to the number you entered. If you make an invalid entry, *varname* is set to null. Either way **select** stores your response in the keyword variable **REPLY** and then executes the *commands* between **do** and **done**. If you press RETURN without entering a choice, the shell redisplay the menu and the **PS3** prompt.

The **select** structure continues to issue the **PS3** prompt and execute the *commands* until something causes it to exit—typically a **break** or **exit** statement. A **break** statement exits from the loop and an **exit** statement exits from the script.

The following script illustrates the use of **select**:

```
$ cat fruit2
#!/bin/bash
PS3="Choose your favorite fruit from these possibilities: "
select FRUIT in apple banana blueberry kiwi orange watermelon STOP
do
    if [ "$FRUIT" == "" ]; then
        echo -e "Invalid entry.\n"
        continue
    elif [ $FRUIT = STOP ]; then
        echo "Thanks for playing!"
        break
    fi
echo "You chose $FRUIT as your favorite."
echo -e "That is choice number $REPLY.\n"
done
```

```

$ fruit2
1) apple      3) blueberry  5) orange      7) STOP
2) banana     4) kiwi       6) watermelon
Choose your favorite fruit from these possibilities: 3
You chose blueberry as your favorite.
That is choice number 3.

Choose your favorite fruit from these possibilities: 99
Invalid entry.

Choose your favorite fruit from these possibilities: 7
Thanks for playing!

```

After setting the **PS3** prompt and establishing the menu with the **select** statement, **fruit2** executes the *commands* between **do** and **done**. If the user makes an invalid entry, the shell sets *varname* (**\$FRUIT**) to a null value, so **fruit2** first tests whether **\$FRUIT** is null. If it is, **echo** displays an error and **continue** causes the shell to redisplay the **PS3** prompt. If the entry is valid, the script tests whether the user wants to stop. If so, **echo** displays a message and **break** exits from the **select** structure (and from the script). If the user entered a valid response and does not want to stop, the script displays the name and number of the user's response. (See page 914 for information about the **-e** option to **echo**.)

## HERE DOCUMENT

A Here document allows you to redirect input to a shell script from within the shell script itself. A Here document is so called because it is *here*—immediately accessible in the shell script—instead of *there*, perhaps in another file.

The following script, named **birthday**, contains a Here document. The two less than (**<<**) symbols in the first line indicate that a Here document follows. One or more characters that delimit the Here document follow the less than symbols—this example uses a plus sign. Whereas the opening delimiter must appear adjacent to the less than symbols, the closing delimiter must be on a line by itself. The shell sends everything between the two delimiters to the process as standard input. In the example it is as though you had redirected standard input to **grep** from a file, except that the file is embedded in the shell script:

```

$ cat birthday
grep -i "$1" <<+
Alex    June 22
Barbara February 3
Darlene May 8
Helen   March 13
Jenny   January 23
Nancy   June 26
+
$ birthday Jenny
Jenny   January 23
$ birthday june
Alex    June 22
Nancy   June 26

```

When you run **birthday**, it lists all the Here document lines that contain the argument you called it with. In this case the first time **birthday** is run, it displays Jenny's birthday because it is called with an argument of **Jenny**. The second run displays all the birthdays in June. The **-i** argument causes **grep**'s search not to be case sensitive.

**optional** The next script, named **bundle**,<sup>2</sup> includes a clever use of a Here document. The **bundle** script is an elegant example of a script that creates a shell archive (**shar**) file. The script, shown following, creates a file that is itself a shell script containing several other files as well as the code to re-create the original files.

```
$ cat bundle
#!/bin/bash
# bundle: group files into distribution package

echo "# To unbundle, bash this file"
for i
do
    echo "echo $i 1>&2"
    echo "cat >$i <<'End of $i'"
    cat $i
    echo "End of $i"
done
```

Just as the shell does not treat special characters that occur in standard input of a shell script as special, so the shell does not treat the special characters that occur between the delimiters in a Here document as special.

As the following example shows, the output of **bundle** is a shell script, which is redirected to a file named **bothfiles**. It contains the contents of each file given as an argument to **bundle** (**file1** and **file2** in this case) inside a Here document. To extract the original files from **bothfiles**, you simply run it as an argument to a bash command. Before each Here document is a **cat** command that causes the Here document to be written to a new file when **bothfiles** is run:

```
$ cat file1
This is a file.
It contains two lines.
$ cat file2
This is another file.
It contains
three lines.

$ bundle file1 file2 > bothfiles
$ cat bothfiles
# To unbundle, bash this file
echo file1 1>&2
cat >file1 <<'End of file1'
```

2. Thanks to Brian W. Kernighan and Rob Pike, *The Unix Programming Environment* (Englewood Cliffs, N.J.: Prentice Hall, 1984), 98. Reprinted with permission.

```

This is a file.
It contains two lines.
End of file1
echo file2 1>&2
cat >file2 <<'End of file2'
This is another file.
It contains
three lines.
End of file2

```

In the next example, **file1** and **file2** are removed before **bothfiles** is run. The **bothfiles** script echoes the names of the files it creates as it creates them. The **ls** command then shows that **bothfiles** has re-created **file1** and **file2**:

```

$ rm file1 file2
$ bash bothfiles
file1
file2
$ ls
bothfiles
file1
file2

```

## FILE DESCRIPTORS

As discussed on page 284, before a process can read from or write to a file it must open that file. When a process opens a file, Linux associates a number (called a *file descriptor*) with the file. Each process has its own set of open files and its own file descriptors. After opening a file, a process reads from and writes to that file by referring to its file descriptor. When it no longer needs the file, the process closes the file, freeing the file descriptor.

A typical Linux process starts with three open files: standard input (file descriptor 0), standard output (file descriptor 1), and standard error (file descriptor 2). Often those are the only files the process needs. Recall that you redirect standard output with the symbol **>** or the symbol **1>** and that you redirect standard error with the symbol **2>**. Although you can redirect other file descriptors, because file descriptors other than 0, 1, and 2 do not have any special conventional meaning, it is rarely useful to do so. The exception is in programs that you write yourself, in which case you control the meaning of the file descriptors and can take advantage of redirection.

Opening a file descriptor    The Bourne Again Shell opens files using the **exec** builtin as follows:

```

exec n> outfile
exec m< infile

```

The first line opens *outfile* for output and holds it open, associating it with file descriptor *n*. The second line opens *infile* for input and holds it open, associating it with file descriptor *m*.

Duplicating a file descriptor    The `<&n` token duplicates an input file descriptor; use `>&n` to duplicate an output file descriptor. You can duplicate a file descriptor by making it refer to the same file as another open file descriptor, such as standard input or output. Use the following format to open or redirect file descriptor *n* as a duplicate of file descriptor *m*:

*exec n<&m*

Once you have opened a file, you can use it for input and output in two different ways. First, you can use I/O redirection on any command line, redirecting standard output to a file descriptor with `>&n` or redirecting standard input from a file descriptor with `<&n`. Second, you can use the `read` (page 937) and `echo` builtins. If you invoke other commands, including functions (page 335), they inherit these open files and file descriptors. When you have finished using a file, you can close it with

*exec n<&-*

When you invoke the shell function in the next example, named `mycp`, with two arguments, it copies the file named by the first argument to the file named by the second argument. If you supply only one argument, the script copies the file named by the argument to standard output. If you invoke `mycp` with no arguments, it copies standard input to standard output.

### A function is not a shell script

**tip** The `mycp` example is a shell function; it will not work as you expect if you execute it as a shell script. (It will work: The function will be created in a very short-lived subshell, which is probably of little use.) You can enter this function from the keyboard. If you put the function in a file, you can run it as an argument to the `.` (dot) builtin (page 283). You can also put the function in a startup file if you want it to be always available (page 337).

---

```
function mycp ()
{
  case $# in
    0)
      # zero arguments
      # file descriptor 3 duplicates standard input
      # file descriptor 4 duplicates standard output
      exec 3<&0 4<&1
      ;;
    1)
      # one argument
      # open the file named by the argument for input
      # and associate it with file descriptor 3
      # file descriptor 4 duplicates standard output
      exec 3< $1 4<&1
      ;;
    2)
      # two arguments
      # open the file named by the first argument for input
      # and associate it with file descriptor 3
      # open the file named by the second argument for output
      # and associate it with file descriptor 4
      exec 3< $1 4> $2
      ;;
```

```

        *)
        echo "Usage: mycp [source [dest]]"
        return 1
        ;;
    esac

    # call cat with input coming from file descriptor 3
    # and output going to file descriptor 4
    cat <&3 >&4

    # close file descriptors 3 and 4
    exec 3<&- 4<&-
}

```

The real work of this function is done in the line that begins with `cat`. The rest of the script arranges for file descriptors 3 and 4, which are the input and output of the `cat` command, to be associated with the appropriate files.

**optional** The next program takes two filenames on the command line, sorts both, and sends the output to temporary files. The program then merges the sorted files to standard output, preceding each line by a number that indicates which file it came from.

```

$ cat sortmerg
#!/bin/bash
usage ()
{
    if [ $# -ne 2 ]; then
        echo "Usage: $0 file1 file2" 2>&1
        exit 1
    fi
}

# Default temporary directory
: ${TMPDIR:=/tmp}

# Check argument count
usage "$@"

# Set up temporary files for sorting
file1=$TMPDIR/$$.file1
file2=$TMPDIR/$$.file2

# Sort
sort $1 > $file1
sort $2 > $file2

# Open $file1 and $file2 for reading. Use file descriptors 3 and 4.
exec 3<$file1
exec 4<$file2

# Read the first line from each file to figure out how to start.
read Line1 <&3
status1=$?
read Line2 <&4
status2=$?

```

```
# Strategy: while there is still input left in both files:
#   Output the line that should come first.
#   Read a new line from the file that line came from.
while [ $status1 -eq 0 -a $status2 -eq 0 ]
do
    if [[ "$Line2" > "$Line1" ]]; then
        echo -e "1.\t$Line1"
        read -u3 Line1
        status1=$?
    else
        echo -e "2.\t$Line2"
        read -u4 Line2
        status2=$?
    fi
done

# Now one of the files is at end-of-file.
# Read from each file until the end.
# First file1:
while [ $status1 -eq 0 ]
do
    echo -e "1.\t$Line1"
    read Line1 <&3
    status1=$?
done
# Next file2:
while [[ $status2 -eq 0 ]]
do
    echo -e "2.\t$Line2"
    read Line2 <&4
    status2=$?
done

# Close and remove both input files
exec 3<&- 4<&-
rm -f $file1 $file2
exit 0
```

---

## PARAMETERS AND VARIABLES

Shell parameters and variables were introduced on page 299. This section adds to the previous coverage with a discussion of array variables, global versus local variables, special and positional parameters, and expanding null and unset variables.

### ARRAY VARIABLES

The Bourne Again Shell supports one-dimensional array variables. The subscripts are integers with zero-based indexing (i.e., the first element of the array has the subscript 0). The following format declares and assigns values to an array:



*name=(element1 element2 ...)*

The following example assigns four values to the array **NAMES**:

```
$ NAMES=(max helen sam zach)
```

You reference a single element of an array as follows:

```
$ echo ${NAMES[2]}
sam
```

The subscripts `[*]` and `[@]` both extract the entire array but work differently when used within double quotation marks. An `@` produces an array that is a duplicate of the original array; an `*` produces a single element of an array (or a plain variable) that holds all the elements of the array separated by the first character in **IFS** (normally a `SPACE`). In the following example, the array **A** is filled with the elements of the **NAMES** variable using an `*`, and **B** is filled using an `@`. The `declare` builtin with the `-a` option displays the values of the arrays (and reminds you that **bash** uses zero-based indexing for arrays):

```
$ A=("${NAMES[*]}")
$ B=("${NAMES[@]}")

$ declare -a
declare -a A=([0]="max helen sam zach")
declare -a B=([0]="max" [1]="helen" [2]="sam" [3]="zach")
...
declare -a NAMES=([0]="max" [1]="helen" [2]="sam" [3]="zach")'
```

From the output of `declare`, you can see that **NAMES** and **B** have multiple elements. In contrast, **A**, which was assigned its value with an `*` within double quotation marks, has only one element: **A** has all its elements enclosed between double quotation marks.

In the next example, `echo` attempts to display element 1 of array **A**. Nothing is displayed because **A** has only one element and that element has an index of 0. Element 0 of array **A** holds all four names. Element 1 of **B** holds the second item in the array and element 0 holds the first item.

```
$ echo ${A[1]}

$ echo ${A[0]}
max helen sam zach
$ echo ${B[1]}
helen
$ echo ${B[0]}
max
```

You can apply the `${#name[*]}` operator to array variables, returning the number of elements in the array:

```
$ echo ${#NAMES[*]}
4
```

The same operator, when given the index of an element of an array in place of `*`, returns the length of the element:

```
$ echo ${#NAMES[1]}
5
```

You can use subscripts on the left side of an assignment statement to replace selected elements of the array:

```
$ NAMES[1]=alex
$ echo ${NAMES[*]}
max alex sam zach
```

## LOCALITY OF VARIABLES

By default variables are local to the process in which they are declared. Thus a shell script does not have access to variables declared in your login shell unless you explicitly make the variables available (global). Under `bash`, `export` makes a variable available to child processes.

`export` Once you use the `export` builtin with a variable name as an argument, the shell places the value of the variable in the calling environment of child processes. This *call by value* gives each child process a copy of the variable for its own use.

The following `extest1` shell script assigns a value of `american` to the variable named `cheese` and then displays its filename (`extest1`) and the value of `cheese`. The `extest1` script then calls `subtest`, which attempts to display the same information. Next `subtest` declares a `cheese` variable and displays its value. When `subtest` finishes, it returns control to the parent process, which is executing `extest1`. At this point `extest1` again displays the value of the original `cheese` variable.

```
$ cat extest1
cheese=american
echo "extest1 1: $cheese"
subtest
echo "extest1 2: $cheese"
$ cat subtest
echo "subtest 1: $cheese"
cheese=swiss
echo "subtest 2: $cheese"
$ extest1
extest1 1: american
subtest 1:
subtest 2: swiss
extest1 2: american
```

The `subtest` script never receives the value of `cheese` from `extest1`, and `extest1` never loses the value. Unlike in the real world, a child can never affect its parent's attributes. When a process attempts to display the value of a variable that has not been declared, as is the case with `subtest`, the process displays nothing; the value of an undeclared variable is that of a null string.

The following **extest2** script is the same as **extest1** except that it uses **export** to make **cheese** available to the **subtest** script:

```
$ cat extest2
export cheese=american
echo "extest2 1: $cheese"
subtest
echo "extest2 2: $cheese"
$ extest2
extest2 1: american
subtest 1: american
subtest 2: swiss
extest2 2: american
```

Here the child process inherits the value of **cheese** as **american** and, after displaying this value, changes *its copy* to **swiss**. When control is returned to the parent, the parent's copy of **cheese** retains its original value: **american**.

An **export** builtin can optionally include an assignment:

```
export cheese=american
```

The preceding statement is equivalent to the following two statements:

```
cheese=american
export cheese
```

Although it is rarely done, you can export a variable before you assign a value to it. You do not need to export an already-exported variable a second time after you change its value. For example, you do not usually need to export **PATH** when you assign a value to it in **~/.bash\_profile** because it is typically exported in the **/etc/profile** global startup file.

## FUNCTIONS

Because functions run in the same environment as the shell that calls them, variables are implicitly shared by a shell and a function it calls.

```
$ function nam () {
> echo $myname
> myname=zach
> }

$ myname=sam
$ nam
sam
$ echo $myname
zach
```

In the preceding example, the **myname** variable is set to **sam** in the interactive shell. Then the **nam** function is called. It displays the value of **myname** it has (**sam**) and sets **myname** to **zach**. The final **echo** shows that, in the interactive shell, the value of **myname** has been changed to **zach**.

Function local variables    Local variables are helpful in a function written for general use. Because the function is called by many scripts that may be written by different programmers, you need to make sure that the names of the variables used within the function do not interact with variables of the same name in the programs that call the function. Local variables eliminate this problem. When used within a function, the `typeset` builtin declares a variable to be local to the function it is defined in.

The next example shows the use of a local variable in a function. It uses two variables named `count`. The first is declared and assigned a value of 10 in the interactive shell. Its value never changes, as `echo` verifies after `count_down` is run. The other `count` is declared, using `typeset`, to be local to the function. Its value, which is unknown outside the function, ranges from 4 to 1, as the `echo` command within the function confirms.

The example shows the function being entered from the keyboard; it is not a shell script. (See the tip “A function is not a shell script” on page 922).

```
$ function count_down () {
> typeset count
> count=$1
> while [ $count -gt 0 ]
> do
> echo "$count..."
> ((count=count-1))
> sleep 1
> done
> echo "Blast Off."
> }
$ count=10
$ count_down 4
4...
3...
2...
1...
Blast Off.
$ echo $count
10
```

The `((count=count-1))` assignment is enclosed between double parentheses, which cause the shell to perform an arithmetic evaluation (page 950). Within the double parentheses you can reference shell variables without the leading dollar sign (\$).

## SPECIAL PARAMETERS

Special parameters enable you to access useful values pertaining to command-line arguments and the execution of shell commands. You reference a shell special parameter by preceding a special character with a dollar sign (\$). As with positional parameters, it is not possible to modify the value of a special parameter by assignment.

## \$\$: PID NUMBER

The shell stores in the \$\$ parameter the PID number of the process that is executing it. In the following interaction, `echo` displays the value of this variable and the `ps` utility confirms its value. Both commands show that the shell has a PID number of 5209:

```
$ echo $$
5209
$ ps
  PID TTY          TIME CMD
 5209 pts/1    00:00:00 bash
 6015 pts/1    00:00:00 ps
```

Because `echo` is built into the shell, the shell does not have to create another process when you give an `echo` command. However, the results are the same whether `echo` is a builtin or not, because the shell substitutes the value of \$\$ *before* it forks a new process to run a command. Try using the `echo` utility (`/bin/echo`), which is run by another process, and see what happens. In the following example, the shell substitutes the value of \$\$ and passes that value to `cp` as a prefix for a filename:

```
$ echo $$
8232
$ cp memo $$ .memo
$ ls
8232.memo memo
```

Incorporating a PID number in a filename is useful for creating unique filenames when the meanings of the names do not matter; it is often used in shell scripts for creating names of temporary files. When two people are running the same shell script, these unique filenames keep them from inadvertently sharing the same temporary file.

The following example demonstrates that the shell creates a new shell process when it runs a shell script. The `id2` script displays the PID number of the process running it (not the process that called it—the substitution for \$\$ is performed by the shell that is forked to run `id2`):

```
$ cat id2
echo "$0 PID= $$"
$ echo $$
8232
$ id2
./id2 PID= 8362
$ echo $$
8232
```

The first `echo` displays the PID number of the interactive shell. Then `id2` displays its name (`$0`) and the PID of the subshell that it is running in. The last `echo` shows that the PID number of the interactive shell has not changed.

**#!** The value of the PID number of the last process that you ran in the background is stored in **#!**. The following example executes **sleep** as a background task and uses **echo** to display the value of **#!**:

```
$ sleep 60 &
[1] 8376
$ echo $!
8376
```

## **\$?: EXIT STATUS**

When a process stops executing for any reason, it returns an *exit status* to the parent process. The exit status is also referred to as a *condition code* or a *return code*. The  **\$?**  variable stores the exit status of the last command.

By convention a nonzero exit status represents a *false* value and means that the command failed. A zero is *true* and indicates that the command was successful. In the following example, the first **ls** command succeeds and the second fails:

```
$ ls es
es
$ echo $?
0
$ ls xxx
ls: xxx: No such file or directory
$ echo $?
1
```

You can specify the exit status that a shell script returns by using the **exit** builtin, followed by a number, to terminate the script. If you do not use **exit** with a number to terminate a script, the exit status of the script is that of the last command the script ran.

```
$ cat es
echo This program returns an exit status of 7.
exit 7
$ es
This program returns an exit status of 7.
$ echo $?
7
$ echo $?
0
```

The **es** shell script displays a message and terminates execution with an **exit** command that returns an exit status of 7, the user-defined exit status in this script. The first **echo** then displays the value of the exit status of **es**. The second **echo** displays the value of the exit status of the first **echo**. The value is 0 because the first **echo** was successful.

## **POSITIONAL PARAMETERS**

The *positional* parameters comprise the command name and command-line arguments. They are called *positional* because within a shell script, you refer to them by

their position on the command line. Only the `set` builtin (page 934) allows you to change the values of positional parameters with one exception: You cannot change the value of the command name from within a script.

## **\$#: NUMBER OF COMMAND-LINE ARGUMENTS**

The `$#` parameter holds the number of arguments on the command line (positional parameters), not counting the command itself:

```
$ cat num_args
echo "This script was called with $# arguments."
$ num_args sam max zach
This script was called with 3 arguments.
```

## **\$0: NAME OF THE CALLING PROGRAM**

The shell stores the name of the command you used to call a program in parameter `$0`. This parameter is numbered zero because it appears before the first argument on the command line:

```
$ cat abc
echo "The command used to run this script is $0"
$ abc
The command used to run this script is ./abc
$ /home/sam/abc
The command used to run this script is /home/sam/abc
```

The preceding shell script uses `echo` to verify the name of the script you are executing. You can use the `basename` utility and command substitution to extract and display the simple filename of the command:

```
$ cat abc2
echo "The command used to run this script is $(basename $0)"
$ /home/sam/abc2
The command used to run this script is abc2
```

## **\$1–\$n: COMMAND-LINE ARGUMENTS**

The first argument on the command line is represented by parameter `$1`, the second argument by `$2`, and so on up to `$n`. For values of *n* over 9, the number must be enclosed within braces. For example, the twelfth command-line argument is represented by `${12}`. The following script displays positional parameters that hold command-line arguments:

```
$ cat display_5args
echo First 5 arguments are $1 $2 $3 $4 $5

$ display_5args jenny alex helen
First 5 arguments are jenny alex helen
```

The `display_5args` script displays the first five command-line arguments. The shell assigns a null value to each parameter that represents an argument that is not

present on the command line. Thus the `$4` and `$5` variables have null values in this example.

- `$*` The `$*` variable represents all the command-line arguments, as the `display_all` program demonstrates:

```
$ cat display_all
echo All arguments are $*

$ display_all a b c d e f g h i j k l m n o p
All arguments are a b c d e f g h i j k l m n o p
```

Enclose references to positional parameters between double quotation marks. The quotation marks are particularly important when you are using positional parameters as arguments to commands. Without double quotation marks, a positional parameter that is not set or that has a null value disappears:

```
$ cat showargs
echo "$0 was called with $# arguments, the first is :$1:."

$ showargs a b c
./showargs was called with 3 arguments, the first is :a:.
$ echo $xx

$ showargs $xx a b c
./showargs was called with 3 arguments, the first is :a:.
$ showargs "$xx" a b c
./showargs was called with 4 arguments, the first is :.:.
```

The `showargs` script displays the number of arguments (`$#`) followed by the value of the first argument enclosed between colons. The preceding example first calls `showargs` with three simple arguments. Next the `echo` command demonstrates that the `$xx` variable, which is not set, has a null value. In the final two calls to `showargs`, the first argument is `$xx`. In the first case the command line becomes `showargs a b c`; the shell passes `showargs` three arguments. In the second case the command line becomes `showargs " a b c`, which results in calling `showargs` with four arguments. The difference in the two calls to `showargs` illustrates a subtle potential problem that you should keep in mind when using positional parameters that may not be set or that may have a null value.

- `"$*" versus "$@"` The `$*` and `$@` parameters work the same way except when they are enclosed within double quotation marks. Using `"$*" yields a single argument (with SPACES or the value of IFS [page 309] between the positional parameters), whereas "$@" produces a list wherein each positional parameter is a separate argument. This difference typically makes "$@" more useful than "$*" in shell scripts.`

The following scripts help to explain the difference between these two special parameters. In the second line of both scripts, the single quotation marks keep the shell from interpreting the enclosed special characters so they can be displayed as themselves. The `bb1` script shows that `set "$*" assigns multiple arguments to the first command-line parameter:`



```

$ cat bb1
set "$*"
echo $# parameters with "$*"
echo 1: $1
echo 2: $2
echo 3: $3

$ bb1 a b c
1 parameters with "$*"
1: a b c
2:
3:

```

The **bb2** script shows that `set "$@"` assigns each argument to a different command-line parameter:

```

$ cat bb2
set "$@"
echo $# parameters with "$@"
echo 1: $1
echo 2: $2
echo 3: $3

$ bb2 a b c
3 parameters with "$@"
1: a
2: b
3: c

```

## shift: PROMOTES COMMAND-LINE ARGUMENTS

The `shift` builtin promotes each command-line argument. The first argument (which was `$1`) is discarded. The second argument (which was `$2`) becomes the first argument (now `$1`), the third becomes the second, and so on. Because no “unshift” command exists, you cannot bring back arguments that have been discarded. An optional argument to `shift` specifies the number of positions to shift (and the number of arguments to discard); the default is 1.

The following **demo\_shift** script is called with three arguments. Double quotation marks around the arguments to `echo` preserve the spacing of the output. The program displays the arguments and shifts them repeatedly until there are no more arguments left to shift:

```

$ cat demo_shift
echo "arg1= $1    arg2= $2    arg3= $3"
shift
echo "arg1= $1    arg2= $2    arg3= $3"
shift
echo "arg1= $1    arg2= $2    arg3= $3"
shift
echo "arg1= $1    arg2= $2    arg3= $3"
shift

```

```
$ demo_shift alice helen jenny
arg1= alice   arg2= helen   arg3= jenny
arg1= helen   arg2= jenny   arg3=
arg1= jenny   arg2=         arg3=
arg1=         arg2=         arg3=
```

Repeatedly using `shift` is a convenient way to loop over all the command-line arguments in shell scripts that expect an arbitrary number of arguments. See page 893 for a shell script that uses `shift`.

## set: INITIALIZES COMMAND-LINE ARGUMENTS

When you call the `set` builtin with one or more arguments, it assigns the values of the arguments to the positional parameters, starting with `$1`. The following script uses `set` to assign values to the positional parameters `$1`, `$2`, and `$3`:

```
$ cat set_it
set this is it
echo $3 $2 $1
$ set_it
it is this
```

Combining command substitution (page 348) with the `set` builtin is a convenient way to get standard output of a command in a form that can be easily manipulated in a shell script. The following script shows how to use `date` and `set` to provide the date in a useful format. The first command shows the output of `date`. Then `cat` displays the contents of the `dateset` script. The first command in this script uses command substitution to set the positional parameters to the output of the `date` utility. The next command, `echo $*`, displays all positional parameters resulting from the previous `set`. Subsequent commands display the values of parameters `$1`, `$2`, `$3`, and `$4`. The final command displays the date in a format you can use in a letter or report:

```
$ date
Sat Jan  9 23:39:18 PST 2010
$ cat dateset
set $(date)
echo $*
echo
echo "Argument 1: $1"
echo "Argument 2: $2"
echo "Argument 3: $3"
echo "Argument 6: $6"
echo
echo "$2 $3, $6"

$ dateset
Sat Jan 9 23:39:25 PST 2010

Argument 1: Wed
Argument 2: Jan
Argument 3: 9
Argument 6: 2008

Jan 9, 2010
```

You can also use the *+format* argument to `date` to modify the format of its output.

When used without any arguments, `set` displays a list of the shell variables that are set, including user-created variables and keyword variables. Under `bash`, this list is the same as that displayed by `declare` and `typeset` when they are called without any arguments.

The `set` builtin also accepts options that let you customize the behavior of the shell. For more information refer to “`set ±o`: Turns Shell Features On and Off” on page 339.

## EXPANDING NULL AND UNSET VARIABLES

The expression `${name}` (or just `$name` if it is not ambiguous) expands to the value of the `name` variable. If `name` is null or not set, `bash` expands `${name}` to a null string. The Bourne Again Shell provides the following alternatives to accepting the expanded null string as the value of the variable:

- Use a default value for the variable.
- Use a default value and assign that value to the variable.
- Display an error.

You can choose one of these alternatives by using a modifier with the variable name. In addition, you can use `set -o nounset` (page 341) to cause `bash` to display an error and exit from a script whenever an unset variable is referenced.

### :- USES A DEFAULT VALUE

The `:-` modifier uses a default value in place of a null or unset variable while allowing a nonnull variable to represent itself:

```
${name:-default}
```

The shell interprets `:-` as “If `name` is null or unset, expand *default* and use the expanded value in place of `name`; else use `name`.” The following command lists the contents of the directory named by the `LIT` variable. If `LIT` is null or unset, it lists the contents of `/home/alex/literature`:

```
$ ls ${LIT:-/home/alex/literature}
```

The default can itself have variable references that are expanded:

```
$ ls ${LIT:-$HOME/literature}
```

### := ASSIGNS A DEFAULT VALUE

The `:=` modifier does not change the value of a variable. You may want to change the value of a null or unset variable to its default in a script, however. You can do so with the `:=` modifier:

```
${name:=default}
```

The shell expands the expression `${name:=default}` in the same manner as it expands `${name:-default}` but also sets the value of *name* to the expanded value of *default*. If a script contains a line such as the following and `LIT` is unset or null at the time this line is executed, `LIT` is assigned the value `/home/alex/literature`:

```
$ ls ${LIT:=/home/alex/literature}
```

: builtin Shell scripts frequently start with the `:` (colon) builtin followed on the same line by the `:=` expansion modifier to set any variables that may be null or unset. The `:` builtin evaluates each token in the remainder of the command line but does not execute any commands. Without the leading colon (`:`), the shell evaluates and attempts to execute the “command” that results from the evaluation.

Use the following syntax to set a default for a null or unset variable in a shell script (there is a `SPACE` following the first colon):

```
: ${name:=default}
```

When a script needs a directory for temporary files and uses the value of `TEMPDIR` for the name of this directory, the following line makes `TEMPDIR` default to `/tmp`:

```
: ${TEMPDIR:=/tmp}
```

## **:? DISPLAYS AN ERROR MESSAGE**

Sometimes a script needs the value of a variable but you cannot supply a reasonable default at the time you write the script. If the variable is null or unset, the `?:` modifier causes the script to display an error message and terminate with an exit status of 1:

```
${name:?message}
```

You must quote *message* if it contains `SPACES`. If you omit *message*, the shell displays the default error message (**parameter null or not set**). Interactive shells do not exit when you use `?:`. In the following command, `TESTDIR` is not set so the shell displays on standard error the expanded value of the string following `?:`. In this case the string includes command substitution for `date`, with the `%T` format being followed by the string **error, variable not set**.

```
cd ${TESTDIR:?$(date +%T) error, variable not set.}
bash: TESTDIR: 16:16:14 error, variable not set.
```

---

## **BUILTIN COMMANDS**

Builtin commands were introduced in Chapter 7. Commands that are built in to a shell do not fork a new process when you execute them. This section discusses the `type`, `read`, `exec`, `trap`, `kill`, and `getopts` builtins and concludes with Table 27-6 on page 949, which lists many `bash` builtins.

## type: DISPLAYS INFORMATION ABOUT A COMMAND

The `type` builtin provides information about a command:

```
$ type cat echo who if lt
cat is hashed (/bin/cat)
echo is a shell builtin
who is /usr/bin/who
if is a shell keyword
lt is aliased to 'ls -ltrh | tail'
```

The preceding output shows the files that would be executed if you gave `cat` or `who` as a command. Because `cat` has already been called from the current shell, it is in the *hash table* (page 1085) and `type` reports that `cat` is **hashed**. The output also shows that a call to `echo` runs the `echo` builtin, `if` is a keyword, and `lt` is an alias.

## read: ACCEPTS USER INPUT

When you begin writing shell scripts, you soon realize that one of the most common tasks for user-created variables is storing information a user enters in response to a prompt. Using `read`, scripts can accept input from the user and store that input in variables. The `read` builtin reads one line from standard input and assigns the words on the line to one or more variables:

```
$ cat read1
echo -n "Go ahead: "
read firstline
echo "You entered: $firstline"
$ read1
Go ahead: This is a line.
You entered: This is a line.
```

The first line of the `read1` script uses `echo` to prompt you to enter a line of text. The `-n` option suppresses the following `NEWLINE`, allowing you to enter a line of text on the same line as the prompt. The second line reads the text into the variable `firstline`. The third line verifies the action of `read` by displaying the value of `firstline`. The variable is quoted (along with the text string) in this example because you, as the script writer, cannot anticipate which characters the user might enter in response to the prompt. Consider what would happen if the variable were not quoted and the user entered `*` in response to the prompt:

```
$ cat read1_no_quote
echo -n "Go ahead: "
read firstline
echo You entered: $firstline
$ read1_no_quote
Go ahead: *
You entered: read1 read1_no_quote script.1
$ ls
read1  read1_no_quote  script.1
```

The `ls` command lists the same words as the script, demonstrating that the shell expands the asterisk into a list of files in the working directory. When the variable `$firstline` is surrounded by double quotation marks, the shell does not expand the asterisk. Thus the `read1` script behaves correctly:

```
$ read1
Go ahead: *
You entered: *
```

If you want the shell to interpret the special meanings of special characters, do not use quotation marks.

**REPLY** The `read` builtin has features that can make it easier to use. When you do not specify a variable to receive `read`'s input, `bash` puts the input into the variable named **REPLY**. You can use the `-p` option to prompt the user instead of using a separate `echo` command. The following `read1a` script performs exactly the same task as `read1`:

```
$ cat read1a
read -p "Go ahead: "
echo "You entered: $REPLY"
```

The `read2` script prompts for a command line and reads the user's response into the variable `cmd`. The script then attempts to execute the command line that results from the expansion of the `cmd` variable:

```
$ cat read2
read -p "Enter a command: " cmd
$cmd
echo "Thanks"
```

In the following example, `read2` reads a command line that calls the `echo` builtin. The shell executes the command and then displays **Thanks**. Next `read2` reads a command line that executes the `who` utility:

```
$ read2
Enter a command: echo Please display this message.
Please display this message.
Thanks
$ read2
Enter a command: who
alex      pts/4      Jun 17 07:50  (:0.0)
scott     pts/12      Jun 17 11:54  (bravo.example.com)
Thanks
```

If `cmd` does not expand into a valid command line, the shell issues an error message:

```
$ read2
Enter a command: xxx
./read2: line 2: xxx: command not found
Thanks
```

The `read3` script reads values into three variables. The `read` builtin assigns one word (a sequence of nonblank characters) to each variable:

```
$ cat read3
read -p "Enter something: " word1 word2 word3
echo "Word 1 is: $word1"
echo "Word 2 is: $word2"
echo "Word 3 is: $word3"

$ read3
Enter something: this is something
Word 1 is: this
Word 2 is: is
Word 3 is: something
```

When you enter more words than `read` has variables, `read` assigns one word to each variable, with all leftover words going to the last variable. Both `read1` and `read2` assigned the first word and all leftover words to the one variable they each had to work with. In the following example, `read` accepts five words into three variables, assigning the first word to the first variable, the second word to the second variable, and the third through fifth words to the third variable:

```
$ read3
Enter something: this is something else, really.
Word 1 is: this
Word 2 is: is
Word 3 is: something else, really.
```

Table 27-4 lists some of the options supported by the `read` builtin.

**Table 27-4** `read` options

Option	Function
<b>-a <i>aname</i></b> (array)	Assigns each word of input to an element of array <i>aname</i> .
<b>-d <i>delim</i></b> (delimiter)	Uses <i>delim</i> to terminate the input instead of NEWLINE.
<b>-e</b> (Readline)	If input is coming from a keyboard, use the Readline Library (page 326) to get input.
<b>-n <i>num</i></b> (number of characters)	Reads <i>num</i> characters and returns. As soon as the user types <i>num</i> characters, <code>read</code> returns; there is no need to press RETURN.
<b>-p <i>prompt</i></b> (prompt)	Displays <i>prompt</i> on standard error without a terminating NEWLINE before reading input. Displays <i>prompt</i> only when input comes from the keyboard.
<b>-s</b> (silent)	Does not echo characters.
<b>-un</b> (file descriptor)	Uses the integer <i>n</i> as the file descriptor that <code>read</code> takes its input from.  <pre>read -u4 arg1 arg2</pre> is equivalent to <pre>read arg1 arg2 &lt;&amp;4</pre> See “File Descriptors” (page 921) for a discussion of redirection and file descriptors.

The `read` builtin returns an exit status of 0 if it successfully reads any data. It has a nonzero exit status when it reaches the EOF (end of file). The following example runs a `while` loop from the command line. It takes its input from the `names` file and terminates after reading the last line from `names`.

```
$ cat names
Alice Jones
Robert Smith
Alice Paulson
John Q. Public

$ while read first rest
> do
> echo $rest, $first
> done < names
Jones, Alice
Smith, Robert
Paulson, Alice
Q. Public, John
$
```

The placement of the redirection symbol (`<`) for the `while` structure is critical. It is important that you place the redirection symbol at the `done` statement and not at the call to `read`.

**optional** Each time you redirect input, the shell opens the input file and repositions the read pointer at the start of the file:

```
$ read line1 < names; echo $line1; read line2 < names; echo $line2
Alice Jones
Alice Jones
```

Here each `read` opens `names` and starts at the beginning of the `names` file. In the following example, `names` is opened once, as standard input of the subshell created by the parentheses. Each `read` then reads successive lines of standard input.

```
$ (read line1; echo $line1; read line2; echo $line2) < names
Alice Jones
Robert Smith
```

Another way to get the same effect is to open the input file with `exec` and hold it open (refer to “File Descriptors” on page 921):

```
$ exec 3< names
$ read -u3 line1; echo $line1; read -u3 line2; echo $line2
Alice Jones
Robert Smith
$ exec 3<&-
```

## exec: EXECUTES A COMMAND

The `exec` builtin has two primary purposes: to run a command without creating a new process and to redirect a file descriptor—including standard input, output, or error—of a shell script from within the script (page 921). When the shell executes a



command that is not built into the shell, it typically creates a new process. The new process inherits environment (global or exported) variables from its parent but does not inherit variables that are not exported by the parent. (For more information refer to “Locality of Variables” on page 926.) In contrast, `exec` executes a command in place of (overlays) the current process.

**exec versus . (dot)** Insofar as `exec` runs a command in the environment of the original process, it is similar to the `.` (dot) command (page 283). However, unlike the `.` command, which can run only shell scripts, `exec` can run both scripts and compiled programs. Also, whereas the `.` command returns control to the original script when it finishes running, `exec` does not. Finally, the `.` command gives the new program access to local variables, whereas `exec` does not.

**exec runs a command** The `exec` builtin used for running a command has the following syntax:

*exec command arguments*

**exec does not return control** Because the shell does not create a new process when you use `exec`, the command runs more quickly. However, because `exec` does not return control to the original program, it can be used only as the last command that you want to run in a script. The following script shows that control is not returned to the script:

```
$ cat exec_demo
who
exec date
echo "This line is never displayed."

$ exec_demo
jenny pts/7 May 30 7:05 (bravo.example.com)
hls pts/1 May 30 6:59 (:0.0)
Mon May 26 11:42:56 PDT 2008
```

The next example, a modified version of the `out` script (page 893), uses `exec` to execute the final command the script runs. Because `out` runs either `cat` or `less` and then terminates, the new version, named `out2`, uses `exec` with both `cat` and `less`:

```
$ cat out2
if [ $# -eq 0 ]
then
    echo "Usage: out2 [-v] filenames" 1>&2
    exit 1
fi
if [ "$1" = "-v" ]
then
    shift
    exec less "$@"
else
    exec cat -- "$@"
fi
```

**exec redirects input and output** The second major use of `exec` is to redirect a file descriptor—including standard input, output, or error—from within a script. The next command causes all subsequent input to a script that would have come from standard input to come from the file named `infile`:

```
exec < infile
```

Similarly the following command redirects standard output and standard error to **outfile** and **errfile**, respectively:

```
exec > outfile 2> errfile
```

When you use **exec** in this manner, the current process is not replaced with a new process, and **exec** can be followed by other commands in the script.

**/dev/tty** When you redirect the output from a script to a file, you must make sure that the user sees any prompts the script displays. The **/dev/tty** device is a pseudonym for the screen the user is working on; you can use this device to refer to the user's screen without knowing which device it is. (The **tty** utility displays the name of the device you are using.) By redirecting the output from a script to **/dev/tty**, you ensure that prompts and messages go to the user's terminal, regardless of which terminal the user is logged in on. Messages sent to **/dev/tty** are also not diverted if standard output and standard error from the script are redirected.

The **to\_screen1** script sends output to three places: standard output, standard error, and the user's screen. When it is run with standard output and standard error redirected, **to\_screen1** still displays the message sent to **/dev/tty** on the user's screen. The **out** and **err** files hold the output sent to standard output and standard error.

```
$ cat to_screen1
echo "message to standard output"
echo "message to standard error" 1>&2
echo "message to the user" > /dev/tty

$ to_screen1 > out 2> err
message to the user
$ cat out
message to standard output
$ cat err
message to standard error
```

The following command redirects the output from a script to the user's screen:

```
exec > /dev/tty
```

Putting this command at the beginning of the previous script changes where the output goes. In **to\_screen2**, **exec** redirects standard output to the user's screen so the **> /dev/tty** is superfluous. Following the **exec** command, all output sent to standard output goes to **/dev/tty** (the screen). Output to standard error is not affected.

```
$ cat to_screen2
exec > /dev/tty
echo "message to standard output"
echo "message to standard error" 1>&2
echo "message to the user" > /dev/tty

$ to_screen2 > out 2> err
message to standard output
message to the user
```

One disadvantage of using **exec** to redirect the output to **/dev/tty** is that all subsequent output is redirected unless you use **exec** again in the script.

You can also redirect the input to `read` (standard input) so that it comes from `/dev/tty` (the keyboard):

```
read name < /dev/tty
```

or

```
exec < /dev/tty
```

## trap: CATCHES A SIGNAL

A *signal* is a report to a process about a condition. Linux uses signals to report interrupts generated by the user (for example, pressing the interrupt key) as well as bad system calls, broken pipes, illegal instructions, and other conditions. The `trap` builtin catches, or traps, one or more signals, allowing you to direct the actions a script takes when it receives a specified signal.

This discussion covers signals that are significant when you work with shell scripts. Table 27-5 lists these signals, the signal numbers that systems often ascribe to them, and the conditions that usually generate each signal. Give the command `kill -l`, `trap -l`, or `man 7 signal` for a list of signal names.

**Table 27-5** Signals

Type	Name	Number	Generating condition
Not a real signal	EXIT	0	Exit because of exit command or reaching the end of the program (not an actual signal but useful in trap)
Hang up	SIGHUP or HUP	1	Disconnect the line
Terminal interrupt	SIGINT or INT	2	Press the interrupt key (usually CONTROL-C)
Quit	SIGQUIT or QUIT	3	Press the quit key (usually CONTROL-SHIFT-  or CONTROL-SHIFT-\)
Kill	SIGKILL or KILL	9	The kill command with the <b>-9</b> option (cannot be trapped; use only as a last resort)
Software termination	SIGTERM or TERM	15	Default of the kill command
Stop	SIGTSTP or TSTP	20	Press the suspend key (usually CONTROL-Z)
Debug	DEBUG		Executes <i>commands</i> specified in the trap statement after each command (not an actual signal but useful in trap)
Error	ERR		Executes <i>commands</i> specified in the trap statement after each command that returns a nonzero exit status (not an actual signal but useful in trap)

When it traps a signal, a script takes whatever action you specify: It can remove files or finish any other processing as needed, display a message, terminate execution immediately, or ignore the signal. If you do not use `trap` in a script, any of the six actual signals listed in Table 27-5 (not `EXIT`, `DEBUG`, or `ERR`) terminates the script. Because a process cannot trap a `KILL` signal, you can use `kill -KILL` (or `kill -9`) as a last resort to terminate a script or any other process. (See page 946 for more information on `kill`.)

The `trap` command has the following syntax:

```
trap ['commands'] [signal]
```

The optional *commands* part specifies the commands that the shell executes when it catches one of the signals specified by *signal*. The *signal* can be a signal name or number—for example, `INT` or `2`. If *commands* is not present, `trap` resets the trap to its initial condition, which is usually to exit from the script.

The `trap` builtin does not require single quotation marks around *commands* as shown in the preceding syntax, but it is a good practice to use them. The single quotation marks cause shell variables within the *commands* to be expanded when the signal occurs, not when the shell evaluates the arguments to `trap`. Even if you do not use any shell variables in the *commands*, you need to enclose any command that takes arguments within either single or double quotation marks. Quoting the *commands* causes the shell to pass to `trap` the entire command as a single argument.

After executing the *commands*, the shell resumes executing the script where it left off. If you want `trap` to prevent a script from exiting when it receives a signal but not to run any commands explicitly, you can specify a null (empty) *commands* string, as shown in the `locktty` script (page 909). The following command traps signal number 15 after which the script continues.

```
trap '' 15
```

The following script demonstrates how the `trap` builtin can catch the terminal interrupt signal (`2`). You can use `SIGINT`, `INT`, or `2` to specify this signal. The script returns an exit status of 1:

```
$ cat inter
#!/bin/bash
trap 'echo PROGRAM INTERRUPTED; exit 1' INT
while true
do
    echo "Program running."
    sleep 1
done
$ inter
Program running.
Program running.
Program running.
CONTROL-C
PROGRAM INTERRUPTED
$
```

`:(null)` builtin The second line of **inter** sets up a trap for the terminal interrupt signal using **INT**. When **trap** catches the signal, the shell executes the two commands between the single quotation marks in the **trap** command. The **echo** builtin displays the message **PROGRAM INTERRUPTED**, **exit** terminates the shell running the script, and the parent shell displays a prompt. If **exit** were not there, the shell would return control to the **while** loop after displaying the message. The **while** loop repeats continuously until the script receives a signal because the **true** utility always returns a *true* exit status. In place of **true** you can use the `:(null)` builtin, which is written as a colon and always returns a 0 (*true*) status.

The **trap** builtin frequently removes temporary files when a script is terminated prematurely so that the files are not left to clutter the filesystem. The following shell script, named **addbanner**, uses two traps to remove a temporary file when the script terminates normally or owing to a hangup, software interrupt, quit, or software termination signal:

```
$ cat addbanner
#!/bin/bash
script=$(basename $0)

if [ ! -r "$HOME/banner" ]
then
    echo "$script: need readable $HOME/banner file" 1>&2
    exit 1
fi

trap 'exit 1' 1 2 3 15
trap 'rm /tmp/$$. $script 2> /dev/null' 0

for file
do
    if [ -r "$file" -a -w "$file" ]
    then
        cat $HOME/banner $file > /tmp/$$. $script
        cp /tmp/$$. $script $file
        echo "$script: banner added to $file" 1>&2
    else
        echo "$script: need read and write permission for $file" 1>&2
    fi
done
```

When called with one or more filename arguments, **addbanner** loops through the files, adding a header to the top of each. This script is useful when you use a standard format at the top of your documents, such as a standard layout for memos, or when you want to add a standard header to shell scripts. The header is kept in a file named `~/banner`. Because **addbanner** uses the **HOME** variable, which contains the pathname of the user's home directory, the script can be used by several users without modification. If Alex had written the script with `/home/alex` in place of **\$HOME** and then given the script to Jenny, either she would have had to change it or **addbanner** would have used Alex's **banner** file when Jenny ran it (assuming Jenny had read permission for the file).

The first trap in **addbanner** causes it to exit with a status of 1 when it receives a hangup, software interrupt (terminal interrupt or quit signal), or software termination signal. The second trap uses a 0 in place of **signal-number**, which causes trap to execute its command argument *whenever* the script exits because it receives an **exit** command or reaches its end. Together these traps remove a temporary file whether the script terminates normally or prematurely. Standard error of the second trap is sent to **/dev/null** for cases in which trap attempts to remove a nonexistent temporary file. In those cases **rm** sends an error message to standard error; because standard error is redirected, the user does not see this message.

See page 909 for another example that uses trap.

## kill: ABORTS A PROCESS

The **kill** builtin sends a signal to a process or job. The **kill** command has the following syntax:

```
kill [-signal] PID
```

where *signal* is the signal name or number (for example, **INT** or **2**) and *PID* is the process identification number of the process that is to receive the signal. You can specify a job number (page 241) as *%n* in place of *PID*. If you omit *signal*, **kill** sends a **TERM** (software termination, number 15) signal. For more information on signal names and numbers see Table 27-5 on page 943.

The following command sends the **TERM** signal to job number 1:

```
$ kill -TERM %1
```

Because **TERM** is the default signal for **kill**, you can also give this command as **kill %1**. Give the command **kill -l** (lowercase “l”) to display a list of signal names.

A program that is interrupted often leaves matters in an unpredictable state: Temporary files may be left behind (when they are normally removed), and permissions may be changed. A well-written application traps, or detects, signals and cleans up before exiting. Most carefully written applications trap the **INT**, **QUIT**, and **TERM** signals.

To terminate a program, first try **INT** (press **CONTROL-C**, if the job is in the foreground). Because an application can be written to ignore these signals, you may need to use the **KILL** signal, which cannot be trapped or ignored; it is a “sure kill.” For more information refer to “kill: Sends a Signal to a Process” on page 409.

## getopts: PARSES OPTIONS

The **getopts** builtin parses command-line arguments, thereby making it easier to write programs that follow the Linux argument conventions. The syntax for **getopts** is

```
getopts optstring varname [arg ...]
```

where *optstring* is a list of the valid option letters, *varname* is the variable that receives the options one at a time, and *arg* is the optional list of parameters to be processed. If *arg* is not present, **getopts** processes the command-line arguments. If *optstring* starts with a colon (:), the script takes care of generating error messages; otherwise, **getopts** generates error messages.

The `getopts` builtin uses the **OPTIND** (option index) and **OPTARG** (option argument) variables to store option-related values. When a shell script starts, the value of **OPTIND** is 1. Each time `getopts` locates an argument, it increments **OPTIND** to the index of the next option to be processed. If the option takes an argument, `bash` assigns the value of the argument to **OPTARG**.

To indicate that an option takes an argument, follow the corresponding letter in *optstring* with a colon (:). The option string **dxo:lt:r** indicates that `getopts` should search for **-d**, **-x**, **-o**, **-l**, **-t**, and **-r** options and that the **-o** and **-t** options take arguments.

Using `getopts` as the *test-command* in a **while** control structure allows you to loop over the options one at a time. The `getopts` builtin checks the option list for options that are in *optstring*. Each time through the loop, `getopts` stores the option letter it finds in *varname*.

Suppose that you want to write a program that can take three options:

1. A **-b** option indicates that the program should ignore whitespace at the start of input lines.
2. A **-t** option followed by the name of a directory indicates that the program should use that directory for temporary files. Otherwise, it should use **/tmp**.
3. A **-u** option indicates that the program should translate all its output to uppercase.

In addition, the program should ignore all other options and end option processing when it encounters two hyphens (**--**).

The problem is to write the portion of the program that determines which options the user has supplied. The following solution does not use `getopts`:

```
SKIPBLANKS=
TMPDIR=/tmp
CASE=lower
while [[ "$1" = -* ]] # [[ = ]] does pattern match
do
    case $1 in
        -b) SKIPBLANKS=TRUE ;;
        -t) if [ -d "$2" ]
              then
                  TMPDIR=$2
              shift
            else
                  echo "$0: -t takes a directory argument." >&2
                  exit 1
            fi ;;
        -u) CASE=upper ;;
        --) break ;;          # Stop processing options
        *)  echo "$0: Invalid option $1 ignored." >&2 ;;
    esac
    shift
done
```

This program fragment uses a loop to check and shift arguments while the argument is not `--`. As long as the argument is not two hyphens, the program continues to loop through a `case` statement that checks for possible options. The `--` `case` label breaks out of the `while` loop. The `*` `case` label recognizes any option; it appears as the last `case` label to catch any unknown options, displays an error message, and allows processing to continue. On each pass through the loop, the program does a shift to get to the next argument. If an option takes an argument, the program does an extra shift to get past that argument.

The following program fragment processes the same options, but uses `getopts`:

```
SKIPBLANKS=
TMPDIR=/tmp
CASE=lower

while getopts :bt:u arg
do
    case $arg in
        b)    SKIPBLANKS=TRUE ;;
        t)    if [ -d "$OPTARG" ]
                then
                    TMPDIR=$OPTARG
                else
                    echo "$0: $OPTARG is not a directory." >&2
                    exit 1
                fi ;;
        u)    CASE=upper ;;
        :)    echo "$0: Must supply an argument to -$OPTARG." >&2
                exit 1 ;;
        \?)   echo "Invalid option -$OPTARG ignored." >&2 ;;
        esac
    done
```

In this version of the code, the `while` structure evaluates the `getopts` builtin each time it comes to the top of the loop. The `getopts` builtin uses the `OPTIND` variable to keep track of the index of the argument it is to process the next time it is called. There is no need to call `shift` in this example.

In the `getopts` version of the script the `case` patterns do not start with a hyphen because the value of `arg` is just the option letter (`getopts` strips off the hyphen). Also, `getopts` recognizes `--` as the end of the options, so you do not have to specify it explicitly as in the `case` statement in the first example.

Because you tell `getopts` which options are valid and which require arguments, it can detect errors in the command line and handle them in two ways. This example uses a leading colon in *optstring* to specify that you check for and handle errors in your code; when `getopts` finds an invalid option, it sets *varname* to `?` and `OPTARG` to the option letter. When it finds an option that is missing an argument, `getopts` sets *varname* to `:` and `OPTARG` to the option lacking an argument.

The `\?` `case` pattern specifies the action to take when `getopts` detects an invalid option. The `:` `case` pattern specifies the action to take when `getopts` detects a missing



option argument. In both cases `getopts` does not write any error message; it leaves that task to you.

If you omit the leading colon from *optstring*, both an invalid option and a missing option argument cause *varname* to be assigned the string `?`. `OPTARG` is not set and `getopts` writes its own diagnostic message to standard error. Generally this method is less desirable because you have less control over what the user sees when an error is made.

Using `getopts` will not necessarily make your programs shorter. Its principal advantages are that it provides a uniform programming interface and it enforces standard option handling.

## A PARTIAL LIST OF BUILTINS

Table 27-6 lists some of the `bash` builtins. See “Listing `bash` builtins” on page 247 for instructions on how to display complete lists of builtins.

**Table 27-6** `bash` builtins

Builtin	Function
<code>:</code>	Returns 0 or <i>true</i> (the null builtin; page 945)
<code>.</code> (dot)	Executes a shell script as part of the current process (page 283)
<code>bg</code>	Puts a suspended job in the background (page 295)
<code>break</code>	Exits from a looping control structure (page 910)
<code>cd</code>	Changes to another working directory (page 196)
<code>continue</code>	Starts with the next iteration of a looping control structure (page 910)
<code>echo</code>	Displays its arguments (page 159)
<code>eval</code>	Scans and evaluates the command line (page 337)
<code>exec</code>	Executes a shell script or program in place of the current process (page 940)
<code>exit</code>	Exits from the current shell (usually the same as <code>CONTROL-D</code> from an interactive shell; page 930)
<code>export</code>	Places the value of a variable in the calling environment (makes it global; page 926)
<code>fg</code>	Brings a job from the background into the foreground (page 294)
<code>getopts</code>	Parses arguments to a shell script (page 946)
<code>jobs</code>	Displays list of background jobs (page 294)
<code>kill</code>	Sends a signal to a process or job (page 409)
<code>pwd</code>	Displays the name of the working directory (page 192)

**Table 27-6** bash builtins (continued)

Builtin	Function
read	Reads a line from standard input (page 937)
readonly	Declares a variable to be readonly (page 303)
set	Sets shell flags or command-line argument variables; with no argument, lists all variables (pages 339 and 934)
shift	Promotes each command-line argument (page 933)
test	Compares arguments (page 889)
times	Displays total times for the current shell and its children
trap	Traps a signal (page 943)
type	Displays how each argument would be interpreted as a command (page 937)
umask	Returns the value of the file-creation mask (page 440)
unset	Removes a variable or function (page 303)
wait	Waits for a background process to terminate

## EXPRESSIONS

An expression is composed of constants, variables, and operators that can be processed to return a value. This section covers arithmetic, logical, and conditional expressions as well as operators. Table 27-8 on page 953 lists the `bash` operators.

## ARITHMETIC EVALUATION

The Bourne Again Shell can perform arithmetic assignments and evaluate many different types of arithmetic expressions, all using integers. The shell performs arithmetic assignments in a number of ways. One is with arguments to the `let` builtin:

```
$ let "VALUE=VALUE * 10 + NEW"
```

In the preceding example, the variables `VALUE` and `NEW` contain integer values. Within a `let` statement you do not need to use dollar signs (\$) in front of variable names. Double quotation marks must enclose a single argument, or expression, that contains `SPACES`. Because most expressions contain `SPACES` and need to be quoted, `bash` accepts *((expression))* as a synonym for *let "expression"*, obviating the need for both quotation marks and dollar signs:

```
$ ((VALUE=VALUE * 10 + NEW))
```

You can use either form wherever a command is allowed and can remove the `SPACES` if you like. In the following example, the asterisk (\*) does not need to be quoted because the shell does not perform pathname expansion on the right side of an assignment (page 302):

```
$ let VALUE=VALUE*10+NEW
```

Because each argument to `let` is evaluated as a separate expression, you can assign values to more than one variable on a single line:

```
$ let "COUNT = COUNT + 1" VALUE=VALUE*10+NEW
```

You need to use commas to separate multiple assignments within a set of double parentheses:

```
$ ((COUNT = COUNT + 1, VALUE=VALUE*10+NEW))
```

### Arithmetic evaluation versus arithmetic expansion

**tip** Arithmetic evaluation differs from arithmetic expansion. As explained on page 346, arithmetic expansion uses the syntax `$(expression)`, evaluates *expression*, and replaces `$(expression)` with the result. You can use arithmetic expansion to display the value of an expression or to assign that value to a variable.

Arithmetic evaluation uses the `let expression` or `((expression))` syntax, evaluates *expression*, and returns a status code. You can use arithmetic evaluation to perform a logical comparison or an assignment.

Logical expressions You can use the `((expression))` syntax for logical expressions, although that task is frequently left to `[[expression]]`. The next example expands the `age_check` script (page 346) to include logical arithmetic evaluation in addition to arithmetic expansion:

```
$ cat age2
#!/bin/bash
echo -n "How old are you? "
read age
if ((30 < age && age < 60)); then
    echo "Wow, in $((60-age)) years, you'll be 60!"
else
    echo "You are too young or too old to play."
fi

$ age2
How old are you? 25
You are too young or too old to play.
```

The *test-statement* for the `if` structure evaluates two logical comparisons joined by a Boolean AND and returns 0 (*true*) if they are both *true* or 1 (*false*) otherwise.

## LOGICAL EVALUATION (CONDITIONAL EXPRESSIONS)

The syntax of a conditional expression is

```
[[ expression ]]
```

where *expression* is a Boolean (logical) expression. You must precede a variable name with a dollar sign (\$) within *expression*. The result of executing this builtin, like the `test` builtin, is a return status. The *conditions* allowed within the brackets are almost a superset of those accepted by `test` (page 889). Where the `test` builtin uses `-a` as a Boolean AND operator, `[[ expression ]]` uses `&&`. Similarly, where `test` uses `-o` as a Boolean OR operator, `[[ expression ]]` uses `||`.

You can replace the line that tests **age** in the **age2** script (preceding) with the following conditional expression. You must surround the **[[** and **]]** tokens with whitespace or a command terminator, and place dollar signs before the variables:

```
if [[ 30 < $age && $age < 60 ]]; then
```

You can also use **test**'s relational operators **-gt**, **-ge**, **-lt**, **-le**, **-eq**, and **-ne**:

```
if [[ 30 -lt $age && $age -lt 60 ]]; then
```

String comparisons    The **test** builtin tests whether strings are equal or unequal. The **[[ expression ]]** syntax adds comparison tests for string operators. The **>** and **<** operators compare strings for order (for example, **"aa" < "bbb"**). The **=** operator tests for pattern match, not just equality: **[[ string = pattern ]]** is *true* if *string* matches *pattern*. This operator is not symmetrical; the *pattern* must appear on the right side of the equal sign. For example, **[[ artist = a\* ]]** is *true* (**= 0**), whereas **[[ a\* = artist ]]** is *false* (**= 1**):

```
$ [[ artist = a* ]]
$ echo $?
0
$ [[ a* = artist ]]
$ echo $?
1
```

The next example uses a command list that starts with a compound condition. The condition tests that the directory **bin** and the file **src/myscript.bash** exist. If this is *true*, **cp** copies **src/myscript.bash** to **bin/myscript**. If the copy succeeds, **chmod** makes **myscript** executable. If any of these steps fails, **echo** displays a message.

```
$ [[ -d bin && -f src/myscript.bash ]] && cp src/myscript.bash \
bin/myscript && chmod +x bin/myscript || echo "Cannot make \
executable version of myscript"
```

# STRING PATTERN MATCHING

The Bourne Again Shell provides string pattern-matching operators that can manipulate pathnames and other strings. These operators can delete from strings prefixes or suffixes that match patterns. The four operators are listed in Table 27-7.

**Table 27-7**    String operators

Operator	Function
#	Removes minimal matching prefixes
##	Removes maximal matching prefixes
%	Removes minimal matching suffixes
%%	Removes maximal matching suffixes

The syntax for these operators is

```
${varname op pattern}
```

where *op* is one of the operators listed in Table 27-7 and *pattern* is a match pattern similar to that used for filename generation. These operators are commonly used to manipulate pathnames so as to extract or remove components or to change suffixes:

```
$ SOURCEFILE=/usr/local/src/prog.c
$ echo ${SOURCEFILE#/*/}
local/src/prog.c
$ echo ${SOURCEFILE##*/}
prog.c
$ echo ${SOURCEFILE%/*}
/usr/local/src
$ echo ${SOURCEFILE%%/*}

$ echo ${SOURCEFILE%.c}
/usr/local/src/prog
$ CHOPFIRST=${SOURCEFILE#/*/}
$ echo $CHOPFIRST
local/src/prog.c
$ NEXT=${CHOPFIRST%%/*}
$ echo $NEXT
local
```

Here the string-length operator, `${#name}`, is replaced by the number of characters in the value of *name*:

```
$ echo $SOURCEFILE
/usr/local/src/prog.c
$ echo ${#SOURCEFILE}
21
```

## OPERATORS

Arithmetic expansion and arithmetic evaluation use the same syntax, precedence, and associativity of expressions as the C language. Table 27-8 lists operators in order of decreasing precedence (priority of evaluation); each group of operators has equal precedence. Within an expression you can use parentheses to change the order of evaluation.

**Table 27-8** Operators

Type of operator/operator	Function
<b>Post</b>	
	<i>var</i> ++ Postincrement
	<i>var</i> -- Postdecrement
<b>Pre</b>	
	++ <i>var</i> Preincrement
	-- <i>var</i> Predecrement

**Table 27-8**    Operators (continued)

Type of operator/operator	Function
Unary	
	– Unary minus
	+ Unary plus
Negation	
	! Boolean NOT (logical negation)
	~ Complement (bitwise negation)
Exponentiation	
	** Exponent
Multiplication, division, remainder	
	* Multiplication
	/ Division
	% Remainder
Addition, subtraction	
	– Subtraction
	+ Addition
Bitwise shifts	
	<< Left bitwise shift
	>> Right bitwise shift
Comparison	
	<= Less than or equal
	>= Greater than or equal
	< Less than
	> Greater than
Equality, inequality	
	== Equality
	!= Inequality
Bitwise	
	& Bitwise AND
	^ Bitwise XOR (exclusive OR)
	Bitwise OR

**Table 27-8** Operators (continued)

Type of operator/operator	Function
<b>Boolean (logical)</b>	
	<b>&amp;&amp;</b> Boolean AND
	<b>  </b> Boolean OR
<b>Conditional evaluation</b>	
	<b>?:</b> Ternary operator
<b>Assignment</b>	
	<b>=, *=, /=, %=, +=, -=</b> , Assignment <b>&lt;&lt;=, &gt;&gt;=, &amp;=, ^=,  =</b>
<b>Comma</b>	
	<b>,</b> Comma

Pipe The pipe token has higher precedence than operators. You can use pipes anywhere in a command that you can use simple commands. For example, the command line

```
$ cmd1 | cmd2 || cmd3 | cmd4 && cmd5 | cmd6
```

is interpreted as if you had typed

```
$ ((cmd1 | cmd2) || (cmd3 | cmd4)) && (cmd5 | cmd6)
```

### Do not rely on rules of precedence: use parentheses

**tip** Do not rely on the precedence rules when you use compound commands. Instead, use parentheses to explicitly state the order in which you want the shell to interpret the commands.

Increment and  
decrement  
operators

The postincrement, postdecrement, preincrement, and predecrement operators work with variables. The pre- operators, which appear in front of the variable name as in **++COUNT** and **--VALUE**, first change the value of the variable (**++** adds 1; **--** subtracts 1) and then provide the result for use in the expression. The post- operators appear after the variable name as in **COUNT++** and **VALUE--**; they first provide the unchanged value of the variable for use in the expression and then change the value of the variable.

```
$ N=10
$ echo $N
10
$ echo $((--N+3))
12
$ echo $N
9
$ echo $((N++ - 3))
6
$ echo $N
10
```

Remainder The remainder operator (%) gives the remainder when its first operand is divided by its second. For example, the expression `$((15%7))` has the value 1.

Boolean The result of a Boolean operation is either 0 (*false*) or 1 (*true*).

The `&&` (AND) and `||` (OR) Boolean operators are called *short-circuiting* operators. If the result of using one of these operators can be decided by looking only at the left operand, the right operand is not evaluated. The `&&` operator causes the shell to test the exit status of the command preceding it. If the command succeeded, `bash` executes the next command; otherwise, it skips the remaining commands on the command line. You can use this construct to execute commands conditionally:

```
$ mkdir bkup && cp -r src bkup
```

This compound command creates the directory `bkup`. If `mkdir` succeeds, the contents of directory `src` is copied recursively to `bkup`.

The `||` separator also causes `bash` to test the exit status of the first command but has the opposite effect: The remaining command(s) are executed only if the first one failed (that is, exited with nonzero status):

```
$ mkdir bkup || echo "mkdir of bkup failed" >> /tmp/log
```

The exit status of a command list is the exit status of the last command in the list. You can group lists with parentheses. For example, you could combine the previous two examples as

```
$ (mkdir bkup && cp -r src bkup) || echo "mkdir failed" >> /tmp/log
```

In the absence of parentheses, `&&` and `||` have equal precedence and are grouped from left to right. The following examples use the `true` and `false` utilities. These utilities do nothing and return *true* (0) and *false* (1) exit statuses, respectively:

```
$ false; echo $?  
1
```

The  `$?`  variable holds the exit status of the preceding command (page 930). The next two commands yield an exit status of 1 (*false*):

```
$ true || false && false  
$ echo $?  
1  
$ (true || false) && false  
$ echo $?  
1
```

Similarly the next two commands yield an exit status of 0 (*true*):

```
$ false && false || true  
$ echo $?  
0  
$ (false && false) || true  
$ echo $?  
0
```



Because `||` and `&&` have equal precedence, the parentheses in the two preceding pairs of examples do nothing to change the order of operations.

Because the expression on the right side of a short-circuiting operator may never get executed, you must be careful with assignment statements in that location. The following example demonstrates what can happen:

```
$ ((N=10,Z=0))
$ echo $((N || ((Z+=1)) ))
1
$ echo $Z
0
```

Because the value of `N` is nonzero, the result of the `||` (OR) operation is 1 (*true*), no matter what the value of the right side is. As a consequence `((Z+=1))` is never evaluated and `Z` is not incremented.

**Ternary** The ternary operator, `? :`, decides which of two expressions should be evaluated, based on the value returned from a third expression:

*expression1 ? expression2 : expression3*

If *expression1* produces a *false* (0) value, *expression3* is evaluated; otherwise, *expression2* is evaluated. The value of the entire expression is the value of *expression2* or *expression3*, depending on which one is evaluated. If *expression1* is *true*, *expression3* is not evaluated. If *expression1* is *false* *expression2* is not evaluated:

```
$ ((N=10,Z=0,COUNT=1))
$ ((T=N>COUNT?++Z:--Z))
$ echo $T
1
$ echo $Z
1
```

**Assignment** The assignment operators, such as `+=`, are shorthand notations. For example, `N+=3` is the same as `((N=N+3))`.

**Other bases** The following commands use the syntax *base#n* to assign base 2 (binary) values. First `v1` is assigned a value of 0101 (5 decimal) and `v2` is assigned a value of 0110 (6 decimal). The `echo` utility verifies the decimal values.

```
$ ((v1=2#0101))
$ ((v2=2#0110))
$ echo "$v1 and $v2"
5 and 6
```

Next the bitwise AND operator (`&`) selects the bits that are on in both 5 (0101 binary) and 6 (0110 binary). The result is binary 0100, which is 4 decimal.

```
$ echo $(( v1 & v2 ))
4
```

The Boolean AND operator (`&&`) produces a result of 1 if both of its operands are nonzero and a result of 0 otherwise. The bitwise inclusive OR operator (`|`) selects the bits that are on in either 0101 or 0110, resulting in 0111, which is 7 decimal. The Boolean OR operator (`||`) produces a result of 1 if either of its operands is nonzero and a result of 0 otherwise.

```
$ echo $(( v1 && v2 ))
1
$ echo $(( v1 | v2 ))
7
$ echo $(( v1 || v2 ))
1
```

Next the bitwise exclusive OR operator (`^`) selects the bits that are on in either, but not both, of the operands 0101 and 0110, yielding 0011, which is 3 decimal. The Boolean NOT operator (`!`) produces a result of 1 if its operand is 0 and a result of 0 otherwise. Because the exclamation point in `$(( ! v1 ))` is enclosed within double parentheses, it does not need to be escaped to prevent the shell from interpreting the exclamation point as a history event. The comparison operators produce a result of 1 if the comparison is *true* and a result of 0 otherwise.

```
$ echo $(( v1 ^ v2 ))
3
$ echo $(( ! v1 ))
0
$ echo $(( v1 < v2 ))
1
$ echo $(( v1 > v2 ))
0
```

---

## SHELL PROGRAMS

The Bourne Again Shell has many features that make it a good programming language. The structures that `bash` provides are not a random assortment. Rather, they have been chosen to provide most of the structural features that are in other procedural languages, such as C or Pascal. A procedural language provides the ability to

- Declare, assign, and manipulate variables and constant data. The Bourne Again Shell provides string variables, together with powerful string operators, and integer variables, along with a complete set of arithmetic operators.
- Break large problems into small ones by creating subprograms. The Bourne Again Shell allows you to create functions and call scripts from other scripts. Shell functions can be called recursively; that is, a Bourne Again Shell function can call itself. You may not need to use recursion often, but it may allow you to solve some apparently difficult problems with ease.
- Execute statements conditionally, using statements such as `if`.

- Execute statements iteratively, using statements such as **while** and **for**.
- Transfer data to and from the program, communicating with both data files and users.

Programming languages implement these capabilities in different ways but with the same ideas in mind. When you want to solve a problem by writing a program, you must first figure out a procedure that leads you to a solution—that is, an *algorithm*. Typically you can implement the same algorithm in roughly the same way in different programming languages, using the same kinds of constructs in each language.

Chapter 9 and this chapter have introduced numerous **bash** features, many of which are useful for interactive use as well as for shell programming. This section develops two complete shell programs, demonstrating how to combine some of these features effectively. The programs are presented as problems for you to solve along with sample solutions.

## A RECURSIVE SHELL SCRIPT

A recursive construct is one that is defined in terms of itself. Alternatively, you might say that a recursive program is one that can call itself. This may seem circular, but it need not be. To avoid circularity a recursive definition must have a special case that is not self-referential. Recursive ideas occur in everyday life. For example, you can define an ancestor as your mother, your father, or one of their ancestors. This definition is not circular; it specifies unambiguously who your ancestors are: your mother or your father, or your mother's mother or father or your father's mother or father, and so on.

A number of Linux system utilities can operate recursively. See the **-R** option to the **chmod**, **chown**, and **cp** utilities for examples.

**Solve the following problem by using a recursive shell function:**

---

Write a shell function named **makepath** that, given a pathname, creates all components in that pathname as directories. For example, the command **makepath a/b/c/d** should create directories **a**, **a/b**, **a/b/c**, and **a/b/c/d**. (The **mkdir** utility supports a **-p** option that does exactly this. Solve the problem without using **mkdir -p**.)

---

One algorithm for a recursive solution follows:

1. Examine the path argument. If it is a null string or if it names an existing directory, do nothing and return.
2. If it is a simple path component, create it (using **mkdir**) and return.
3. Otherwise, call **makepath** using the path prefix of the original argument. This step eventually creates all the directories up to the last component, which you can then create with **mkdir**.

In general, a recursive function must invoke itself with a simpler version of the problem than it was given until it is finally called with a simple case that does not need to call itself. Following is one possible solution based on this algorithm:

```
makepath    # this is a function
            # enter it at the keyboard, do not run it as a shell script
            #
            function makepath()
            {
                if [[ ${#1} -eq 0 || -d "$1" ]]
                then
                    return 0          # Do nothing
                fi
                if [[ "${1%/*}" = "$1" ]]
                then
                    mkdir $1
                    return $?
                fi
                makepath ${1%/*} || return 1
                mkdir $1
                return $?
            }
```

In the test for a simple component (the `if` statement in the middle of the function), the left expression is the argument after the shortest suffix that starts with a `/` character has been stripped away (page 952). If there is no such character (for example, if `$1` is `alex`), nothing is stripped off and the two sides are equal. If the argument is a simple filename preceded by a slash, such as `/usr`, the expression `${1%/*}` evaluates to a null string. To make the function work in this case, you must take two precautions: Put the left expression within quotation marks and ensure that the recursive function behaves sensibly when it is passed a null string as an argument. In general, good programs are robust: They should be prepared for borderline, invalid, or meaningless input and behave appropriately in such cases.

By giving the following command from the shell you are working in, you turn on debugging tracing so that you can watch the recursion work:

```
$ set -o xtrace
```

(Give the same command, but replace the hyphen with a plus sign (+) to turn debugging off.) With debugging turned on, the shell displays each line in its expanded form as it executes the line. A `+` precedes each line of debugging output. In the following example, the first line that starts with `+` shows the shell calling `makepath`. The `makepath` function is called from the command line with arguments of `a/b/c`. Subsequently it calls itself with arguments of `a/b` and finally `a`. All the work is done (using `mkdir`) as each call to `makepath` returns.

```
$ makepath a/b/c
+ makepath a/b/c
+ [[ 5 -eq 0 ]]
+ [[ -d a/b/c ]]
+ [[ a/b = \a\/\b\/\c ]]
+ makepath a/b
+ [[ 3 -eq 0 ]]
+ [[ -d a/b ]]
+ [[ a = \a\/\b ]]
```

```

+ makepath a
+ [[ 1 -eq 0 ]]
+ [[ -d a ]]
+ [[ a = \a ]]
+ mkdir a
+ return 0
+ mkdir a/b
+ return 0
+ mkdir a/b/c
+ return 0

```

The function works its way down the recursive path and back up again.

It is instructive to invoke **makepath** with an invalid path and see what happens. The following example, run with debugging turned on, tries to create the path **/a/b**, which requires that you create directory **a** in the root directory. Unless you have permission to write to the root directory, you are not permitted to create this directory.

```

$ makepath /a/b
+ makepath /a/b
+ [[ 4 -eq 0 ]]
+ [[ -d /a/b ]]
+ [[ /a = \/\a\/\b ]]
+ makepath /a
+ [[ 2 -eq 0 ]]
+ [[ -d /a ]]
+ [[ '' = \/\a ]]
+ makepath
+ [[ 0 -eq 0 ]]
+ return 0
+ mkdir /a
mkdir: cannot create directory '/a': Permission denied
+ return 1
+ return 1

```

The recursion stops when **makepath** is denied permission to create the **/a** directory. The error return is passed all the way back, so the original **makepath** exits with nonzero status.

## Use local variables with recursive functions

**tip** The preceding example glossed over a potential problem that you may encounter when you use a recursive function. During the execution of a recursive function, many separate instances of that function may be active simultaneously. All but one of them are waiting for their child invocation to complete.

Because functions run in the same environment as the shell that calls them, variables are implicitly shared by a shell and a function it calls so that all instances of the function share a single copy of each variable. Sharing variables can give rise to side effects that are rarely what you want. As a rule, you should use **typeset** to make all variables of a recursive function be local variables. See page 928 for more information.

## THE quiz SHELL SCRIPT

Solve the following problem using a bash script:

---

Write a generic multiple-choice quiz program. The program should get its questions from data files, present them to the user, and keep track of the number of correct and incorrect answers. The user must be able to exit from the program at any time with a summary of results to that point.

---

The detailed design of this program and even the detailed description of the problem depend on a number of choices: How will the program know which subjects are available for quizzes? How will the user choose a subject? How will the program know when the quiz is over? Should the program present the same questions (for a given subject) in the same order each time, or should it scramble them?

Of course, you can make many perfectly good choices that implement the specification of the problem. The following details narrow the problem specification:

- Each subject will correspond to a subdirectory of a master quiz directory. This directory will be named in the environment variable `QUIZDIR`, whose default will be `~/quiz`. For example, you could have the following directories correspond to the subjects engineering, art, and politics: `~/quiz/engineering`, `~/quiz/art`, and `~/quiz/politics`. Put the `quiz` directory in `/usr/games` if you want all users to have access to it (requires root privileges).
- Each subject can have several questions. Each question is represented by a file in its subject's directory.
- The first line of each file that represents a question is the text of the question. If it takes more than one line, you must escape the `NEWLINE` with a backslash. (This setup makes it easy to read a single question with the `read` builtin.) The second line of the file is an integer that specifies the number of choices. The next lines are the choices themselves. The last line is the correct answer. Following is a sample question file:

```
Who discovered the principle of the lever?  
4  
Euclid  
Archimedes  
Thomas Edison  
The Lever Brothers  
Archimedes
```

- The program presents all the questions in a subject directory. At any point the user can interrupt the quiz with `CONTROL-C`, whereupon the program will summarize the results so far and exit. If the user does not interrupt, the program summarizes the results and exits when it has asked all questions for the chosen subject.
- The program scrambles the questions in a subject before presenting them.

Following is a top-level design for this program:

1. Initialize. This involves a number of steps, such as setting the counts of the number of questions asked so far and the number of correct and wrong answers to zero. Sets up to trap CONTROL-C.
2. Present the user with a choice of subjects and get the user's response.
3. Change to the corresponding subject directory.
4. Determine the questions to be asked (that is, the filenames in that directory). Arrange them in random order.
5. Repeatedly present questions and ask for answers until the quiz is over or is interrupted by the user.
6. Present the results and exit.

Clearly some of these steps (such as step 3) are simple, whereas others (such as step 4) are complex and worthy of analysis on their own. Use shell functions for any complex step, and use the `trap` builtin to handle a user interrupt.

Here is a skeleton version of the program with empty shell functions:

```
function initialize
{
# Initializes variables.
}
function choose_subj
{
# Writes choice to standard output.
}

function scramble
{
# Stores names of question files, scrambled,
# in an array variable named questions.
}

function ask
{
# Reads a question file, asks the question, and checks the
# answer. Returns 1 if the answer was correct, 0 otherwise. If it
# encounters an invalid question file, exit with status 2.
}

function summarize
{
# Presents the user's score.
}

# Main program
initialize                                # Step 1 in top-level design

subject=$(choose_subj)                    # Step 2
[[ $? -eq 0 ]] || exit 2                  # If no valid choice, exit
```

```
cd $subject || exit 2          # Step 3
echo                          # Skip a line
scramble                      # Step 4

for ques in ${questions[*]}; do # Step 5
    ask $ques
    result=$?
    (( num_ques=num_ques+1 ))
    if [[ $result == 1 ]]; then
        (( num_correct += 1 ))
    fi
    echo                      # Skip a line between questions
    sleep ${QUIZDELAY:=1}
done

summarize                    # Step 6
exit 0
```

To make reading the results a bit easier for the user, a `sleep` call appears inside the question loop. It delays `$QUIZDELAY` seconds (default = 1) between questions.

Now the task is to fill in the missing pieces of the program. In a sense this program is being written backward. The details (the shell functions) come first in the file but come last in the development process. This common programming practice is called top-down design. In top-down design you fill in the broad outline of the program first and supply the details later. In this way you break the problem up into smaller problems, each of which you can work on independently. Shell functions are a great help in using the top-down approach.

One way to write the `initialize` function follows. The `cd` command causes `QUIZDIR` to be the working directory for the rest of the script and defaults to `~/quiz` if `QUIZDIR` is not set.

```
function initialize ()
{
    trap 'summarize ; exit 0' INT # Handle user interrupts
    num_ques=0                  # Number of questions asked so far
    num_correct=0               # Number answered correctly so far
    first_time=true             # true until first question is asked
    cd ${QUIZDIR:=~/quiz} || exit 2
}
```

Be prepared for the `cd` command to fail. The directory may be unsearchable or conceivably another user may have removed it. The preceding function exits with a status code of 2 if `cd` fails.

The next function, `choose_subj`, is a bit more complicated. It displays a menu using a `select` statement:



```

function choose_subj ()
{
subjects=$(ls)
PS3="Choose a subject for the quiz from the preceding list: "
select Subject in ${subjects[*]}; do
    if [[ -z "$Subject" ]]; then
        echo "No subject chosen. Bye." >&2
        exit 1
    fi
    echo $Subject
    return 0
done
}

```

The function first uses an `ls` command and command substitution to put a list of subject directories in the **subjects** array. Next the **select** structure (page 917) presents the user with a list of subjects (the directories found by `ls`) and assigns the chosen directory name to the **Subject** variable. Finally the function writes the name of the subject directory to standard output. The main program uses command substitution to assign this value to the **subject** variable [**subject**=\$(choose\_subj)].

The **scramble** function presents a number of difficulties. In this solution it uses an array variable (**questions**) to hold the names of the questions. It scrambles the entries in an array using the **RANDOM** variable (each time you reference **RANDOM** it has the value of a [random] integer between 0 and 32767):

```

function scramble ()
{
typeset -i index quescount
questions=$(ls)
quescount=${#questions[*]}           # Number of elements
((index=quescount-1))
while [[ $index > 0 ]]; do
    ((target=RANDOM % index))
    exchange $target $index
    ((index -= 1))
done
}

```

This function initializes the array variable **questions** to the list of filenames (questions) in the working directory. The variable **quescount** is set to the number of such files. Then the following algorithm is used: Let the variable **index** count down from **quescount - 1** (the index of the last entry in the array variable). For each value of **index**, the function chooses a random value **target** between 0 and **index**, inclusive. The command

```
((target=RANDOM % index))
```

produces a random value between 0 and **index - 1** by taking the remainder (the **%** operator) when **\$RANDOM** is divided by **index**. The function then exchanges the elements of **questions** at positions **target** and **index**. It is convenient to do this in another function named **exchange**:

```
function exchange ()
{
temp_value=${questions[$1]}
questions[$1]=${questions[$2]}
questions[$2]=$temp_value
}
```

The **ask** function also uses the **select** structure. It reads the question file named in its argument and uses the contents of that file to present the question, accept the answer, and determine whether the answer is correct. (See the code that follows.)

The **ask** function uses file descriptor 3 to read successive lines from the question file, whose name was passed as an argument and is represented by **\$1** in the function. It reads the question into the **ques** variable and the number of questions into **num\_opts**. The function constructs the variable **choices** by initializing it to a null string and successively appending the next choice. Then it sets **PS3** to the value of **ques** and uses a **select** structure to prompt the user with **ques**. The **select** structure places the user's answer in **answer**, and the function then checks it against the correct answer from the file.

The construction of the **choices** variable is done with an eye toward avoiding a potential problem. Suppose that one answer has some whitespace in it. Then it might appear as two or more arguments in **choices**. To avoid this problem, make sure that **choices** is an array variable. The **select** statement does the rest of the work:

```
quiz    $ cat quiz
        #!/bin/bash

        # remove the # on the following line to turn on debugging
        # set -o xtrace

        #=====
        function initialize ()
        {
        trap 'summarize ; exit 0' INT      # Handle user interrupts
        num ques=0                        # Number of questions asked so far
        num correct=0                     # Number answered correctly so far
        first time=true                   # true until first question is asked
        cd ${QUIZDIR:=$~/quiz} || exit 2
        }

        #=====
        function choose_subj ()
        {
        subjects=(ls)
        PS3="Choose a subject for the quiz from the preceding list: "
        select Subject in ${subjects[*]}; do
            if [[ -z "$Subject" ]]; then
                echo "No subject chosen. Bye." >&2
                exit 1
            fi
            echo $Subject
            return 0
        done
        }
}
```

```

#=====
function exchange ()
{
temp_value=${questions[$1]}
questions[$1]=${questions[$2]}
questions[$2]=$temp_value
}

#=====
function scramble ()
{
typeset -i index quescount
questions=($(ls))
quescount=${#questions[*]}          # Number of elements
((index=quescount-1))
while [[ $index > 0 ]]; do
    ((target=RANDOM % index))
    exchange $target $index
    ((index -= 1))
done
}

#=====
function ask ()
{
exec 3<$1
read -u3 ques || exit 2
read -u3 num_opts || exit 2

index=0
choices=()
while (( index < num_opts )) ; do
    read -u3 next_choice || exit 2
    choices=("${choices[@]}" "$next_choice")
    ((index += 1))
done
read -u3 correct_answer || exit 2
exec 3<&-

if [[ $first_time = true ]]; then
    first_time=false
    echo -e "You may press the interrupt key at any time to quit.\n"
fi

PS3=$ques" "          # Make $ques the prompt for select
                        # and add some spaces for legibility.
select answer in "${choices[@]"}; do
    if [[ -z "$answer" ]]; then
        echo Not a valid choice. Please choose again.
    elif [[ "$answer" = "$correct_answer" ]]; then
        echo "Correct!"
        return 1
    else
        echo "No, the answer is $correct_answer."
        return 0
    fi
done
}

```

```
#=====
function summarize ()
{
    echo                                # Skip a line
    if (( num_ques == 0 )); then
        echo "You did not answer any questions"
        exit 0
    fi

    (( percent=num_correct*100/num_ques ))
    echo "You answered $num_correct questions correctly, out of \
$num_ques total questions."
    echo "Your score is $percent percent."
}

#=====
# Main program
initialize                                # Step 1 in top-level design

subject=$(choose_subj)                    # Step 2
[[ $? -eq 0 ]] || exit 2                  # If no valid choice, exit

cd $subject || exit 2                    # Step 3
echo                                     # Skip a line
scramble                                 # Step 4

for ques in ${questions[*]}; do         # Step 5
    ask $ques
    result=$?
    (( num_ques=num_ques+1 ))
    if [[ $result == 1 ]]; then
        (( num_correct += 1 ))
    fi
    echo                                # Skip a line between questions
    sleep ${QUIZDELAY:=1}
done

summarize                                # Step 6
exit 0
```

---

## CHAPTER SUMMARY

The shell is a programming language. Programs written in this language are called shell scripts, or simply scripts. Shell scripts provide the decision and looping control structures present in high-level programming languages while allowing easy access to system utilities and user programs. Shell scripts can use functions to modularize and simplify complex tasks.

**Control structures** The control structures that use decisions to select alternatives are **if...then**, **if...then...else**, and **if...then...elif**. The **case** control structure provides a multiway branch and can be used when you want to express alternatives using a simple pattern-matching syntax.

The looping control structures are **for...in**, **for**, **until**, and **while**. These structures perform one or more tasks repetitively.

The **break** and **continue** control structures alter control within loops: **break** transfers control out of a loop, and **continue** transfers control immediately to the top of a loop.

The Here document allows input to a command in a shell script to come from within the script itself.

**File descriptors** The Bourne Again Shell provides the ability to manipulate file descriptors. Coupled with the **read** and **echo** builtins, file descriptors allow shell scripts to have as much control over input and output as programs written in lower-level languages.

**Variables** You assign attributes, such as **readonly**, to **bash** variables using the **typeset** builtin. The Bourne Again Shell provides operators to perform pattern matching on variables, provide default values for variables, and evaluate the length of variables. This shell also supports array variables and local variables for functions and provides built-in integer arithmetic capability, using the **let** builtin and an expression syntax similar to the C programming language.

**Builtins** Bourne Again Shell builtins include **type**, **read**, **exec**, **trap**, **kill**, and **getopts**. The **type** builtin displays information about a command, including its location; **read** allows a script to accept user input.

The **exec** builtin executes a command without creating a new process. The new command overlays the current process, assuming the same environment and PID number of that process. This builtin executes user programs and other Linux commands when it is *not* necessary to return control to the calling process.

The **trap** builtin catches a signal sent by Linux to the process running the script and allows you to specify actions to be taken upon receipt of one or more signals. You can use this builtin to cause a script to ignore the signal that is sent when the user presses the interrupt key.

The **kill** builtin allows you to terminate a running program. The **getopts** builtin parses command-line arguments, making it easier to write programs that follow standard Linux conventions for command-line arguments and options.

**Utilities in scripts** In addition to using control structures, builtins, and functions, shell scripts generally call Linux utilities. The **find** utility, for instance, is commonplace in shell scripts that search for files in the system hierarchy and can perform a vast range of tasks, from simple to complex.

A well-written shell script adheres to standard programming practices, such as specifying the shell to execute the script on the first line of the script, verifying the number and type of arguments that the script is called with, displaying a standard usage message to report command-line errors, and redirecting all informational messages to standard error.

**Expressions** There are two basic types of expressions: arithmetic and logical. Arithmetic expressions allow you to do arithmetic on constants and variables, yielding a numeric result. Logical (Boolean) expressions compare expressions or strings, or test conditions to yield a *true* or *false* result. As with all decisions within Linux shell scripts, a *true* status is represented by the value zero; *false*, by any nonzero value.

## EXERCISES

1. Rewrite the **journal** script of Chapter 9 (question 5, page 354) by adding commands to verify that the user has write permission for a file named **journal-file** in the user's home directory, if such a file exists. The script should take appropriate actions if **journal-file** exists and the user does not have write permission to the file. Verify that the modified script works.
2. The special parameter "\$@" is referenced twice in the **out** script (page 893). Explain what would be different if the parameter "\$\*" were used in its place.
3. Write a filter that takes a list of files as input and outputs the basename (page 916) of each file in the list.
4. Write a function that takes a single filename as an argument and adds execute permission to the file for the user.
  - a. When might such a function be useful?
  - b. Revise the script so that it takes one or more filenames as arguments and adds execute permission for the user for each file argument.
  - c. What can you do to make the function available every time you log in?
  - d. Suppose that, in addition to having the function available on subsequent login sessions, you want to make the function available now in your current shell. How would you do so?
5. When might it be necessary or advisable to write a shell script instead of a shell function? Give as many reasons as you can think of.
6. Write a shell script that displays the names of all directory files, but no other types of files, in the working directory.
7. Write a script to display the time every 15 seconds. Read the **date** man page and display the time, using the %r field descriptor. Clear the window (using the **clear** command) each time before you display the time.
8. Enter the following script named **savefiles**, and give yourself execute permission to the file:

```
$ cat savefiles
#!/bin/bash
echo "Saving files in current directory in file savethem."
exec > savethem
for i in *
do
    echo "=====
    echo "File: $i"
    echo "=====
    cat "$i"
done
```

- 
- a. What error message do you get when you execute this script? Rewrite the script so that the error does not occur, making sure the output still goes to **savethem**.
    - b. What might be a problem with running this script twice in the same directory? Discuss a solution to this problem.
  9. Read the **bash** **man** or **info** page, try some experiments, and answer the following questions:
    - a. How do you export a function?
    - b. What does the **hash** builtin do?
    - c. What happens if the argument to **exec** is not executable?
  10. Using the **find** utility, perform the following tasks:
    - a. List all files in the working directory and all subdirectories that have been modified within the last day.
    - b. List all files that you have read access to on the system that are larger than 1 megabyte.
    - c. Remove all files named **core** from the directory structure rooted at your home directory.
    - d. List the inode numbers of all files in the working directory whose filenames end in **.c**.
    - e. List all files that you have read access to on the root filesystem that have been modified in the last 30 days.
  11. Write a short script that tells you whether the permissions for two files, whose names are given as arguments to the script, are identical. If the permissions for the two files are identical, output the common permission field. Otherwise, output each filename followed by its permission field. (*Hint:* Try using the **cut** utility.)
  12. Write a script that takes the name of a directory as an argument and searches the file hierarchy rooted at that directory for zero-length files. Write the names of all zero-length files to standard output. If there is no option on the command line, have the script delete the file after displaying its name, asking the user for confirmation, and receiving positive confirmation. A **-f** (force) option on the command line indicates that the script should display the filename but not ask for confirmation before deleting the file.

## ADVANCED EXERCISES

13. Write a script that takes a colon-separated list of items and outputs the items, one per line, to standard output (without the colons).
14. Generalize the script written in exercise 13 so that the character separating the list items is given as an argument to the function. If this argument is absent, the separator should default to a colon.
15. Write a function named **funload** that takes as its single argument the name of a file containing other functions. The purpose of **funload** is to make all functions in the named file available in the current shell; that is, **funload** loads the functions from the named file. To locate the file, **funload** searches the colon-separated list of directories given by the environment variable **FUNPATH**. Assume that the format of **FUNPATH** is the same as **PATH** and that searching **FUNPATH** is similar to the shell's search of the **PATH** variable.
16. Rewrite **bundle** (page 920) so that the script it creates takes an optional list of filenames as arguments. If one or more filenames are given on the command line, only those files should be re-created; otherwise, all files in the shell archive should be re-created. For example, suppose that all files with the filename extension **.c** are bundled into an archive named **srcshell**, and you want to unbundle just the files **test1.c** and **test2.c**. The following command will unbundle just these two files:

```
$ bash srcshell test1.c test2.c
```

17. What kind of links will the **lnks** script (page 896) not find? Why?
18. In principle, recursion is never necessary. It can always be replaced by an iterative construct, such as **while** or **until**. Rewrite **makepath** (page 960) as a nonrecursive function. Which version do you prefer? Why?
19. Lists are commonly stored in environment variables by putting a colon (:) between each of the list elements. (The value of the **PATH** variable is a good example.) You can add an element to such a list by concatenating the new element to the front of the list, as in

```
PATH=/opt/bin:$PATH
```

If the element you add is already in the list, you now have two copies of it in the list. Write a shell function named **addenv** that takes two arguments: (1) the name of a shell variable and (2) a string to prepend to the list that is the value of the shell variable only if that string is not already an element of the list. For example, the call

```
addenv PATH /opt/bin
```



would add **/opt/bin** to **PATH** only if that pathname is not already in **PATH**. Be sure that your solution works even if the shell variable starts out empty. Also make sure that you check the list elements carefully. If **/usr/opt/bin** is in **PATH** but **/opt/bin** is not, the example just given should still add **/opt/bin** to **PATH**. (*Hint:* You may find this exercise easier to complete if you first write a function **locate\_field** that tells you whether a string is an element in the value of a variable.)

20. Write a function that takes a directory name as an argument and writes to standard output the maximum of the lengths of all filenames in that directory. If the function's argument is not a directory name, write an error message to standard output and exit with nonzero status.
21. Modify the function you wrote for exercise 20 to descend all subdirectories of the named directory recursively and to find the maximum length of any filename in that hierarchy.
22. Write a function that lists the number of ordinary files, directories, block special files, character special files, FIFOs, and symbolic links in the working directory. Do this in two different ways:
  - a. Use the first letter of the output of **ls -l** to determine a file's type.
  - b. Use the file type condition tests of the **[[ *expression* ]]** syntax to determine a file's type.
23. Modify the **quiz** program (page 966) so that the choices for a question are randomly arranged.

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# THE PERL SCRIPTING LANGUAGE

## IN THIS CHAPTER

Introduction to Perl.....	976
Help .....	977
Running a Perl Program .....	980
Syntax .....	981
Variables .....	983
Control Structures.....	991
Working with Files.....	1000
Sort .....	1003
Subroutines.....	1005
Regular Expressions .....	1007
CPAN Modules.....	1013
Examples.....	1015

Larry Wall created the Perl (Practical Extraction and Report Language) programming language for working with text. Perl uses syntax and concepts from `awk`, `sed`, `C`, the Bourne Shell, Smalltalk, Lisp, and English. It was designed to scan and extract information from text files and generate reports based on that information. Since its introduction in 1987, Perl has expanded enormously—its documentation growing up with it. Today, in addition to text processing, Perl is used for system administration, software development, and general-purpose programming.

Perl code is portable because Perl has been implemented on many operating systems (see [www.cpan.org/ports](http://www.cpan.org/ports)). Perl is an informal, practical, robust, easy-to-use, efficient, and complete language. It is a down-and-dirty language that supports procedural and object-oriented programming. It is not necessarily elegant.

One of the things that distinguishes Perl from many other languages is its linguistic origins. In English you say, “I will buy a car if I win the lottery.” Perl allows you to mimic that syntax. Another distinction is that Perl has singular and plural variables, the former holding single values and the latter holding lists of values.

## INTRODUCTION TO PERL

A couple of quotes from the manual shed light on Perl's philosophy:

Many of Perl's syntactic elements are optional. Rather than requiring you to put parentheses around every function call and declare every variable, you can often leave such explicit elements off and Perl will frequently figure out what you meant. This is known as Do What I Mean, abbreviated DWIM. It allows programmers to be lazy and to code in a style with which they are comfortable.

The Perl motto is "There's more than one way to do it." Divining how many more is left as an exercise to the reader.

One of Perl's biggest assets is its support by thousands of third-party modules. The Comprehensive Perl Archive Network (CPAN; [www.cpan.org](http://www.cpan.org)) is a repository for many of the modules and other information related to Perl. See page 1013 for information on downloading, installing, and using these modules in Perl programs.

### Install `perl-doc`

**tip** The **perl-doc** package holds a wealth of information. Install this package before you start using Perl; see the next page for more information.

The best way to learn Perl is to work with it. Copy and modify the programs in this chapter until they make sense to you. Many system tools are written in Perl. The first line of most of these tools begins with `#!/usr/bin/perl`, which tells the shell to pass the program to Perl for execution. Most files that contain the string `/usr/bin/perl` are Perl programs. The following command uses `grep` to search the `/usr/bin` and `/usr/sbin` directories recursively (`-r`) for files containing the string `/usr/bin/perl`; it lists many local system tools written in Perl:

```
$ grep -r /usr/bin/perl /usr/bin /usr/sbin | head -4
/usr/bin/defoma-user:#!/usr/bin/perl -w
/usr/bin/pod2latex:#!/usr/bin/perl
/usr/bin/pod2latex:    eval 'exec /usr/bin/perl -S $0 ${1+"$@"}'
/usr/bin/splain:#!/usr/bin/perl
```

Review these programs—they demonstrate how Perl is used in the real world. Copy a system program to a directory you own before modifying it. Do not run a system program while running with **root** privileges unless you know what you are doing.

## MORE INFORMATION

Local man pages: See the `perl` and `perltoc` man pages for lists of Perl man pages

Web Perl home page: [www.perl.com](http://www.perl.com)

CPAN: [www.cpan.org](http://www.cpan.org)

blog: [perlbuzz.com](http://perlbuzz.com)

Book *Programming Perl*, third edition, by Wall, Christiansen, & Orwant, O'Reilly & Associates (July 2000)

## HELP

Perl is a forgiving language. As such, it is easy to write Perl code that runs but does not perform as you intended. Perl includes many tools that can help you find coding mistakes. The `-w` option and the `use warnings` statement can produce helpful diagnostic messages. The `use strict` statement (see the `perldebtut` man page) can impose order on a program by requiring, among other things, that you declare variables before you use them. When all else fails, you can use Perl's builtin debugger to step through a program. See the `perldebtut` and `perldebug` man pages for more information.

## perldoc

You must install the `perl-doc` package before you can use `perldoc`.

The `perldoc` utility locates and displays local Perl documentation. It is similar to `man` (page 125) but specific to Perl. It works with files that include lines of `pod` (plain old documentation), a clean and simple documentation language. When embedded in a Perl program, `pod` enables you to include documentation for the entire program, not just code-level comments, in a Perl program.

Following is a simple Perl program that includes `pod`. The two lines following `=cut` are the program; the rest is `pod`-format documentation.

```
$ cat pod.ex1.pl
#!/usr/bin/perl

=head1 A Perl Program to Say I<Hi there.>

This simple Perl program includes documentation in B<pod> format.
The following B<=cut> command tells B<perldoc> that what follows
is not documentation.

=cut
# A Perl program
print "Hi there.\n";

=head1 pod Documentation Resumes with Any pod Command

See the B<perldoc.perl.org/perlpod.html> page for more information
on B<pod> and B<perldoc.perl.org> for complete Perl documentation.
```

You can use Perl to run the program:

```
$ perl pod.ex1.pl
Hi there.
```

Or you can use `perldoc` to display the documentation:

```
$ perldoc pod.ex1.pl
POD.EX1(1)      User Contributed Perl Documentation      POD.EX1(1)
```

#### A Perl Program to Say Hi there.

This simple Perl program includes documentation in **pod** format. The following `=cut` command tells **perldoc** that what follows is not documentation.

#### pod Documentation Resumes with Any pod Command

See the [perldoc.perl.org/perlpod.html](http://perldoc.perl.org/perlpod.html) page for more information on **pod** and [perldoc.perl.org](http://perldoc.perl.org) for complete Perl documentation.

```
perl v5.10.0      2008-10-14      POD.EX1(1)
```

Most publicly distributed modules and scripts, as well as Perl itself, include embedded **pod**-format documentation. For example, the following command displays information about the Perl **print** function:

```
$ perldoc -f print
print FILEHANDLE LIST
print LIST
print    Prints a string or a list of strings. Returns true if successful.
        FILEHANDLE may be a scalar variable name, in which case the variable
        contains the name of or a reference to the filehandle, thus introducing
        one level of indirection. (NOTE: If FILEHANDLE is a variable and the
        next token is a term, it may ...
```

Once you have installed a module (page 1013), you can use `perldoc` to display documentation for that module. The following example shows `perldoc` displaying information on the locally installed **Timestamp::Simple** module:

```
$ perldoc Timestamp::Simple
Timestamp::Simple(3)  User Contributed Perl Documentation Timestamp::Simple(3)
```

```
NAME
    Timestamp::Simple - Simple methods for timestamping
```

#### SYNOPSIS

```
    use Timestamp::Simple qw(stamp);
    print stamp, "\n";
...

```

Give the command `man perldoc` or `perldoc perldoc` to display the `perldoc` man page and read more about this tool.

### Make Perl programs readable

---

**tip** Although Perl has many shortcuts that are good choices for one-shot programming, the code in this chapter presents code that is easy to understand and easy to maintain.

---

## TERMINOLOGY

This section defines some of the terms used in this chapter.

- Module** A Perl *module* is a self-contained chunk of Perl code, frequently containing several functions that work together. A module can be called from another module or from a Perl program. A module must have a unique name. To help ensure unique names, Perl provides a hierarchical *namespace* (page 1095) for modules, separating components of a name with double colons (::). Example module names are **Timestamp::Simple** and **WWW::Mechanize**.
- Distribution** A Perl *distribution* is a set of one or more modules that perform a task. You can search for distributions and modules at [search.cpan.org](http://search.cpan.org). Examples of distributions include **Timestamp-Simple** (the **Timestamp-Simple-1.01.tar.gz** archive file contains the **Timestamp::Simple** module only) and **WWW-Mechanize** (**WWW-Mechanize-1.34.tar.gz** contains the **WWW::Mechanize** module, plus supporting modules including **WWW::Mechanize::Link** and **WWW::Mechanize::Image**).
- Package** A *package* defines a Perl namespace. For example, in the variable with the name **\$WWW::Mechanize::ex**, **\$ex** is a scalar variable in the **WWW::Mechanize** package, where “package” is used in the sense of a namespace. Using the same name, such as **WWW::Mechanize**, for a distribution, a package, and a module can be confusing.
- Block** A *block* is zero or more statements, delimited by curly braces ({}), that defines a scope. The shell control structure syntax explanations refer to these elements as *commands*. See the **if...then** control structure on page 888 for an example.
- Package variable** A *package variable* is defined within the package it appears in. Other packages can refer to package variables by using the variable’s fully qualified name (for example, **\$Text::Wrap::columns**). By default, variables are package variables unless you define them as lexical variables.
- Lexical variable** A *lexical variable*, which is defined by preceding the name of a variable with the keyword **my** (see the tip on page 984), is defined only within the block or file it appears in. Other languages refer to a lexical variable as a local variable. Because Perl 4 used the keyword **local** with a different meaning, Perl 5 uses the keyword **lexical** in its place. When programming using **bash**, variables that are not exported (page 926) are local to the program they are used in.
- List** A *list* is a series of zero or more scalars. The following list has three elements—two numbers and a string:
- ```
(2, 4, 'Zach')
```
- Array** An *array* is a variable that holds a list of elements in a defined order. In the following line of code, **@a** is an array. See page 987 for more information about array variables.
- ```
@a = (2, 4, 'Zach')
```
- Compound statement** A *compound statement* is a statement made up of other statements. For example, the **if** compound statement (page 991) incorporates an **if** statement that normally includes other statements within the block it controls.

## RUNNING A PERL PROGRAM

There are several ways you can run a program written in Perl. The `-e` option enables you to enter a program on the command line:

```
$ perl -e 'print "Hi there.\n"'
Hi there.
```

The `-e` option is a good choice for testing Perl syntax and running brief, one-shot programs. This option requires that the Perl program appear as a single argument on the command line. The program must immediately follow this option—it is an argument to this option. An easy way to write this type of program is to enclose the program within single quotation marks.

Because Perl is a member of the class of utilities that take input from a file or standard input (page 234), you can give the command `perl` and enter the program terminated by `CONTROL-D` (end of file). Perl reads the program from standard input:

```
$ perl
print "Hi there.\n";
CONTROL-D
Hi there.
```

The preceding techniques are useful for quick, one-off command-line programs but are not helpful for running more complex programs. Most of the time, a Perl program is stored in a text file. Although not required, the file typically has a filename extension of `.pl`. Following is the same simple program used in the previous examples stored in a file:

```
$ cat simple.pl
print "Hi there.\n";
```

You can run this program by specifying its name as an argument to Perl:

```
$ perl simple.pl
Hi there.
```

Most commonly and similarly to most shell scripts, the file containing the Perl program is executable. In the following example, `chmod` (page 287) makes the `simple2.pl` file executable. As explained on page 288, the `#!` at the start of the first line of the file instructs the shell to pass the rest of the file to `/usr/bin/perl` for execution.

```
$ chmod 755 simple2.pl
$ cat simple2.pl
#!/usr/bin/perl -w
print "Hi there.\n";

$ ./simple2.pl
Hi there.
```

In this example, the `simple2.pl` program is executed as `./simple2.pl` because the working directory is not in the user's `PATH` (page 306). The `-w` option tells Perl to issue warning messages when it identifies potential errors in the code.



## PERL VERSION 5.10

All examples in this chapter were run under Perl 5.10. Give the following command to see which version of Perl the local system is running:

```
$ perl -v
```

```
This is perl, v5.10.0 built for i486-linux-gnu-thread-multi
...
```

**use feature 'say'** The **say** function is a Perl 6 feature that is available in Perl 5.10. It works the same way as **print**, except it adds a **NEWLINE** (**\n**) at the end of each line it outputs. Some versions of Perl require you to tell Perl explicitly that you want to use **say**. The **use** function in the following example tells Perl to enable **say**. Try running this program without the **use** line to see if the local version of Perl requires it.

```
$ cat 5.10.pl
use feature 'say';
say 'Output by say.';
print 'Output by print.';
say 'End.'
$ perl 5.10.pl
Output by say.
Output by print.End.
$
```

Earlier versions of Perl If you are running an earlier version of Perl, you will need to replace **say** in the examples in this chapter with **print** and terminate the **print** statement with a quoted **\n**:

```
$ cat 5.8.pl
print 'Output by print in place of say.', "\n";
print 'Output by print.';
print 'End.', "\n";

$ perl 5.8.pl
Output by print in place of say.
Output by print.End.
```

## SYNTAX

This section describes the major components of a Perl program.

**Statements** A Perl program comprises one or more *statements*, each terminated by a semicolon (;). These statements are free-form with respect to *whitespace* (page 1115), except for whitespace within quoted strings. Multiple statements can appear on a single line, each terminated by a semicolon. The following programs are equivalent. The first occupies two lines, the second only one; look at the differences in the spacing around the equal and plus signs. See **use feature 'say'** (above) if these programs complain about **say** not being available.

```
$ cat statement1.pl
$n=4;
say "Answer is ", $n + 2;
$ perl statement1.pl
Answer is 6

$ cat statement2.pl
$n = 4; say "Answer is ", $n+2;
$ perl statement2.pl
Answer is 6
```

Expressions The syntax of Perl expressions frequently corresponds to the syntax of C expressions but is not always the same. Perl expressions are covered in examples throughout this chapter.

Quotation marks All character strings must be enclosed within single or double quotation marks. Perl differentiates between the two types of quotation marks in a manner similar to the way the shell does (page 301): Double quotation marks allow Perl to interpolate enclosed variables and interpret special characters such as `\n` (NEWLINE), whereas single quotation marks do not. Table 28-1 lists some of Perl's special characters.

The following example demonstrates how different types of quotation marks, and the absence of quotation marks, affect Perl in converting scalars between numbers and strings. The single quotation marks in the first `print` statement prevent Perl from interpolating the `$string` variable and from interpreting the `\n` special character. The leading `\n` in the second `print` statement forces the output of that statement to appear on a new line.

```
$ cat string1.pl
$string="5";      # $string declared as a string, but it will not matter

print '$string+5\n'; # Perl displays $string+5 literally because of
                    # the single quotation marks
print "\n$string+5\n"; # Perl interpolates the value of $string as a string
                    # because of the double quotation marks
print $string+5, "\n"; # Lack of quotation marks causes Perl to interpret
                    # $string as a numeric variable and to add 5;
                    # the \n must appear between double quotation marks

$ perl string1.pl
$string+5\n
5+5
10
```

Slash By default, regular expressions are delimited by slashes (/). The following example tests whether the string `hours` contains the pattern `our`; see page 1008 for more information on regular expression delimiters in Perl.

```
$ perl -e 'if ("hours" =~ /our/) {say "yes";}'
```

The local version of Perl may require `use feature 'say'` (page 981) to work properly:

```
$ perl -e 'use feature "say"; if ("hours" =~ /our/) {say "yes";}'
```

Backslash	Within a string enclosed between double quotation marks, a backslash escapes (quotes) another backslash. Thus Perl displays " <code>\\n</code> " as <code>\n</code> . Within a regular expression, Perl does not expand a metacharacter preceded by a backslash. See the <code>string1.pl</code> program on the previous page.
Comments	As in the shell, a comment in Perl begins with a pound sign ( <code>#</code> ) and ends at the end of the line (just before the <code>NEWLINE</code> character).
Special characters	Table 28-1 lists some of the characters that are special within strings in Perl. Perl interpolates these characters when they appear between double quotation marks but not when they appear between single quotation marks. Table 28-3 on page 1010 lists metacharacters, which are special within regular expressions.

**Table 28-1** Some Perl special characters

Character	When within double quotation marks, interpolated as
<code>\0xx</code> (zero)	The ASCII character whose octal value is <code>xx</code>
<code>\a</code>	An alarm (bell or beep) character (ASCII 7)
<code>\e</code>	An ESCAPE character (ASCII 27)
<code>\n</code>	A NEWLINE character (ASCII 10)
<code>\r</code>	A RETURN character (ASCII 13)
<code>\t</code>	A TAB character (ASCII 9)

## VARIABLES

Like human languages, Perl distinguishes between singular and plural data. Strings and numbers are singular; lists of strings or numbers are plural. Perl provides three types of variables: *scalar* (singular), *array* (plural), and *hash* (plural; also called *associative arrays*). Perl identifies each type of variable by a special character preceding its name. The name of a scalar variable begins with a dollar sign (`$`), an array variable begins with an at sign (`@`), and a hash variable begins with a percent sign (`%`). As opposed to the way the shell identifies variables, Perl requires the leading character to appear each time you reference a variable, including when you assign a value to the variable:

```
$ name="Zach" ; echo "$name"           (bash)
Zach

$ perl -e '$name="Zach" ; print "$name\n";' (perl)
Zach
```

Variable names, which are case sensitive, can include letters, digits, and the underscore character (`_`). A Perl variable is a package variable (page 979) unless it is preceded by

the keyword **my**, in which case it is a lexical variable (page 979) that is defined only within the block or file it appears in. See “Subroutines” on page 1005 for a discussion of the locality of Perl variables.

### Lexical variables overshadow package variables

---

**caution** If a lexical variable and a package variable have the same name, within the block or file in which the lexical variable is defined, the name refers to the lexical variable and not to the package variable.

---

A Perl variable comes into existence when you assign a value to it—you do not need to define or initialize a variable, although it may make a program more understandable to do so. Normally, Perl does not complain when you reference an uninitialized variable:

```
$ cat variable1.pl
#!/usr/bin/perl
my $name = 'Sam';
print "Hello, $nam, how are you?\n"; # Typo, e left off of name

$ ./variable1.pl
Hello, , how are you?
```

**use strict** Include **use strict** to cause Perl to require variables to be declared before being assigned values. See the **perldebtut man** page for more information. When you include **use strict** in the preceding program, Perl displays an error message:

```
$ cat variable1b.pl
#!/usr/bin/perl
use strict;
my $name = 'Sam';
print "Hello, $nam, how are you?\n"; # Typo, e left off of name

$ ./variable1b.pl
Global symbol "$nam" requires explicit package name at ./variable1b.pl line 4.
Execution of ./variable1b.pl aborted due to compilation errors.
```

### Using my: lexical versus package variables

---

**tip** In **variable1.pl**, **\$name** is declared to be lexical by preceding its name with the keyword **my**; its name and value are known within the file **variable1.pl** only. Declaring a variable to be lexical limits its scope to the block or file it is defined in. Although not necessary in this case, declaring variables to be lexical is good practice. This habit becomes especially useful when you write longer programs, subroutines, and packages, where it is harder to keep variable names unique. Declaring all variables to be lexical is mandatory when you write routines that will be used within code written by others. This practice allows those who work with your routines to use whichever variable names they like, without regard to which variable names you used in the code you wrote.

The shell and Perl scope variables differently. In the shell, if you do not **export** a variable, it is local to the routine it is used in (page 926). In Perl, if you do not use **my** to declare a variable to be lexical, it is defined for the package it appears in.

---

**-w and use warnings** The **-w** option and the **use warnings** statement perform the same function: They cause Perl to generate an error message when it detects a syntax error. In the following example, Perl displays two warnings. The first tells you that you have used the variable named **\$nam** once, on line 3, which probably indicates an error. This message is helpful when you mistype the name of a variable. Under Perl 5.10, the second warning specifies the name of the uninitialized variable. This warning refers to the same problem as the first warning. Although it is not hard to figure out which of the two variables is undefined in this simple program, doing so in a complex program can take a lot of time.

```
$ cat variable1a.pl
#!/usr/bin/perl -w
my $name = 'Sam';
print "Hello, $nam, how are you?\n"; # Prints warning because of typo and -w

$ ./variable1a.pl
Name "main::nam" used only once: possible typo at ./variable1a.pl line 3.
Use of uninitialized value $nam in concatenation (.) or string at ./variable1a.pl line 3.
Hello, , how are you?
```

You can also use **-w** on the command line. If you use **-e** as well, make sure the argument that follows this option is the program you want to execute (e.g., **-e -w** does not work). See the tip on page 1008.

```
$ perl -w -e 'my $name = "Sam"; print "Hello, $nam, how are you?\n"'
Name "main::nam" used only once: possible typo at -e line 1.
Use of uninitialized value $nam in concatenation (.) or string at -e line 1.
Hello, , how are you?
```

**undef and defined** An undefined variable has the special value **undef**, which evaluates to zero (0) in a numeric expression and expands to an empty string ("") when you print it. Use the **defined** function to determine whether a variable has been defined. The following example, which uses constructs explained later in this chapter, calls **defined** with an argument of **\$name** and negates the result with an exclamation point (!). The result is that the **print** statement is executed if **\$name** is *not* defined.

```
$ cat variable2.pl
#!/usr/bin/perl
if (!defined($name)) {
    print "The variable '$name' is not defined.\n"
};

$ ./variable2.pl
The variable '$name' is not defined.
```

Because the **-w** option causes Perl to warn you when you reference an undefined variable, using this option would generate a warning.

## SCALAR VARIABLES

A scalar variable has a name that begins with a dollar sign (\$) and holds a single string or number: It is a singular variable. Because Perl converts between the two

when necessary, you can use strings and numbers interchangeably. Perl interprets scalar variables as strings when it makes sense to interpret them as strings, and as numbers when it makes sense to interpret them as numbers. Perl's judgment in these matters is generally good.

The following example shows some uses of scalar variables. The first two lines of code (lines 3 and 4) assign the string **Sam** to the scalar variable **\$name** and the numbers 5 and 2 to the scalar variables **\$n1** and **\$n2**, respectively. In this example, multiple statements, each terminated with a semicolon (;), appear on a single line. See **use feature 'say'** on page 981 if this program complains about **say** not being available.

```
$ cat scalars1.pl
#!/usr/bin/perl -w

$name = "Sam";
$n1 = 5; $n2 = 2;

say "$name $n1 $n2";
say "$n1 + $n2";
say '$name $n1 $n2';
say $n1 + $n2, " ", $n1 * $n2;
say $name + $n1;

$ ./scalars1.pl
Sam 5 2
5 + 2
$name $n1 $n2
7 10
Argument "Sam" isn't numeric in addition (+) at ./scalars1.pl line 11.
5
```

**Double quotation marks** The first **say** statement sends the string enclosed within double quotation marks to standard output (the screen unless you redirect it). Within double quotation marks, Perl expands variable names to the value of the named variable. Thus the first **say** statement displays the values of three variables, separated from each other by SPACES. The second **say** statement includes a plus sign (+). Perl does not recognize operators such as + within either type of quotation marks. Thus Perl displays the plus sign between the values of the two variables.

**Single quotation marks** The third **say** statement sends the string enclosed within single quotation marks to standard output. Within single quotation marks, Perl interprets all characters literally, so it displays the string exactly as it appears between the single quotation marks.

In the fourth **say** statement, the operators are not quoted, and Perl performs the addition and multiplication as specified. Without the quoted SPACE, Perl would concatenate the two numbers (710). The last **say** statement attempts to add a string and a number; the **-w** option causes Perl to display an error message before displaying 5. The 5 results from adding **Sam**, which Perl evaluates as 0 in a numerical context, to the number 5 (0 + 5 = 5).

## ARRAY VARIABLES

An array variable is an ordered container of scalars whose name begins with an at sign (@) and whose first element is numbered zero (zero-based indexing). Because an array can hold zero or more scalars, it is a plural variable. Arrays are ordered; hashes (page 990) are unordered. In Perl, arrays grow as needed. If you reference an uninitialized element of an array, such as an element beyond the end of the array, Perl returns **undef**.

The first statement in the following program assigns the values of two numbers and a string to the array variable named **@arrayvar**. Because Perl uses zero-based indexing, the first **say** statement displays the value of the second element of the array (the element with the index 1). This statement specifies the variable **\$arrayvar[1]** as a scalar (singular) because it refers to a single value. The second **say** statement specifies the variable **@arrayvar[1,2]** as a list (plural) because it refers to multiple values (the elements with the indexes 1 and 2).

```
$ cat arrayvar1.pl
#!/usr/bin/perl -w
@arrayvar = (8, 18, "Sam");
say $arrayvar[1];
say "@arrayvar[1,2]";

$ perl arrayvar1.pl
18
18 Sam
```

The next example shows a couple of ways to determine the length of an array and presents more information on using quotation marks within **print** statements. The first assignment statement in **arrayvar2.pl** assigns values to the first six elements of the **@arrayvar2** array. When used in a scalar context, Perl evaluates the name of an array as the length of the array. The second assignment statement assigns the number of elements in **@arrayvar2** to the scalar variable **\$num**.

```
$ cat arrayvar2.pl
#!/usr/bin/perl -w
@arrayvar2 = ("apple", "bird", 44, "Tike", "metal", "pike");

$num = @arrayvar2;                # number of elements in array
print "Elements: ", $num, "\n";    # two equivalent print statements
print "Elements: $num\n";

print "Last: $#arrayvar2\n";       # index of last element in array

$ ./arrayvar2.pl
Elements: 6
Elements: 6
Last: 5
```

The first two **print** statements in **arrayvar2.pl** display the string **Elements:**, a SPACE, the value of **\$num**, and a NEWLINE, each using a different syntax. The first of these

statements displays three values, using commas to separate them within the **print** statement. The second **print** statement has one argument and demonstrates that Perl expands a variable (replaces the variable with its value) when the variable is enclosed within double quotation marks.

**\$#array** The final **print** statement in **arrayvar2.pl** shows that Perl evaluates the variable **\$#array** as the index of the last element in the array named *array*. Because Perl uses zero-based indexing by default, this variable evaluates to one less than the number of elements in the array.

The next example works with elements of an array and uses a dot (., the string concatenation operator). The first two lines assign values to four scalar variables. The third line shows that you can assign values to array elements using scalar variables, arithmetic, and concatenated strings. The dot operator concatenates strings, so Perl evaluates **\$va . \$vb** as **Sam** concatenated with **uel**—that is, as **Samuel** (see the output of the last **print** statement).

```
$ cat arrayvar3.pl
#!/usr/bin/perl -w
$v1 = 5; $v2 = 8;
$va = "Sam"; $vb = "uel";
@arrayvar3 = ($v1, $v1 * 2, $v1 * $v2, "Max", "Zach", $va . $vb);

print $arrayvar3[2], "\n";           # one element of an array is a scalar
print @arrayvar3[2,4], "\n";        # two elements of an array are a list
print @arrayvar3[2..4], "\n\n";     # a slice

print "@arrayvar3[2,4]", "\n";      # a list, elements separated by SPACES
print "@arrayvar3[2..4]", "\n\n";   # a slice, elements separated by SPACES

print "@arrayvar3\n";               # an array, elements separated by SPACES

$ ./arrayvar3.pl
40
40Zach
40MaxZach

40 Zach
40 Max Zach

5 10 40 Max Zach Samuel
```

The first **print** statement in **arrayvar3.pl** displays the third element (the element with an index of 2) of the **@arrayvar3** array. This statement uses **\$** in place of **@** because it refers to a single element of the array. The subsequent **print** statements use **@** because they refer to more than one element. Within the brackets that specify an array subscript, two subscripts separated by a comma specify two elements of an array. The second **print** statement, for example, displays the third and fifth elements of the array.



**Array slice** When you separate two elements of an array with two dots (`..`; the range operator), Perl substitutes all elements between and including the two specified elements. A portion of an array comprising elements is called a *slice*. The third `print` statement in the preceding example displays the elements with indexes 2, 3, and 4 (the third, fourth, and fifth elements) as specified by `2..4`. Perl puts no SPACES between the elements it displays.

Within a `print` statement, when you enclose an array variable, including its subscripts, within double quotation marks, Perl puts a SPACE between each of the elements. The fourth and fifth `print` statements in the preceding example illustrate this syntax. The last `print` statement displays the entire array, with elements separated by SPACES.

**shift, push, pop, and splice** The next example demonstrates several functions you can use to manipulate arrays. The example uses the `@colors` array, which is initialized to a list of seven colors. The `shift` function returns and removes the first element of an array, `push` adds an element to the end of an array, and `pop` returns and removes the last element of an array. The `splice` function replaces elements of an array with another array; in the example, `splice` inserts the `@ins` array starting at index 1 (the second element), replacing two elements of the array. See **use feature 'say'** on page 981 if this program complains about `say` not being available. See the `perlfunc` man page for more information on the functions described in this paragraph.

```
$ cat ./shift1.pl
#!/usr/bin/perl -w

@colors = ("red", "orange", "yellow", "green", "blue", "indigo", "violet");

say "                      Display array: @colors";
say " Display and remove first element of array: ", shift (@colors);
say "          Display remaining elements of array: @colors";

push (@colors, "WHITE");
say "    Add element to end of array and display: @colors";

say " Display and remove last element of array: ", pop (@colors);
say "          Display remaining elements of array: @colors";

@ins = ("GRAY", "FERN");
splice (@colors, 1, 2, @ins);
say "Replace second and third elements of array: @colors";

$ ./shift1.pl

                      Display array: red orange yellow green blue indigo violet
Display and remove first element of array: red
          Display remaining elements of array: orange yellow green blue indigo violet
    Add element to end of array and display: orange yellow green blue indigo violet WHITE
Display and remove last element of array: WHITE
          Display remaining elements of array: orange yellow green blue indigo violet
Replace second and third elements of array: orange GRAY FERN blue indigo violet
```

## HASH VARIABLES

A hash variable, sometimes called an associative array variable, is a plural data structure that holds an array of key–value pairs. It uses strings as keys (indexes) and is optimized to return a value quickly when given a key. Each key must be a unique scalar. Hashes are unordered; arrays (page 987) are ordered. When you assign a hash to a list, the key–value pairs are preserved, but their order is neither alphabetical nor the order in which they were inserted into the hash; instead, the order is effectively random.

Perl provides two syntaxes to assign values to a hash. The first uses a single assignment statement for each key–value pair:

```
$ cat hash1.pl
#!/usr/bin/perl -w
$hashvar1{boat} = "tuna";
$hashvar1{"number five"} = 5;
$hashvar1{4} = "fish";

@arrayhash1 = %hashvar1;
say "@arrayhash1";

$ ./hash1.pl
boat tuna 4 fish number five 5
```

Within an assignment statement, the key is located within braces to the left of the equal sign; the value is on the right side of the equal sign. As illustrated in the preceding example, keys and values can take on either numeric or string values. You do not need to quote string keys unless they contain SPACES. This example also shows that you can display the keys and values held by a hash, each separated from the next by a SPACE, by assigning the hash to an array variable and then printing that variable enclosed within double quotation marks.

The next example shows the other way of assigning values to a hash and illustrates how to use the **keys** and **values** functions to extract keys and values from a hash. After assigning values to the **%hash2** hash, **hash2.pl** calls the **keys** function with an argument of **%hash2** and assigns the resulting list of keys to the **@array\_keys** array. The program then uses the **values** function to assign values to the **@array\_values** array.

```
$ cat hash2.pl
#!/usr/bin/perl -w

%hash2 = (
    boat => "tuna",
    "number five" => 5,
    4 => "fish",
);

@array_keys = keys(%hash2);
say " Keys: @array_keys";

@array_values = values(%hash2);
say "Values: @array_values";
```

```
$ ./hash2.pl
  Keys: boat 4 number five
  Values: tuna fish 5
```

Because Perl automatically quotes a single word that appears to the left of the `=>` operator, you do not need quotation marks around **boat** in the third line of this program. However, removing the quotation marks from around **number five** would generate an error because the string contains a SPACE.

## CONTROL STRUCTURES

Control flow statements alter the order of execution of statements within a Perl program. Starting on page 888, Chapter 27 discusses **bash** control structures in detail and includes flow diagrams. Perl control structures perform the same functions as their **bash** counterparts, although the two languages use different syntaxes. The description of each control structure in this section references the discussion of the same control structure under **bash**.

In this section, the ***bold italic*** words in the syntax description are the items you supply to cause the structure to have the desired effect, the *nonbold italic* words are the keywords Perl uses to identify the control structure, and `{...}` represents a block (page 979) of statements. Many of these structures use an expression, denoted as ***expr***, to control their execution. See **if/unless** (next) for an example and explanation of a syntax description.

### if/unless

The **if** and **unless** control structures are compound statements that have the following syntax:

```
if (expr) {...}
unless (expr) {...}
```

These structures differ only in the sense of the test they perform. The **if** structure executes the block of statements *if* ***expr*** evaluates to *true*; **unless** executes the block of statements *unless* ***expr*** evaluates to *true* (i.e., if ***expr*** is *false*).

The *if* appears in nonbold type because it is a keyword; it must appear exactly as shown. The ***expr*** is an expression; Perl evaluates it and executes the block (page 979) of statements represented by `{...}` if the expression evaluates as required by the control structure.

**File test operators** The ***expr*** in the following example, `-r memo1`, uses the `-r` file test operator to determine if a file named **memo1** exists in the working directory and if the file is readable. Although this operator tests only whether you have read permission for the file, the file must exist for you to have read permission; thus it implicitly tests that the file is present. (Perl uses the same file test operators as **bash**; see Table 27-1 on page 891.) If this expression evaluates to *true*, Perl executes the

block of statements (in this case one statement) between the braces. If the expression evaluates to *false*, Perl skips the block of statements. In either case, Perl then exits and returns control to the shell.

```
$ cat if1.pl
#!/usr/bin/perl -w
if (-r "memo1") {
    say "The file 'memo1' exists and is readable.";
}

$ ./if1.pl
The file 'memo1' exists and is readable.
```

Following is the same program written using the postfix **if** syntax. Which syntax you use depends on which part of the statement is more important to someone reading the code.

```
$ cat if1a.pl
#!/usr/bin/perl -w
say "The file 'memo1' exists and is readable." if (-r "memo1");
```

The next example uses a **print** statement to display a prompt on standard output and uses the statement **\$entry = <>**; to read a line from standard input and assign the line to the variable **\$entry**. Reading from standard input, working with other files, and use of the magic file handle (**<>**) for reading files specified on the command line are covered on page 1000.

Comparison  
operators

Perl uses different operators to compare numbers from those it uses to compare strings. Table 28-2 lists numeric and string comparison operators. In the following example, the expression in the **if** statement uses the **==** numeric comparison operator to compare the value the user entered and the number 28. This operator performs a numeric comparison, so the user can enter 28, 28.0, or 00028 and in all cases the result of the comparison will be *true*. Also, because the comparison is numeric, Perl ignores both the whitespace around and the **NEWLINE** following the user's entry. The **-w** option causes Perl to issue a warning if the user enters a nonnumeric value and the program uses that value in an arithmetic expression; without this option Perl silently evaluates the expression as *false*.

```
$ cat if2.pl
#!/usr/bin/perl -w
print "Enter 28: ";
$entry = <>;
if ($entry == 28) {
    print "Thank you for entering 28.\n";
}
print "End.\n";

$ ./if2.pl
Enter 28: 28.0
Thank you for entering 28.
End.
```

**Table 28-2** Comparison operators

Numeric operators	String operators	Value returned based on the relationship between the values preceding and following the operator
<code>==</code>	<code>eq</code>	True if equal
<code>!=</code>	<code>ne</code>	True if not equal
<code>&lt;</code>	<code>lt</code>	True if less than
<code>&gt;</code>	<code>gt</code>	True if greater than
<code>&lt;=</code>	<code>le</code>	True if less than or equal
<code>&gt;=</code>	<code>ge</code>	True if greater than or equal
<code>&lt;=&gt;</code>	<code>cmp</code>	0 if equal, 1 if greater than, -1 if less than

The next program is similar to the preceding one, except it tests for equality between two strings. The `chomp` function (page 1001) removes the trailing `NEWLINE` from the user's entry—without this function the strings in the comparison would never match. The `eq` comparison operator compares strings. In this example the result of the string comparison is *true* when the user enters the string `five`. Leading or trailing whitespace will yield a result of *false*, as would the string `5`, although none of these entries would generate a warning because they are legitimate strings.

```
$ cat if2a.pl
#!/usr/bin/perl -w
print "Enter the word 'five': ";
$entry = <>;
chomp ($entry);
if ($entry eq "five") {           # use eq for a string comparison
    print "Thank you for entering 'five'.\n";
}
print "End.\n";

$ ./if2a.pl
Enter the word 'five': five
Thank you for entering 'five'.
End.
```

## if...else

The `if...else` control structure is a compound statement that is similar to the `bash if...then...else` control structure (page 892). It implements a two-way branch using the following syntax:

```
if (expr) {...} else {...}
```

- die** The next program prompts the user for two different numbers and stores those numbers in `$num1` and `$num2`. If the user enters the same number twice, an `if` structure executes a `die` function, which sends its argument to standard error and aborts program execution.

If the user enters different numbers, the `if...else` structure reports which number is larger. Because *expr* performs a numeric comparison, the program accepts numbers that include decimal points.

```
$ cat ifelse.pl
#!/usr/bin/perl -w
print "Enter a number: ";
$num1 = <>;
print "Enter another, different number: ";
$num2 = <>;

if ($num1 == $num2) {
    die ("Please enter two different numbers.\n");
}
if ($num1 > $num2) {
    print "The first number is greater than the second number.\n";
}
else {
    print "The first number is less than the second number.\n";
}

$ ./ifelse.pl
Enter a number: 8
Enter another, different number: 8
Please enter two different numbers.

$ ./ifelse.pl
Enter a number: 5.5
Enter another, different number: 5
The first number is greater than the second number.
```

## if...elsif...else

Similar to the bash `if...then...elif` control structure (page 895), the Perl `if...elsif...else` control structure is a compound statement that implements a nested set of `if...else` structures using the following syntax:

```
if (expr) {...} elsif {...} ... else {...}
```

The next program implements the functionality of the preceding `ifelse.pl` program using an `if...elsif...else` structure. A `print` statement replaces the `die` statement because the last statement in the program displays the error message; the program terminates after executing this statement anyway. You can use the `STDERR` handle (page 1000) to cause Perl to send this message to standard error instead of standard output.

```
$ cat ifelsif.pl
#!/usr/bin/perl -w
print "Enter a number: ";
$num1 = <>;
print "Enter another, different number: ";
$num2 = <>;
```

```

if ($num1 > $num2) {
    print "The first number is greater than the second number.\n";
}
elsif ($num1 < $num2) {
    print "The first number is less than the second number.\n";
}
else {
    print "Please enter two different numbers.\n";
}

```

## foreach/for

The Perl **foreach** and **for** keywords are synonyms; you can replace one with the other in any context. These structures are compound statements that have two syntaxes. Some programmers use one syntax with **foreach** and the other syntax with the **for**, although there is no need to do so. This book uses **foreach** with both syntaxes.

### foreach: SYNTAX 1

The first syntax for the **foreach** structure is similar to the shell's **for...in** structure (page 901):

```
foreach|for [var] (list) {...}
```

where *list* is a list of expressions or variables. Perl executes the block of statements once for each item in *list*, sequentially assigning to *var* the value of one item in *list* on each iteration, starting with the first item. If you do not specify *var*, Perl assigns values to the `$_` variable (page 999).

The following program demonstrates a simple **foreach** structure. On the first pass through the loop, Perl assigns the string **Mo** to the variable **\$item** and the **say** statement displays the value of this variable followed by a `NEWLINE`. On the second and third passes through the loop, **\$item** is assigned the value of **Larry** and **Curly**. When there are no items left in the list, Perl continues with the statement following the **foreach** structure. In this case, the program terminates. See **use feature 'say'** on page 981 if this program complains about **say** not being available.

```

$ cat foreach.pl
foreach $item ("Mo", "Larry", "Curly") {
    say "$item says hello.";
}

$ perl foreach.pl
Mo says hello.
Larry says hello.
Curly says hello.

```

Using `$_` (page 999), you can write this program as follows:

```

$ cat foreacha.pl
foreach ("Mo", "Larry", "Curly") {
    say "$_ says hello.";
}

```

Following is the program using an array:

```
$ cat foreachb.pl
@stooges = ("Mo", "Larry", "Curly");
foreach (@stooges) {
    say "$_ says hello.";
}
```

Following is the program using the **foreach** postfix syntax:

```
$ cat foreachc.pl
@stooges = ("Mo", "Larry", "Curly");
say "$_ says hello." foreach @stooges;
```

The loop variable (**\$item** and **\$\_** in the preceding examples) references the elements in the *list* within the parentheses. When you modify the loop variable, you modify the element in the list. The **uc** function returns an upshifted version of its argument. The next example shows that modifying the loop variable **\$stooge** modifies the **@stooges** array:

```
$ cat foreachd.pl
@stooges = ("Mo", "Larry", "Curly");
foreach $stooge (@stooges) {
    $stooge = uc $stooge;
    say "$stooge says hello.";
}
say "$stooges[1] is uppercase"

$ perl foreachd.pl
MO says hello.
LARRY says hello.
CURLY says hello.
LARRY is uppercase
```

See page 1003 for an example that loops through command-line arguments.

## last AND next

Perl's **last** and **next** statements allow you to interrupt a loop; they are analogous to the Bourne Again Shell's **break** and **continue** statements (page 910). The **last** statement transfers control to the statement following the block of statements controlled by the loop structure, terminating execution of the loop. The **next** statement transfers control to the end of the block of statements, which continues execution of the loop with the next iteration.

In the following program, the **if** structure tests whether **\$item** is equal to the string **two**; if it is, the structure executes the **next** command, which skips the **say** statement and continues with the next iteration of the loop. If you replaced **next** with **last**, Perl would exit from the loop and not display **three**. See **use feature 'say'** on page 981 if this program complains about **say** not being available.



```
$ cat foreach1.pl
foreach $item ("one", "two", "three") {
    if ($item eq "two") {
        next;
    }
    say "$item";
}

$ perl foreach1.pl
one
three
```

## foreach: SYNTAX 2

The second syntax for the **foreach** structure is similar to the C **for** structure:

```
foreach|for (expr1; expr2; expr3) {...}
```

The *expr1* initializes the **foreach** loop; Perl evaluates *expr1* one time, before it executes the block of statements. The *expr2* is the termination condition; Perl evaluates it before each pass through the block of statements and executes the block of statements if *expr2* evaluates as *true*. Perl evaluates *expr3* after each pass through the block of statements—it typically increments a variable that is part of *expr2*.

In the next example, the **foreach2.pl** program prompts for three numbers; displays the first number; repeatedly increments this number by the second number, displaying each result until the result would be greater than the third number; and quits. See page 1000 for a discussion of the magic file handle (<>).

```
$ cat ./foreach2.pl
#!/usr/bin/perl -w

print "Enter starting number: ";
$start = <>;

print "Enter ending number: ";
$end = <>;

print "Enter increment: ";
$incr = <>;

if ($start >= $end || $incr < 1) {
    die ("The starting number must be less than the ending number\n",
        "and the increment must be greater than zero.\n");
}

foreach ($count = $start+0; $count <= $end; $count += $incr) {
    say "$count";
}
```

```
$ ./foreach2.pl
Enter starting number: 2
Enter ending number: 10
Enter increment: 3
2
5
8
```

After prompting for three numbers, the preceding program tests whether the starting number is greater than or equal to the ending number or if the increment is less than 1. The `||` is a Boolean OR operator; the expression within the parentheses following `if` evaluates to *true* if either the expression before or the expression after this operator evaluates to *true*.

The `foreach` statement begins by assigning the value of `$start+0` to `$count`. Adding 0 (zero) to the string `$start` forces Perl to work in a numeric context, removing the trailing `NEWLINE` when it performs the assignment. Without this fix, the program would display an extra `NEWLINE` following the first number it displayed.

## while/until

The **while** (page 904) and **until** (page 908) control structures are compound statements that implement conditional loops using the following syntax:

```
while (expr) {...}
```

```
until (expr) {...}
```

These structures differ only in the sense of their termination conditions. The **while** structure repeatedly executes the block of statements *while* *expr* evaluates to *true*; **until** continues *until* *expr* evaluates to *true* (i.e., while *expr* remains *false*).

The following example demonstrates one technique for reading and processing input until there is no more input. Although this example shows input coming from the user (standard input), the technique works the same way for input coming from a file (see the example on page 1002). The user enters `CONTROL-D` on a line by itself to signal the end of file.

In this example, *expr* is `$line = <>`. This statement uses the magic file handle (`<>`; page 1000) to read one line from standard input and assigns the string it reads to the `$line` variable. This statement evaluates to *true* as long as it reads data. When it reaches the end of file, the statement evaluates to *false*. The **while** loop continues to execute the block of statements (in this example, only one statement) as long as there is data to read.

```
$ cat while1.pl
#!/usr/bin/perl -w
$count = 0;
while ($line = <>) {
    print ++$count, ". $line";
}
print "\n$count lines entered.\n";
```

```
$ ./while1.pl
Good Morning.
1. Good Morning.
Today is Monday.
2. Today is Monday.
CONTROL-D
```

2 lines entered.

In the preceding example, `$count` keeps track of the number of lines the user enters. Putting the `++` increment operator before a variable (`++$count`; called a preincrement operator) increments the variable before Perl evaluates it. Alternatively, you could initialize `$count` to 1 and increment it with `$count++` (postincrement), but then in the final `print` statement `$count` would equal one more than the number of lines entered.

- \$ The `$.` variable keeps track of the number of lines of input a program has read. Using `$.` you can rewrite the previous example as follows:

```
$ cat while1a.pl
#!/usr/bin/perl -w
while ($line = <>) {
    print $., ". $line";
}
print "\n$. lines entered.\n";
```

- `$_` Frequently you can simplify Perl code by using the `$_` variable. You can use `$_` many places in a Perl program—think of `$_` as meaning *it*, the object of what you are doing. It is the default operand for many operations. For example, the following section of code processes a line using the `$line` variable. It reads a line into `$line`, removes any trailing `NEWLINE` from `$line` using `chomp` (page 1001), and checks whether a regular expression matches `$line`.

```
while (my $line = <>) {
    chomp $line;
    if ($line =~ /regex/) ...
}
```

You can rewrite this code by using `$_` to replace `$line`:

```
while (my $_ = <>) {
    chomp $_;
    if ($_ =~ /regex/) ...
}
```

Because `$_` is the default operand in each of these instances, you can also omit `$_` altogether:

```
while (<>) {
    chomp;
    if (/regex/) ...
}
```

# read into \$\_  
# chomp \$\_  
# if \$\_ matches regex

## WORKING WITH FILES

Opening a file and  
assigning a handle

A *handle* is a name that you can use in a Perl program to refer to a file or process that is open for reading and/or writing. When you are working with the shell, handles are referred to as *file descriptors* (page 921). As when you are working with the shell, the kernel automatically opens handles for standard input (page 230), standard output (page 230), and standard error (page 284) before it runs a program. The kernel closes these descriptors after a program finishes running. The names for these handles are **STDIN**, **STDOUT**, and **STDERR**, respectively. You must manually open handles to read from or write to other files or processes. The syntax of an **open** statement is

```
open (file-handle, ['mode',] "file-ref");
```

where *file-handle* is the name of the handle or a variable you will use in the program to refer to the file or process named by *file-ref*. If you omit *mode* or specify a *mode* of **<**, Perl opens the file for input (reading). Specify *mode* as **>** to truncate and write to a file or as **>>** to append to a file.

See page 1016 for a discussion of reading from and writing to processes.

Writing to a file The **print** function writes output to a file or process. The syntax of a **print** statement is

```
print [file-handle] "text";
```

where *file-handle* is the name of the handle you specified in an **open** statement and *text* is the information you want to output. The *file-handle* can also be **STDOUT** or **STDERR**, as explained earlier. Except when you send information to standard output, you must specify a handle in a **print** statement. Do not place a comma after *file-handle*. Also, do not enclose arguments to **print** within parentheses because doing so can create problems.

Reading from a file The following expression reads one line, including the **NEWLINE** (**\n**), from the file or process associated with *file-handle*:

```
<file-handle>
```

This expression is typically used in a statement such as

```
$line = <IN>;
```

which reads into the variable **\$line** one line from the file or process identified by the handle **IN**.

Magic file  
handle (<>)

To facilitate reading from files named on the command line or from standard input, Perl provides the *magic file handle*. This book uses this file handle in most examples. In place of the preceding line, you can use

```
$line = <>;
```

This file handle causes a Perl program to work like many Linux utilities: It reads from standard input unless the program is called with one or more arguments, in which case it reads from the files named by the arguments. See page 234 for an explanation of how this feature works with `cat`.

The `print` statement in the first line in the next example includes the optional handle `STDOUT`; the next `print` statement omits this handle; the final `print` statement uses the `STDERR` file handle, which causes `print`'s output to go to standard error. The first `print` statement prompts the user to enter something. The string that this statement outputs is terminated with a `SPACE`, not a `NEWLINE`, so the user can enter information on the same line as the prompt. The second line then uses a magic file handle to read one line from standard input, which it assigns to `$userline`. Because of the magic file handle, if you call `file1.pl` with an argument that is a filename, it reads one line from that file instead of from standard input. The command line that runs `file1.pl` uses `2>` (see “File descriptors” on page 284) to redirect standard error (the output of the third `print` statement) to the `file1.err` file.

```
$ cat file1.pl
print STDOUT "Enter something: ";
$userline = <>;
print "1>>>$userline<<<\n";
chomp ($userline);
print "2>>>$userline<<<\n";
print STDERR "3. Error message.\n";

$ perl file1.pl 2> file1.err
Enter something: hi there
1>>>hi there
<<<
2>>>hi there<<<

$ cat file1.err
3. Error message.
```

**chomp/chop** The two `print` statements following the user input in `file1.pl` display the value of `$userline` immediately preceded by greater than signs (`>`) and followed by less than signs (`<`). The first of these statements demonstrates that `$userline` includes a `NEWLINE`: The less than signs following the string the user entered appear on the line following the string. The `chomp` function removes a trailing `NEWLINE`, if it exists, from a string. After `chomp` processes `$userline`, the `print` statement shows that this variable no longer contains a `NEWLINE`. (The `chop` function is similar to `chomp`, except it removes *any* trailing character from a string.)

The next example shows how to read from a file. It uses an `open` statement to assign the lexical file handle `$infile` to the file `/usr/share/dict/words`. Each iteration of the `while` structure evaluates an expression that reads a line from the file represented by `$infile` and assigns the line to `$line`. When `while` reaches the end of file, the expression evaluates to *false*; control then passes out of the `while` structure. The block of one statement displays the line as it was read from the file, including the `NEWLINE`.

This program copies `/usr/share/dict/words` to standard output. A pipe (`|`; page 158) is then used to send the output through `head` (page 154), which displays the first four lines of the file (the first line is blank).

```
$ cat file2.pl
open (my $infile, "/usr/share/dict/words") or die "Cannot open dictionary: $!\n";
while ($line = <$infile>) {
    print $line;
}
```

```
$ perl file2.pl | head -4
```

```
A
A's
AOL
```

**\$!** The **\$!** variable holds the last system error. In a numeric context, it holds the system error number; in a string context, it holds the system error string. If the **words** file is not present on the system, **file2.pl** displays the following message:

```
Cannot open dictionary: No such file or directory
```

If you do not have read permission for the file, the program displays this message:

```
Cannot open dictionary: Permission denied
```

Displaying the value of **\$!** gives the user more information about what went wrong than simply saying that the program could not open the file.

### Always check for an error when opening a file

---

**tip** When a Perl program attempts to open a file and fails, the program does not display an error message unless it checks whether **open** returned an error. In **file2.pl**, the **or** operator in the **open** statement causes Perl to execute **die** (page 993) if **open** fails. The **die** statement sends the message **Cannot open the dictionary** followed by the system error string to standard error and terminates the program.

---

**@ARGV** The **@ARGV** array holds the arguments from the command line Perl was called with. When you call the following program with a list of filenames, it displays the first line of each file. If the program cannot read a file, **die** (page 993) sends an error message to standard error and quits. The **foreach** structure loops through the command-line arguments, as represented by **@ARGV**, assigning each argument in turn to **\$filename**. The **foreach** block starts with an **open** statement. Perl executes the **open** statement that precedes the OR Boolean operator (**or**) or, if that fails, Perl executes the statement following the **or** operator (**die**). The result is that Perl either opens the file named by **\$filename** and assigns **IN** as its handle or, if it cannot open that file, executes the **die** statement and quits. The **print** statement displays the name of the file followed by a colon and the first line of the file. When it accepts **\$line = <IN>** as an argument to **print**, Perl displays the value of **\$line** following the assignment. After reading a line from a file, the program closes the file.

```

$ cat file3.pl
foreach $filename (@ARGV) {
    open (IN, $filename) or die "Cannot open file '$filename': $!\n";
    print "$filename: ", $line = <IN>;
    close (IN);
}
$ perl file3.pl f1 f2 f3 f4
f1: First line of file f1.
f2: First line of file f2.
Cannot open file 'f3': No such file or directory

```

The next example is similar to the preceding one, except it takes advantage of several Perl features that make the code simpler. It does not quit when it cannot read a file. Instead, Perl displays an error message and continues. The first line of the program uses **my** to declare **\$filename** to be a lexical variable. Next, **while** uses the magic file handle to open and read each line of each file named by the command-line arguments; **\$ARGV** holds the name of the file. When there are no more files to read, the **while** condition [**<>**] is *false*, **while** transfers control outside the **while** block, and the program terminates. Perl takes care of all file opening and closing operations; you do not have to write code to take care of these tasks. Perl also performs error checking.

The program displays the first line of each file named by a command-line argument. Each time through the **while** block, **while** reads another line. When it finishes with one file, it starts reading from the next file. Within the **while** block, **if** tests whether it is processing a new file. If it is, the **if** block displays the name of the file and the (first) line from the file and then assigns the new filename (**\$ARGV**) to **\$filename**.

```

$ cat file3a.pl
my $filename;
while (<>) {
    if ($ARGV ne $filename) {
        print "$ARGV: $_";
        $filename = $ARGV;
    }
}

$ perl file3a.pl f1 f2 f3 f4
f1: First line of file f1.
f2: First line of file f2.
Can't open f3: No such file or directory at file3a.pl line 3, <> line 3.
f4: First line of file f4.

```

---

## SORT

**reverse** The **sort** function returns elements of an array ordered numerically or alphabetically, based on the *locale* (page 1091) environment. The **reverse** function is not related to **sort**; it simply returns the elements of an array in reverse order.

The first two lines of the following program assign values to the `@colors` array and display these values. Each of the next two pairs of lines uses `sort` to put the values in the `@colors` array in order, assign the result to `@scolors`, and display `@scolors`. These sorts put uppercase letters before lowercase letters. Observe the positions of **Orange** and **Violet**, both of which begin with an uppercase letter, in the sorted output. The first assignment statement in these two pairs of lines uses the full sort syntax, including the block `{$a cmp $b}` that tells Perl to use the `cmp` subroutine, which compares strings, and to put the result in ascending order. When you omit the block in a `sort` statement, as is the case in the second assignment statement, Perl also performs an ascending textual sort.

```
$ cat sort3.pl
@colors = ("red", "Orange", "yellow", "green", "blue", "indigo", "Violet");

say "@colors";

@scolors = sort {$a cmp $b} @colors;      # ascending sort with
say "@scolors";                          # an explicit block

@scolors = sort @colors;                  # ascending sort with
say "@scolors";                          # an implicit block

@scolors = sort {$b cmp $a} @colors;      # descending sort
say "@scolors";

@scolors = sort {lc($a) cmp lc($b)} @colors; # ascending folded sort
say "@scolors";
```

```
$ perl sort3.pl
red Orange yellow green blue indigo Violet
Orange Violet blue green indigo red yellow
Orange Violet blue green indigo red yellow
yellow red indigo green blue Violet Orange
blue green indigo Orange red Violet yellow
```

The third sort in the preceding example reverses the positions of `$a` and `$b` in the block to specify a descending sort. The last sort converts the strings to lowercase before comparing them, providing a sort wherein the uppercase letters are folded into the lowercase letters. As a result, **Orange** and **Violet** appear in alphabetical order.

To perform a numerical sort, specify the `<=>` subroutine in place of `cmp`. The following example demonstrates ascending and descending numerical sorts:

```
$ cat sort4.pl
@numbers = (22, 188, 44, 2, 12);

print "@numbers\n";

@snumbers = sort {$a <=> $b} @numbers;
print "@snumbers\n";

@snumbers = sort {$b <=> $a} @numbers;
print "@snumbers\n";
```



```
$ perl sort4.pl
22 188 44 2 12
2 12 22 44 188
188 44 22 12 2
```

## SUBROUTINES

All variables are package variables (page 979) unless you use the **my** function to define them to be lexical variables (page 979). Lexical variables defined in a subroutine are local to that subroutine.

The following program includes a main part and a subroutine named **add()**. This program uses the variables named **\$one**, **\$two**, and **\$ans**, all of which are package variables: They are available to both the main program and the subroutine. The call to the subroutine does not pass values to the subroutine and the subroutine returns no values. This setup is not typical: It demonstrates that all variables are package variables unless you use **my** to declare them to be lexical variables.

The **subroutine1.pl** program assigns values to two variables and calls a subroutine. The subroutine adds the values of the two variables and assigns the result to another variable. The main part of the program displays the result.

```
$ cat subroutine1.pl
$one = 1;
$two = 2;
add();
print "Answer is $ans\n";

sub add {
    $ans =$one + $two
}

$ perl subroutine1.pl
Answer is 3
```

The next example is similar to the previous one, except the subroutine takes advantage of a **return** statement to return a value to the main program. The program assigns the value returned by the subroutine to the variable **\$ans** and displays that value. Again, all variables are package variables.

```
$ cat subroutine2.pl
$one = 1;
$two = 2;
$ans = add();
print "Answer is $ans\n";

sub add {
    return ($one + $two)
}

$ perl subroutine2.pl
Answer is 3
```

Keeping variables local to a subroutine is important in many cases. The subroutine in the next example changes the values of variables and insulates the calling program from these changes by declaring and using lexical variables. This setup is more typical.

- ① When you pass values in a call to a subroutine, Perl makes those values available in the array named `@_` in the subroutine. Although `@_` is local to the subroutine, its elements are aliases for the parameters the subroutine was called with. Changing a value in the `@_` array changes the value of the underlying variable, which may not be what you want. The next program avoids this pitfall by assigning the values passed to the subroutine to lexical variables.

The `subroutine3.pl` program calls the `addplusone()` subroutine with two variables as arguments and assigns the value returned by the subroutine to a variable. The first statement in the subroutine declares two lexical variables and assigns to them the values from the `@_` array. The `my` function declares these variables to be lexical. (See the tip on lexical and package variables on page 984.) Although you can use `my` without assigning values to the declared variables, the syntax in the example is more commonly used. The next two statements increment the lexical variables `$lcl_one` and `$lcl_two`. The `print` statement displays the value of `$lcl_one` within the subroutine. The `return` statement returns the sum of the two incremented, lexical variables.

```
$ cat subroutine3.pl
$one = 1;
$two = 2;
$ans = addplusone($one, $two);
print "Answer is $ans\n";
print "Value of 'lcl_one' in main: $lcl_one\n";
print "Value of 'one' in main: $one\n";

sub addplusone {
    my ($lcl_one, $lcl_two) = @_;
    $lcl_one++;
    $lcl_two++;
    print "Value of 'lcl_one' in sub: $lcl_one\n";
    return ($lcl_one + $lcl_two)
}

$ perl subroutine3.pl
Value of 'lcl_one' in sub: 2
Answer is 5
Value of 'lcl_one' in main:
Value of 'one' in main: 1
```

After displaying the result returned by the subroutine, the `print` statements in the main program demonstrate that `$lcl_one` is not defined in the main program (it is local to the subroutine) and that the value of `$one` has not changed.

The next example illustrates another way to work with parameters passed to a subroutine. This subroutine does not use variables other than the `@_` array it was passed and does not change the values of any elements of that array.

```
$ cat subroutine4.pl
$one = 1;
$two = 2;
$ans = addplusone($one, $two);
print "Answer is $ans\n";
sub addplusone {
    return ($_[0] + $_[1] + 2);
}

$ perl subroutine4.pl
Answer is 5
```

The final example in this section presents a more typical Perl subroutine. The subroutine **max()** can be called with any number of numeric arguments and returns the value of the largest argument. It uses the **shift** function to assign to **\$biggest** the value of the first argument the subroutine was called with and to shift the rest of the arguments. After using **shift**, argument number 2 becomes argument number 1 (8), argument 3 becomes argument 2 (64), and argument 4 becomes argument 3 (2). Next, **foreach** loops over the remaining arguments (**@\_**). Each time through the **foreach** block, Perl assigns to **\$\_** the value of each of the arguments, in order. The **\$biggest** variable is assigned the value of **\$\_** if **\$\_** is bigger than **\$biggest**. When **max()** finishes going through its arguments, **\$biggest** holds the maximum value, which **max()** returns.

```
$ cat subroutine5.pl
$ans = max (16, 8, 64, 2);
print "Maximum value is $ans\n";

sub max {
    my $biggest = shift; # Assign first and shift the rest of the arguments to max()
    foreach (@_) {      # Loop through remaining arguments
        $biggest = $_ if $_ > $biggest;
    }
    return ($biggest);
}

$ perl subroutine5.pl
Maximum value is 64
```

---

## REGULAR EXPRESSIONS

Appendix A defines and discusses regular expressions as you can use them in many Linux utilities. All of the material in Appendix A applies to Perl, except as noted. In addition to the facilities described in Appendix A, Perl offers regular expression features that allow you to perform more complex string processing. This section reviews some of the regular expressions covered in Appendix A and describes some of the additional features of regular expressions available in Perl. It also introduces the syntax Perl uses for working with regular expressions.

## SYNTAX AND THE `=~` OPERATOR

The `-l` option The Perl `-l` option applies `chomp` to each line of input and places `\n` at the end of each line of output. The examples in this section use the Perl `-l` and `-e` (page 980) options. Because the program must be specified as a single argument, the examples enclose the Perl programs within single quotation marks. The shell interprets the quotation marks and does not pass them to Perl.

### Using other options with `-e`

**tip** When you use another option with `-e`, the program must immediately follow the `-e` on the command line. Like many other utilities, Perl allows you to combine options following a single hyphen; if `-e` is one of the combined options, it must appear last in the list of options. Thus you can use `perl -l -e` or `perl -le` but not `perl -e -l` or `perl -el`.

*/ is the default delimiter* By default, Perl delimits a regular expression with slashes (/). The first program uses the `=~` operator to search for the pattern `ge` in the string `aged`. You can think of the `=~` operator as meaning “contains.” Using different terminology, the `=~` operator determines whether the regular expression `ge` has a match in the string `aged`. The regular expression in this example contains no special characters; the string `ge` is part of the string `aged`. Thus the expression within the parentheses evaluates to `true` and Perl executes the `print` statement.

```
$ perl -le 'if ("aged" =~ /ge/) {print "true";}'  
true
```

You can achieve the same functionality by using a postfix `if` statement:

```
$ perl -le 'print "true" if "aged" =~ /ge/'  
true
```

**!~** The `!~` operator works in the opposite sense from the `=~` operator. The expression in the next example evaluates to `true` because the regular expression `xy` does *not* match any part of `aged`:

```
$ perl -le 'print "true" if ("aged" !~ /xy/)'  
true
```

As explained on page 1025, a period within a regular expression matches any single character, so the regular expression `a..d` matches the string `aged`:

```
$ perl -le 'print "true" if ("aged" =~ /a..d/)'  
true
```

You can use a variable to hold a regular expression. The following syntax quotes *string* as a regular expression:

```
qr/string/
```

The next example uses this syntax to assign the regular expression `/a..d/` (including the delimiters) to the variable `$re` and then uses that variable as the regular expression:

```
$ perl -le '$re = qr/a..d/; print "true" if ("aged" =~ $re)'
true
```

If you want to include the delimiter within a regular expression, you must quote it. In the next example, the default delimiter, a slash (`/`), appears in the regular expression. To keep Perl from interpreting the `/` in `/usr` as the end of the regular expression, the `/` that is part of the regular expression is quoted by preceding it with a backslash (`\`). See page 1027 for more information on quoting characters in regular expressions.

```
$ perl -le 'print "true" if ("/usr/doc" =~ /\usr/)'
true
```

Quoting several characters by preceding each one with a backslash can make a complex regular expression harder to read. Instead, you can precede a delimited regular expression with `m` and use a paired set of characters, such as `{}`, as the delimiters. In the following example, the caret (`^`) anchors the regular expression to the beginning of the line (page 1026):

```
$ perl -le 'print "true" if ("/usr/doc" =~ m{^usr})'
true
```

You can use the same syntax when assigning a regular expression to a variable:

```
$ perl -le '$pn = qr{^usr}; print "true" if ("/usr/doc" =~ $pn)'
true
```

Replacement string and assignment Perl uses the syntax shown in the next example to substitute a string (the *replacement string*) for a matched regular expression. The syntax is the same as that found in `vim` and `sed`. In the second line of the example, an `s` before the regular expression instructs Perl to substitute the string between the second and third slashes (**worst**; the replacement string) for a match of the regular expression between the first two slashes (**best**). Implicit in this syntax is the notion that the substitution is made in the string held in the variable on the left of the `=~` operator.

```
$ cat re10a.pl
$stg = "This is the best!";
$stg =~ s/best/worst/;
print "$stg\n";

$ perl re10a.pl
This is the worst!
```

Table 28-3 (on the next page) list some of the characters, called metacharacters, that are considered special within Perl regular expressions. Give the command `perldoc perlre` for more information.

**Table 28-3** Some Perl regular expression metacharacters

Character	Matches
<b>^</b> (caret)	Anchors a regular expression to the beginning of a line (page 1026)
<b>\$</b> (dollar sign)	Anchors a regular expression to the end of a line (page 1026)
<b>(...)</b>	Brackets a regular expression (page 1011)
<b>.</b> (period)	Any single character except NEWLINE ( <b>\n</b> ; page 1025)
<b>\\</b>	A backslash ( <b>\</b> )
<b>\b</b>	A word boundary (zero-width match)
<b>\B</b>	A nonword boundary ( <b>[^\b]</b> )
<b>\d</b>	A single decimal digit ( <b>[0–9]</b> )
<b>\D</b>	A single nondecimal digit ( <b>[^0–9]</b> or <b>[^\d]</b> )
<b>\s</b> (lowercase)	A single whitespace character SPACE, NEWLINE, RETURN, TAB, FORMFEED
<b>\S</b> (uppercase)	A single nonwhitespace character ( <b>[^\s]</b> )
<b>\w</b> (lowercase)	A single word character (a letter or digit; <b>[a-zA-Z0–9]</b> )
<b>\W</b> (uppercase)	A single nonword character ( <b>[^\w]</b> )

**GREEDY MATCHES**

By default Perl performs *greedy matching*, which means a regular expression matches the longest string possible (page 1027). In the following example, the regular expression `/\{.*\}` matches an opening brace followed by any string of characters, a closing brace, and a SPACE (`{remove me} may have two {keep me}` ). Perl substitutes a null string (`//`) for this match.

```
$ cat 5ha.pl
$string = "A line {remove me} may have two {keep me} pairs of braces.";
$string =~ s/{.*} //;
print "$string\n";

$ perl 5ha.pl
A line pairs of braces.
```

Nongreedy matches    The next example shows the classic way of matching the shorter brace-enclosed string from the previous example. This type of match is called *nongreedy* or *parsimonious matching*. Here the regular expression matches

1. An opening brace followed by
2. A character belonging to the character class (page 1025) that includes all characters except a closing brace (`[^}]`) followed by

3. Zero or more occurrences of the preceding character (\*) followed by
4. A closing brace followed by
5. A SPACE.

(A caret as the first character of a character class specifies the class of all characters that do not match the following characters, so `[^]` matches any character that is not a closing brace.)

```
$ cat re5b.pl
$string = "A line {remove me} may have two {keep me} pairs of braces.";
$string =~ s/{[^}]*} //;
print "$string\n";
```

```
$ perl re5b.pl
A line may have two {keep me} pairs of braces.
```

Perl provides a shortcut that allows you to specify a nongreedy match. In the following example, the question mark in `{.*?}` causes the regular expression to match the shortest string that starts with an opening brace followed by any string of characters followed by a closing brace.

```
$ cat re5c.pl
$string = "A line {remove me} may have two {keep me} pairs of braces.";
$string =~ s/{.*?} //;
print "$string\n";
```

```
$ perl re5c.pl
A line may have two {keep me} pairs of braces.
```

## BRACKETING EXPRESSIONS

As explained on page 1028, you can bracket parts of a regular expression and recall those parts in the replacement string. Most Linux utilities use quoted parentheses [i.e., `\(` and `\)`] to bracket a regular expression. In Perl regular expressions, parentheses are special characters. Perl omits the backslashes and uses unquoted parentheses to bracket regular expressions. To specify a parenthesis as a regular character within a regular expression in Perl, you must quote it (page 1027).

The next example uses unquoted parentheses in a regular expression to bracket part of the expression. It then assigns the part of the string that the bracketed expression matched to the variable that held the string in which Perl originally searched for the regular expression.

First the program assigns the string **My name is Sam** to `$stg`. The next statement looks for a match for the regular expression `/My name is (.*)/` in the string held by `$stg`. The part of the regular expression bracketed by parentheses matches **Sam**; the `$1` in the replacement string matches the first (and only in this case) matched bracketed portion of the regular expression. The result is that the string held in `$stg` is replaced by the string **Sam**.

```
$ cat re11.pl
$stg = "My name is Sam";
$stg =~ s/My name is (.*)/$1/;
print "Matched: $stg\n";

$ perl re11.pl
Matched: Sam
```

The next example uses regular expressions to parse a string for numbers. Two variables are initialized to hold a string that contains two numbers. The third line of the program uses a regular expression to isolate the first number in the string. The `\D*` matches a string of zero or more characters that does not include a digit: The `\D` special character matches any single nondigit character. The trailing asterisk makes this part of the regular expression perform a greedy match that does not include a digit (it matches **What is** ). The bracketed regular expression `\d+` matches a string of one or more digits. The parentheses do not affect what the regular expression matches; they allow the `$1` in the replacement string to match what the bracketed regular expression matched. The final `.*` matches the rest of the string. This line assigns the value of the first number in the string to `$string`.

The next line is similar but assigns the second number in the string to `$string2`. The `print` statements display the numbers and the result of subtracting the second number from the first.

```
$ cat re8.pl
$string = "What is 488 minus 78?";
$string2 = $string;
$string =~ s/\D*(\d+).*/$1/;
$string2 =~ s/\D*\d+\D*(\d+).*/$1/;

print "$string\n";
print "$string2\n";
print $string - $string2, "\n";

$ perl re8.pl
488
78
410
```

The next few programs show some of the pitfalls of using unquoted parentheses in regular expressions when you do not intend to bracket part of the regular expression. The first of these programs attempts to match parentheses in a string with unquoted parentheses in a regular expression, but fails. The regular expression `ag(e` matches the same string as the regular expression `age` because the parenthesis is a special character; the regular expression does not match the string `ag(ed)`.

```
$ perl -le 'if ("ag(ed)" =~ /ag(ed)/) {print "true";} else {print "false";}'
false
```

The regular expression in the next example quotes the parentheses by preceding each with a backslash, causing Perl to interpret them as regular characters. The match is successful.



```
$ perl -le 'if ("ag(ed)" =~ /ag(ed\)/) {print "true";} else {print "false";}'
true
```

Next, Perl finds an unmatched parenthesis in a regular expression:

```
$ perl -le 'if ("ag(ed)" =~ /ag(e/) {print "true";} else {print "false";}'
Unmatched ( in regex; marked by <-- HERE in m/ag( <-- HERE e/ at -e line 1.
```

When you quote the parenthesis, all is well and Perl finds a match:

```
$ perl -le 'if ("ag(ed)" =~ /ag(e/) {print "true";} else {print "false";}'
true
```

---

## CPAN MODULES

CPAN (Comprehensive Perl Archive Network) provides Perl documentation, FAQs, modules (page 979), and scripts on its Web site ([www.cpan.org](http://www.cpan.org)). It holds more than 16,000 distributions (page 979) and provides links, mailing lists, and versions of Perl compiled to run under various operating systems (ports of Perl). One way to locate a module is to visit [search.cpan.org](http://search.cpan.org) and use the search box or click one of the classes of modules listed on that page.

This section explains how to download a module from CPAN and how to install and run the module. Perl provides a hierarchical namespace for modules, separating components of a name with double colons (::). The example in this section uses the module named **Timestamp::Simple**, which you can read about and download from [search.cpan.org/dist/Timestamp-Simple](http://search.cpan.org/dist/Timestamp-Simple). The timestamp is the date and time in the format YYYYMMDDHHMMSS

To use a Perl module, you first download the file that holds the module. For this example, the [search.cpan.org/~shoop/Timestamp-Simple-1.01/Simple.pm](http://search.cpan.org/~shoop/Timestamp-Simple-1.01/Simple.pm) Web page has a link on the right side labeled **Download**. Click this link and save the file to the directory you want to work in. You do not need to work as a privileged user until the last step of this procedure, when you install the module.

Most Perl modules come as compressed tar files (page 163). With the downloaded file in the working directory, decompress the file:

```
$ tar xzvf Timestamp-Simple-1.01.tar.gz
Timestamp-Simple-1.01/
Timestamp-Simple-1.01/Simple.pm
Timestamp-Simple-1.01/Makefile.PL
Timestamp-Simple-1.01/README
Timestamp-Simple-1.01/test.pl
Timestamp-Simple-1.01/Changes
Timestamp-Simple-1.01/MANIFEST
Timestamp-Simple-1.01/ARTISTIC
Timestamp-Simple-1.01/GPL
Timestamp-Simple-1.01/META.yml
```

The **README** file in the newly created directory usually provides instructions for building and installing the module. Most modules follow the same steps.

```
$ cd Timestamp-Simple-1.01
$ perl Makefile.PL
Checking if your kit is complete...
Looks good
Writing Makefile for Timestamp::Simple
```

If the module you are building depends on other modules that are not installed on the local system, running **perl Makefile.PL** will display one or more warnings about prerequisites that are not found. This step writes out the makefile even if modules are missing. In this case the next step will fail, and you must build and install missing modules before continuing.

The next step is to run **make** on the makefile you just created. After you run **make**, run **make test** to be sure the module is working.

```
$ make
cp Simple.pm blib/lib/Timestamp/Simple.pm
Manifying blib/man3/Timestamp::Simple.3pm

$ make test
PERL_DL_NONLAZY=1 /usr/bin/perl "-Iblib/lib" "-Iblib/arch" test.pl
1..1
# Running under perl version 5.100000 for linux
# Current time local: Fri Sep  4 18:20:41 2009
# Current time GMT:   Sat Sep  5 01:20:41 2009
# Using Test.pm version 1.25
ok 1
ok 2
ok 3
```

Finally, running with **root** privileges, install the module:

```
# make install
Installing /usr/local/share/perl/5.10.0/Timestamp/Simple.pm
Installing /usr/local/man/man3/Timestamp::Simple.3pm
Writing /usr/local/lib/perl/5.10.0/auto/Timestamp/Simple/.packlist
Appending installation info to /usr/local/lib/perl/5.10.0/perllocal.pod
```

Once you have installed a module, you can use **perldoc** to display the documentation that tells you how to use the module. See page 977 for an example.

Some modules contain **SYNOPSIS** sections. If the module you installed includes such a section, you can test the module by putting the code from the **SYNOPSIS** section in a file and running it as a Perl program:

```
$ cat times.pl
use Timestamp::Simple qw(stamp);
print stamp, "\n";

$ perl times.pl
20090905182627
```

You can then incorporate the module in a Perl program. The following example uses the `timestamp` module to generate a unique filename:

```
$ cat fn.pl
use Timestamp::Simple qw(stamp);

# Save timestamp in a variable
$ts = stamp, "\n";

# Strip off the year
$ts =~ s/....(.*)/\1/;

# Create a unique filename
$fn = "myfile." . $ts;

# Open, write to, and close the file
open (OUTFILE, '>', "$fn");
print OUTFILE "Hi there.\n";
close (OUTFILE);

$ perl fn.pl
$ ls myf*
myfile.0905183010
```

**substr** You can use the **substr** function in place of the regular expression to strip off the year. To do so, replace the line that starts with **\$ts =~** with the following line. Here, **substr** takes on the value of the string **\$ts** starting at position 4 and continuing to the end of the string:

```
$ts = substr ($ts, 4);
```

## EXAMPLES

This section provides some sample Perl programs. First try running these programs as is, and then modify them to learn more about programming with Perl.

The first example runs under Linux and displays the list of groups that the user given as an argument is a member of. Without an argument, it displays the list of groups that the user running the program is a member of. In a Perl program, the `%ENV` hash holds the environment variables from the shell that called Perl. The keys in this hash are the names of environment variables; the values in this hash are the values of the corresponding variables. The first line of the program assigns a username to **\$user**. The **shift** function (page 989) takes on the value of the first command-line argument and shifts the rest of the arguments, if any remain. If the user runs the program with an argument, that argument is assigned to **\$user**. If no argument appears on the command line, **shift** fails and Perl executes the statement following the Boolean OR (`||`). This statement extracts the value associated with the `USER` key in `%ENV`, which is the name of the user running the program.

Accepting output  
from a process

The third statement initializes the array `@list`. Although this statement is not required, it is good practice to include it to make the code easier to read. The next statement opens the `$fh` lexical handle. The trailing pipe symbol (`|`) in the *file-ref* (page 1000) portion of this `open` statement tells Perl to pass the command line preceding the pipe symbol to the shell for execution and to accept standard output from the command when the program reads from the file handle. In this case the command uses `grep` to filter the `/etc/group` file (page 472) for lines containing the username held in `$user`. The `die` statement displays an error message if Perl cannot open the handle.

```
$ cat groupfind.pl
$user = shift || $ENV{"USER"};
say "User $user belongs to these groups:";
@list = ();
open (my $fh, "grep $user /etc/group |") or die "Error: $!\n";
while ($group = <$fh>) {
    chomp $group;
    $group =~ s/(.*?):.*$/1/;
    push @list, $group;
}
close $fh;
@sorted = sort @list;
say "@sorted";

$ perl groupfind.pl
User sam belongs to these groups:
adm admin audio cdrom dialout dip floppy kvm lpadmin ...
```

The `while` structure in `groupfind.pl` reads lines from standard output of `grep` and terminates when `grep` finishes executing. The name of the group appears first on each line in `/etc/group`, followed by a colon and other information, including the names of the users who belong to the group. Following is a line from this file:

```
sam:x:1000:max,zach,helen
```

The line

```
$group =~ s/(.*?):.*$/1/;
```

uses a regular expression and substitution to remove everything except the name of the group from each line. The regular expression `.*:` would perform a greedy match of zero or more characters followed by a colon; putting a question mark after the asterisk causes the expression to perform a nongreedy match (page 1010). Putting parentheses around the part of the expression that matches the string the program needs to display enables Perl to use the string that the regular expression matches in the replacement string. The final `.*` matches the rest of the line. Perl replaces the `$1` in the replacement string with the string the bracketed portion of the regular expression (the part between the parentheses) matched and assigns this value (the name of the group) to `$group`.

The **chomp** statement removes the trailing `NEWLINE` (the regular expression did not match this character). The **push** statement adds the value of `$group` to the end of the `@list` array. Without **chomp**, each group would appear on a line by itself in the output. After the **while** structure finishes processing input from **grep**, **sort** orders `@list` and assigns the result to `@slist`. The final statement displays the sorted list of groups the user belongs to.

**opendir and readdir** The next example introduces the **opendir** and **readdir** functions. The **opendir** function opens a directory in a manner similar to the way **open** opens an ordinary file. It takes two arguments: the name of the directory handle and the name of the directory to open. The **readdir** function reads the name of a file from an open directory.

In the example, **opendir** opens the working directory (specified by `.`) using the `$dir` lexical directory handle. If **opendir** fails, Perl executes the statement following the **or** operator: **die** sends an error message to standard error and terminates the program. With the directory opened, **while** loops through the files in the directory, assigning the filename that **readdir** returns to the lexical variable `$entry`. An **if** statement executes **print** only for those files that are directories (`-d`). The **print** function displays the name of the directory unless the directory is named `.` or `...`. When **readdir** has read all files in the working directory, it returns *false* and control passes to the statement following the **while** block. The **closedir** function closes the open directory and **print** displays a `NEWLINE` following the list of directories the program displayed.

```
$ cat dirs2a.pl
#!/usr/bin/perl
print "The working directory contains these directories:\n";

opendir my $dir, '.' or die "Could not open directory: $!\n";
while (my $entry = readdir $dir) {
    if (-d $entry) {
        print $entry, ' ' unless ($entry eq '.' || $entry eq '..');
    }
}
closedir $dir;
print "\n";

$ ./dirs2a.pl
The working directory contains these directories:
two one
```

**split** The **split** function divides a string into substrings as specified by a delimiter. The syntax of a call to **split** is

```
split (/re/, string);
```

where *re* is the delimiter, which is a regular expression (frequently a single regular character), and *string* is the string that is to be divided. As the next example shows, you can assign the list that **split** returns to an array variable.

The next program runs under Linux and lists the usernames of users with UIDs greater than or equal to 100 listed in the `/etc/passwd` (page 475) file. It uses a **while** structure to read lines from `passwd` into `$user`, and it uses **split** to break the line into substrings separated by colons. The line that begins with `@row` assigns each of these substrings to an element of the `@row` array. The expression the **if** statement evaluates is *true* if the third substring (the UID) is greater than or equal to 100. This expression uses the `>=` numeric comparison operator because it compares two numbers; an alphabetic comparison would use the `ge` string comparison operator.

The **print** statement sends the UID number and the associated username to the `$sortout` file handle. The **open** statement for this handle establishes a pipe that sends its output to `sort -n`. Because the `sort` utility (page 155) does not display any output until it finishes receiving all of the input, `split3.pl` does not display anything until it closes the `$sortout` handle, which it does when it finishes reading the `passwd` file.

```
$ cat split3.pl
#!/usr/bin/perl -w

open ($pass, "/etc/passwd");
open ($sortout, "| sort -n");
while ($user = <$pass>) {
    @row = split (:/:/, $user);
    if ($row[2] >= 100) {
        print $sortout "$row[2] $row[0]\n";
    }
}
close ($pass);
close ($sortout);

$ ./split3.pl
100 libuuid
101 syslog
102 klog
103 avahi-autoipd
104 pulse
...
```

The next example counts and displays the arguments it was called with, using `@ARGV` (page 1002). A **foreach** structure loops through the elements of the `@ARGV` array, which holds the command-line arguments. The `++` preincrement operator increments `$count` before it is displayed.

```
$ cat 10.pl
#!/usr/bin/perl -w

$count = 0;
$num = @ARGV;
print "You entered $num arguments on the command line:\n";
foreach $arg (@ARGV) {
    print ++$count, ". $arg\n";
}
```

```
$ ./10.pl apple pear banana watermelon
You entered 4 arguments on the command line:
1. apple
2. pear
3. banana
4. watermelon
```

---

## CHAPTER SUMMARY

Perl was written by Larry Wall in 1987. Since that time Perl has grown in size and functionality and is now a very popular language used for text processing, system administration, software development, and general-purpose programming. One of Perl's biggest assets is its support by thousands of third-party modules, many of which are stored in the CPAN repository.

The `perldoc` utility locates and displays local Perl documentation. It also allows you to document a Perl program by displaying lines of **pod** (plain old documentation) that you include in the program.

Perl provides three types of variables: scalar (singular variables that begin with a `$`), array (plural variables that begin with an `@`), and hash (also called associative arrays; plural variables that begin with a `%`). Array and hash variables both hold lists, but arrays are ordered while hashes are unordered. Standard control flow statements allow you to alter the order of execution of statements within a Perl program. In addition, Perl programs can take advantage of subroutines that can include variables local to the subroutines (lexical variables).

Regular expressions are one of Perl's strong points. In addition to the same facilities that are available in many Linux utilities, Perl offers regular expression features that allow you to perform more complex string processing.

---

## EXERCISES

1. What are two different ways to turn on warnings in Perl?
2. What is the difference between an array and a hash?
3. In each example, when would you use a hash and when would you use an array?
  - a. Counting the number of occurrences of an IP address in a log file.
  - b. Generating a list of users who are over disk quota for use in a report.
4. Write a regular expression to match a quoted string, such as  
He said, "Go get me the wrench," but I didn't hear him.

5. Write a regular expression to match an IP address in a log file.
6. Many configuration files contain many comments, including commented-out default configuration directives. Write a program to remove these comments from a configuration file.

---

## ADVANCED EXERCISES

7. Write a program that removes `*~` and `*.ico` files from a directory hierarchy. (*Hint:* Use the `File::Find` module.)
8. Describe a programming mistake that Perl's warnings do not report on.
9. Write a Perl program that counts the number of files in the working directory and the number of bytes in those files, by filename extension.
10. Describe the difference between quoting strings using single quotation marks and using double quotation marks.
11. Write a program that copies all files with a `.ico` filename extension in a directory hierarchy to a directory named `icons` in your home directory. (*Hint:* Use the `File::Find` and `File::Copy` modules.)
12. Write a program that analyzes Apache logs. Display the number of bytes served by each path. Ignore unsuccessful page requests. If there are more than ten paths, display the first ten only.

Following is a sample line from an Apache access log. The two numbers following the HTTP/1.1 are the response code and the byte count. A response code of 200 means the request was successful. A byte count of – means no data was transferred.

```
__DATA__
92.50.103.52 - - [19/Aug/2008:08:26:43 -0400] "GET /perl/automated-testing/next_active.gif
HTTP/1.1" 200 980 "http://example.com/perl/automated-testing/navigation_bar.htm"
"Mozilla/5.0 (X11; U; Linux x86_64; en-US; rv:1.8.1.6) Gecko/20061201 Firefox/3.0.0.6
(Fedora); Blazer/4.0"
```



# PART VII

---

## APPENDIXES

### APPENDIX A

REGULAR EXPRESSIONS 1023

### APPENDIX B

HELP 1033

### APPENDIX C

SECURITY 1043

### APPENDIX D

THE FREE SOFTWARE DEFINITION 1063

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# REGULAR EXPRESSIONS

## IN THIS APPENDIX

Characters .....	1024
Delimiters .....	1024
Simple Strings .....	1024
Special Characters .....	1024
Rules .....	1027
Bracketing Expressions .....	1028
The Replacement String .....	1028
Extended Regular Expressions..	1029

A *regular expression* defines a set of one or more strings of characters. A simple string of characters is a regular expression that defines one string of characters: itself. A more complex regular expression uses letters, numbers, and special characters to define many different strings of characters. A regular expression is said to *match* any string it defines.

This appendix describes the regular expressions used by `ed`, `vim`, `emacs`, `grep`, `mawk/gawk`, `sed`, `Perl`, and many other utilities. Refer to page 1007 for more information on Perl regular expressions. The regular expressions used in shell ambiguous file references are different and are described in “Filename Generation/Pathname Expansion” on page 243.

# CHARACTERS

As used in this appendix, a *character* is any character *except* a `NEWLINE`. Most characters represent themselves within a regular expression. A *special character*, also called a *metacharacter*, is one that does not represent itself. If you need to use a special character to represent itself, you must quote it as explained on page 1027.

# DELIMITERS

A character called a *delimiter* usually marks the beginning and end of a regular expression. The delimiter is always a special character for the regular expression it delimits (that is, it does not represent itself but marks the beginning and end of the expression). Although `vim` permits the use of other characters as a delimiter and `grep` does not use delimiters at all, the regular expressions in this appendix use a forward slash (`/`) as a delimiter. In some unambiguous cases, the second delimiter is not required. For example, you can sometimes omit the second delimiter when it would be followed immediately by `RETURN`.

# SIMPLE STRINGS

The most basic regular expression is a simple string that contains no special characters except the delimiters. A simple string matches only itself (Table A-1). In the examples in this appendix, the strings that are matched are underlined and look like this.

**Table A-1** Simple strings

Regular expression	Matches	Examples
<code>/ring/</code>	<u>ring</u>	<u>ring</u> , <u>spring</u> , <u>ringing</u> , <u>stringing</u>
<code>/Thursday/</code>	<u>Thursday</u>	<u>Thursday</u> , <u>Thursday's</u>
<code>/or not/</code>	<u>or not</u>	<u>or not</u> , <u>poor nothing</u>

# SPECIAL CHARACTERS

You can use special characters within a regular expression to cause the regular expression to match more than one string. A regular expression that includes a

special character always matches the longest possible string, starting as far toward the beginning (left) of the line as possible.

## PERIODS

A period (.) matches any character (Table A-2).

**Table A-2** Periods

Regular expression	Matches	Examples
/ .alk/	All strings consisting of a SPACE followed by any character followed by <u>alk</u>	will <u>talk</u> , may <u>balk</u>
/ .ing/	All strings consisting of any character preceding <u>ing</u>	<u>sing</u> song, <u>ping</u> , before <u>ing</u> lenook

## BRACKETS

Brackets ([]) define a *character class*<sup>1</sup> that matches any single character within the brackets (Table A-3). If the first character following the left bracket is a caret (^), the brackets define a character class that matches any single character not within the brackets. You can use a hyphen to indicate a range of characters. Within a character-class definition, backslashes and asterisks (described in the following sections) lose their special meanings. A right bracket (appearing as a member of the character class) can appear only as the first character following the left bracket. A caret is special only if it is the first character following the left bracket. A dollar sign is special only if it is followed immediately by the right bracket.

**Table A-3** Brackets

Regular expression	Matches	Examples
/[bB]ill/	Member of the character class <u>b</u> and <u>B</u> followed by <u>ill</u>	<u>bill</u> , <u>Bill</u> , <u>billed</u>
/t[aeiou].k/	<u>t</u> followed by a lowercase vowel, any character, and a <u>k</u>	<u>talkative</u> , <u>stink</u> , <u>teak</u> , <u>tanker</u>
/#[6-9]/	<u>#</u> followed by a SPACE and a member of the character class <u>6</u> through <u>9</u>	<u># 60</u> , <u># 8:</u> , get <u># 9</u>
/[^a-zA-Z]/	Any character that is not a letter (ASCII character set only)	<u>1</u> , <u>Z</u> , <u>@</u> , <u>,</u> , <u>!</u> , Stop!

1. GNU documentation calls these List Operators and defines Character Class operators as expressions that match a predefined group of characters, such as all numbers (page 1074).

## ASTERISKS

An asterisk can follow a regular expression that represents a single character (Table A-4). The asterisk represents *zero* or more occurrences of a match of the regular expression. An asterisk following a period matches any string of characters. (A period matches any character, and an asterisk matches zero or more occurrences of the preceding regular expression.) A character-class definition followed by an asterisk matches any string of characters that are members of the character class.

**Table A-4** Asterisks

Regular expression	Matches	Examples
/ab*c/	<u>a</u> followed by zero or more <u>b</u> 's followed by <u>a c</u>	<u>ac</u> , <u>abc</u> , <u>abbc</u> , <u>debbcaabbbc</u>
/ab.*c/	<u>ab</u> followed by zero or more characters followed by <u>c</u>	<u>abc</u> , <u>abxc</u> , <u>ab45c</u> , <u>xab 756.345 x cat</u>
/t.*ing/	<u>t</u> followed by zero or more characters followed by <u>ing</u>	<u>thing</u> , <u>ting</u> , <u>I thought of going</u>
/[a-zA-Z ]*/	A string composed only of letters and SPACES	1. <u>any string without numbers or punctuation!</u>
/(.*)/	As long a string as possible between ( and )	Get <u>(this)</u> and <u>(that)</u> ;
/([^]*)/	The shortest string possible that starts with ( and ends with )	<u>(this)</u> , Get <u>(this and that)</u>

## CARETS AND DOLLAR SIGNS

A regular expression that begins with a caret (^) can match a string only at the beginning of a line. In a similar manner, a dollar sign (\$) at the end of a regular expression matches the end of a line. The caret and dollar sign are called anchors because they force (anchor) a match to the beginning or end of a line (Table A-5).

**Table A-5** Carets and dollar signs

Regular expression	Matches	Examples
/^T/	A <u>T</u> at the beginning of a line	<u>This</u> line..., <u>That</u> Time..., In Time
/^[0-9]/	A plus sign followed by a digit at the beginning of a line	<u>+5</u> +45.72, <u>+759</u> Keep this...
/:\$/	A colon that ends a line	...below;

## QUOTING SPECIAL CHARACTERS

You can quote any special character (but not parentheses [except in Perl; page 1011] or a digit) by preceding it with a backslash (Table A-6). Quoting a special character makes it represent itself.

**Table A-6** Quoted special characters

Regular expression	Matches	Examples
/end\./	All strings that contain <u>end</u> followed by a period	The <u>end</u> ., <u>send</u> ., pre <u>tend</u> .mail
/\\	A single backslash	\
/\*/	An asterisk	<u>*</u> .c, an asterisk ( <u>*</u> )
/\[5]/	[5]	it was five [5]
/and\or/	<u>and/or</u>	<u>and/or</u>

## RULES

The following rules govern the application of regular expressions.

### LONGEST MATCH POSSIBLE

A regular expression always matches the longest possible string, starting as far toward the beginning of the line as possible. Perl calls this type of match a *greedy match* (page 1010). For example, given the string

    This (rug) is not what it once was (a long time ago), is it?

the expression `/Th.*is/` matches

    This (rug) is not what it once was (a long time ago), is

and `/(.*)/` matches

    (rug) is not what it once was (a long time ago)

However, `/([^]*)*/` matches

    (rug)

Given the string

    singing songs, singing more and more

the expression `/s.*ing/` matches

    singing songs, singing

and `/s.*ing song/` matches

    singing song

## EMPTY REGULAR EXPRESSIONS

Within some utilities, such as `vim` and `less` (but not `grep`), an empty regular expression represents the last regular expression that you used. For example, suppose you give `vim` the following Substitute command:

```
:s/mike/robert/
```

If you then want to make the same substitution again, you can use the following command:

```
:s//robert/
```

Alternatively, you can use the following commands to search for the string `mike` and then make the substitution

```
/mike/  
:s//robert/
```

The empty regular expression (`//`) represents the last regular expression you used (`/mike/`).

---

## BRACKETING EXPRESSIONS

You can use quoted parentheses, `\(` and `\)`, to *bracket* a regular expression. (However, Perl uses unquoted parentheses to bracket regular expressions; page 1011.) The string that the bracketed regular expression matches can be recalled, as explained in “Quoted Digit.” A regular expression does not attempt to match quoted parentheses. Thus a regular expression enclosed within quoted parentheses matches what the same regular expression without the parentheses would match. The expression `\(regexp\)` matches what `/regexp/` would match; `/a\(b*c\)c/` matches what `/ab*c/c/` would match.

You can nest quoted parentheses. The bracketed expressions are identified only by the opening `\(`, so no ambiguity arises in identifying them. The expression `\([a-z]\([A-Z]*\)x\)` consists of two bracketed expressions, one nested within the other. In the string `3 t dMNORx7 l u`, the preceding regular expression matches `dMNORx`, with the first bracketed expression matching `dMNORx` and the second matching `MNOR`.

---

## THE REPLACEMENT STRING

The `vim` and `sed` editors use regular expressions as search strings within Substitute commands. You can use the ampersand (`&`) and quoted digits (`\n`) special characters to represent the matched strings within the corresponding replacement string.



## AMPERSAND

Within a replacement string, an ampersand (&) takes on the value of the string that the search string (regular expression) matched. For example, the following vim Substitute command surrounds a string of one or more digits with NN. The ampersand in the replacement string matches whatever string of digits the regular expression (search string) matched:

```
:s/[0-9][0-9]*/NN&NN/
```

Two character-class definitions are required because the regular expression `[0-9]*` matches *zero* or more occurrences of a digit, and *any* character string constitutes zero or more occurrences of a digit.

## QUOTED DIGIT

Within the search string, a bracketed regular expression, `\(xxx\)` [(xxx) in Perl], matches what the regular expression would have matched without the quoted parentheses, `xxx`. Within the replacement string, a quoted digit, `\n`, represents the string that the bracketed regular expression (portion of the search string) beginning with the *n*th `\(` matched. Perl accepts a quoted digit for this purpose, but the preferred style is to precede the digit with a dollar sign (`$n`; page 1011). For example, you can take a list of people in the form

```
last-name, first-name initial
```

and put it in the form

```
first-name initial last-name
```

with the following vim command:

```
:1,$s/\([^,]*\), \(.*\)/\2 \1/
```

This command addresses all the lines in the file (`1,$`). The Substitute command (`s`) uses a search string and a replacement string delimited by forward slashes. The first bracketed regular expression within the search string, `\([^,]*\)`, matches what the same unbracketed regular expression, `[,]*`, would match: zero or more characters not containing a comma (the **last-name**). Following the first bracketed regular expression are a comma and a SPACE that match themselves. The second bracketed expression, `\(.*\)`, matches any string of characters (the **first-name** and **initial**).

The replacement string consists of what the second bracketed regular expression matched (`\2`), followed by a SPACE and what the first bracketed regular expression matched (`\1`).

---

## EXTENDED REGULAR EXPRESSIONS

This section covers patterns that use an extended set of special characters. These patterns are called *full regular expressions* or *extended regular expressions*. In addition

to ordinary regular expressions, Perl and vim provide extended regular expressions. The three utilities `egrep`, `grep` when run with the `-E` option (similar to `egrep`), and `mawk/gawk` provide all the special characters included in ordinary regular expressions, except for `\(` and `\)`, as well those included in extended regular expressions.

Two of the additional special characters are the plus sign (+) and the question mark (?). They are similar to \*, which matches *zero* or more occurrences of the previous character. The plus sign matches *one* or more occurrences of the previous character, whereas the question mark matches *zero* or *one* occurrence. You can use any one of the special characters \*, +, and ? following parentheses, causing the special character to apply to the string surrounded by the parentheses. Unlike the parentheses in bracketed regular expressions, these parentheses are not quoted (Table A-7).

Table A-7 Extended regular expressions

Regular expression	Matches	Examples
/ab+c/	a followed by one or more b's followed by a c	yabcw, abbc57
/ab?c/	a followed by zero or one b followed by c	back, abcdef
/(ab)+c/	One or more occurrences of the string ab followed by c	zabcd, ababc!
/(ab)?c/	Zero or one occurrence of the string ab followed by c	xc, abcc

In full regular expressions, the vertical bar (|) special character is a Boolean OR operator. Within vim, you must quote the vertical bar by preceding it with a backslash to make it special (\|). A vertical bar between two regular expressions causes a match with strings that match the first expression, the second expression, or both. You can use the vertical bar with parentheses to separate from the rest of the regular expression the two expressions that are being ORed (Table A-8).

Table A-8 Full regular expressions

Regular expression	Meaning	Examples
/ab ac/	Either <u>ab</u> or <u>ac</u>	ab, ac, abac ( <i>abac is two matches of the regular expression</i> )
/^Exit ^Quit/	Lines that begin with <u>Exit</u> or <u>Quit</u>	Exit, Quit, No Exit
/(D N)\. Jones/	<u>D. Jones</u> or <u>N. Jones</u>	P.D. Jones, N. Jones

## APPENDIX SUMMARY

A regular expression defines a set of one or more strings of characters. A regular expression is said to match any string it defines.

In a regular expression, a special character is one that does not represent itself. Table A-9 lists special characters.

**Table A-9** Special characters

Character	Meaning
.	Matches any single character
*	Matches zero or more occurrences of a match of the preceding character
^	Forces a match to the beginning of a line
\$	A match to the end of a line
\	Quotes special characters
\<	Forces a match to the beginning of a word
\>	Forces a match to the end of a word

Table A-10 lists ways of representing character classes and bracketed regular expressions.

**Table A-10** Character classes and bracketed regular expressions

Class	Defines
[xyz]	Defines a character class that matches <i>x</i> , <i>y</i> , or <i>z</i>
[^xyz]	Defines a character class that matches any character except <i>x</i> , <i>y</i> , or <i>z</i>
[x-z]	Defines a character class that matches any character <i>x</i> through <i>z</i> inclusive
\(xyz\)	Matches what <i>xyz</i> matches (a bracketed regular expression; not Perl)
(xyz)	Matches what <i>xyz</i> matches (a bracketed regular expression; Perl only)

In addition to the preceding special characters and strings (excluding quoted parentheses, except in vim), the characters in Table A-11 are special within full, or extended, regular expressions.

**Table A-11** Extended regular expressions

Expression	Matches
+	Matches one or more occurrences of the preceding character
?	Matches zero or one occurrence of the preceding character

**Table A-11** Extended regular expressions (continued)

Expression	Matches
<b>(xyz)+</b>	Matches one or more occurrences of what <b>xyz</b> matches
<b>(xyz)?</b>	Matches zero or one occurrence of what <b>xyz</b> matches
<b>(xyz)*</b>	Matches zero or more occurrences of what <b>xyz</b> matches
<b>xyz abc</b>	Matches either what <b>xyz</b> or what <b>abc</b> matches (use \  in vim)
<b>(xy ab)c</b>	Matches either what <b>xyz</b> or what <b>abc</b> matches (use \  in vim)

Table A-12 lists characters that are special within a replacement string in sed and vim.

**Table A-12** Replacement strings

String	Represents
<b>&amp;</b>	Represents what the regular expression (search string) matched
<b>\n</b>	A quoted number, <b>n</b> , represents what the <b>n</b> th bracketed regular expression in the search string matched
<b>\$n</b>	A number preceded by a dollar sign, <b>n</b> , represents what the <b>n</b> th bracketed regular expression in the search string matched (Perl only)

# B

## HELP

### IN THIS APPENDIX

Solving a Problem.....	1034
Finding Linux-Related Information .....	1035
Documentation .....	1035
Useful Linux Sites .....	1036
Linux Newsgroups.....	1037
Mailing Lists .....	1037
Words.....	1038
Software .....	1038
Office Suites and Word Processors .....	1040
Specifying a Terminal .....	1040

You need not act as a user or system administrator in isolation. A large community of Linux experts is willing to assist you in learning about, helping you solve problems with, and getting the most out of a Linux system. Before you ask for help, however, make sure you have done everything you can to solve the problem yourself. No doubt, someone has experienced the same problem before you and the answer to your question can be found somewhere on the Internet. Your job is to find it. This appendix lists resources and describes methods that can help you in that task.

## SOLVING A PROBLEM

Following is a list of steps that can help you solve a problem without asking someone for help. Depending on your understanding of and experience with the hardware and software involved, these steps may lead to a solution.

1. Fedora/RHEL comes with extensive documentation. Read the documentation on the specific hardware or software you are having a problem with. If it is a GNU product, use `info`; otherwise, use `man` to find local information. Also look in `/usr/share/doc` for documentation on specific tools. For more information refer to “Where to Find Documentation” on page 124.
2. When the problem involves some type of error or other message, use a search engine, such as Google ([www.google.com/linux](http://www.google.com/linux)) or Google Groups ([groups.google.com](http://groups.google.com)), to look up the message on the Internet. If the message is long, pick a unique part of the message to search for; 10 to 20 characters should be enough. Enclose the search string within double quotation marks.
3. Check whether the Linux Documentation Project ([www.tldp.org](http://www.tldp.org)) has a HOWTO or mini-HOWTO on the subject in question. Search on keywords that relate directly to the product and problem. Read the FAQs.
4. See Table B-1 for other sources of documentation.
5. Use Google or Google Groups to search on keywords that relate directly to the product and problem.
6. When all else fails (or perhaps before you try anything else), examine the system logs in `/var/log`. Running as Superuser, first look at the end of the `messages` file using the following command:

```
# tail -20 /var/log/messages
```

If `messages` contains nothing useful, run the following command. It displays the names of the log files in chronological order, with the most recently modified files appearing at the bottom of the list:

```
$ ls -ltr /var/log
```

If the problem involves a network connection, review the `secure` log file on the local and remote systems. Also look at `messages` on the remote system.

7. The `/var/spool` directory contains subdirectories with useful information: `cups` holds the print queues, `mail` holds the user’s mail files, and so on.

If you are unable to solve a problem yourself, a thoughtful question to an appropriate newsgroup (page 1037) or mailing list (page 1037) can elicit useful information. When you send or post a question, make sure you describe the problem and identify

the local system carefully. Include the version numbers of Fedora/RHEL and any software packages that relate to the problem. Describe the hardware, if appropriate. For a fee, Red Hat provides many types of support.

The author's home page ([www.sobell.com](http://www.sobell.com)) contains corrections to this book, answers to selected chapter exercises, and pointers to other Linux sites.

## FINDING LINUX-RELATED INFORMATION

Fedora/RHEL comes with reference pages stored online. You can read these documents by using the `info` (page 127) or `man` (page 125) utilities. You can read `man` and `info` pages to get more information about specific topics while reading this book or to determine which features are available with Linux. You can search for topics using `apropos` (see page 167 or give the command `man apropos`).

## DOCUMENTATION

Good books are available on various aspects of using and managing UNIX systems in general and Linux systems in particular. In addition, you may find the sites listed in Table B-1 useful.<sup>1</sup>

**Table B-1** Documentation

Site	About the site	URL
<a href="http://freedesktop.org">freedesktop.org</a>	Creates standards for interoperability between open-source desktop environments.	<a href="http://freedesktop.org">freedesktop.org</a>
GNOME	GNOME home page.	<a href="http://www.gnome.org">www.gnome.org</a>
GNU Manuals	GNU manuals.	<a href="http://www.gnu.org/manual">www.gnu.org/manual</a>
Internet FAQ Archives	Searchable FAQ archives.	<a href="http://www.faqs.org">www.faqs.org</a>
<code>info</code>	Instructions for using the <code>info</code> utility.	<a href="http://www.gnu.org/software/texinfo/manual/info">www.gnu.org/software/texinfo/manual/info</a>
KDE Documentation	KDE documentation.	<a href="http://kde.org/documentation">kde.org/documentation</a>
KDE News	KDE news.	<a href="http://dot.kde.org">dot.kde.org</a>

1. The right-hand columns of most of the tables in this appendix show Internet addresses (URLs). All sites have an implicit `http://` prefix unless `ftp://` or `https://` is shown. Refer to “URLs (Web addresses)” on page 18.

**Table B-1** Documentation (continued)

Site	About the site	URL
The Linux Documentation Project	All things related to Linux documentation (in many languages): HOWTOs, guides, FAQs, man pages, and magazines. This is the best overall source for Linux documentation. Make sure to visit the Links page.	<a href="http://www.tldp.org">www.tldp.org</a>
Red Hat Documentation and Support	This site has a link to the Red Hat Knowledgebase that can help answer questions. It also has links to online documentation for Red Hat products and to a support guide.	<a href="http://www.redhat.com/apps/support">www.redhat.com/apps/support</a>
RFCs	Request for comments; see <i>RFC</i> (page 1103).	<a href="http://www.rfc-editor.org">www.rfc-editor.org</a>
System Administrators Guild (SAGE)	SAGE is a group for system administrators.	<a href="http://www.sage.org">www.sage.org</a>

## USEFUL LINUX SITES

Sometimes the sites listed in Table B-2 are so busy that you cannot connect to them. In this case, you are usually given a list of alternative, or *mirror*, sites to try.

**Table B-2** Useful Linux sites

Site	About the site	URL
DistroWatch	A survey of many Linux distributions, including news, reviews, and articles.	<a href="http://distrowatch.com">distrowatch.com</a>
GNU	GNU Project Web server.	<a href="http://www.gnu.org">www.gnu.org</a>
ibiblio	A large library and digital archive. Formerly Metalab; formerly Sunsite.	<a href="http://www.ibiblio.org">www.ibiblio.org</a> <a href="http://www.ibiblio.org/pub/linux">www.ibiblio.org/pub/linux</a> <a href="http://www.ibiblio.org/pub/historic-linux">www.ibiblio.org/pub/historic-linux</a>
LinuxHQ.org	An administrator and power user resource site.	<a href="http://www.linuxhq.org">www.linuxhq.org</a>
Linux Standard Base (LSB)	A group dedicated to standardizing Linux.	<a href="http://www.linuxfoundation.org/collaborate/workgroups/lbs">www.linuxfoundation.org/collaborate/workgroups/lbs</a>
Rpmfind.Net	A good source for rpm files, especially when you need a specific version.	<a href="http://rpmfind.net">rpmfind.net</a>



**Table B-2** Useful Linux sites (continued)

Site	About the site	URL
Sobell	The author's home page contains useful links, errata for this book, code for many of the examples in this book, and answers to selected exercises.	<a href="http://www.sobell.com">www.sobell.com</a>
USENIX	A large, well-established UNIX group. This site has many links, including a list of conferences.	<a href="http://www.usenix.org">www.usenix.org</a>
X.Org	The X Window System home.	<a href="http://www.x.org">www.x.org</a>

## LINUX NEWSGROUPS

One of the best ways of getting specific information is through a newsgroup (refer to “Usenet” on page 392). Frequently you can find the answer to a question by reading postings to the newsgroup. Try using Google Groups ([groups.google.com](http://groups.google.com)) to search through newsgroups to see whether the question has already been asked and answered. Or open a newsreader program and subscribe to appropriate newsgroups. If necessary, you can post a question for someone to answer. Before you do so, make sure you are posting to the correct group and that your question has not already been answered. There is an etiquette to posting questions—see [www.catb.org/~esr/faqs/smart-questions.html](http://www.catb.org/~esr/faqs/smart-questions.html) for a good paper by Eric S. Raymond and Rick Moen titled “How To Ask Questions the Smart Way.”

The newsgroup **comp.os.linux.answers** provides postings of solutions to common problems and periodic postings of the most up-to-date versions of the FAQ and HOWTO documents. The **comp.os.linux.misc** newsgroup has answers to miscellaneous Linux-related questions.

## MAILING LISTS

Subscribing to a mailing list (page 688) allows you to participate in an electronic discussion. With most lists, you can send and receive email dedicated to a specific topic to and from a group of users. Moderated lists do not tend to stray as much as unmoderated lists, assuming the list has a good moderator. The disadvantage of a moderated list is that some discussions may be cut off when they get interesting if the moderator deems that the discussion has gone on for too long. Mailing lists described as bulletins are strictly unidirectional: You cannot post information to these lists but can only receive periodic bulletins. If you have the subscription address for a mailing list but are not sure how to subscribe, put the word **help** in the body and/or header of email that you send to the address. You will usually receive instructions via return email. Red Hat hosts several mailing lists; go to [www.redhat.com/mailman/listinfo](http://www.redhat.com/mailman/listinfo) for more information. You can also use a search engine to search for **mailing list linux**.

# WORDS

Many dictionaries, thesauruses, and glossaries are available online. Table B-3 lists a few of them.

**Table B-3** Looking up words

Site	About the site	URL
ROGET'S Thesaurus	Thesaurus	<a href="http://machaut.uchicago.edu/?resource=Roget's">machaut.uchicago.edu/?resource=Roget's</a>
DICT.org	Multiple-database search for words	<a href="http://www.dict.org">www.dict.org</a>
Dictionary.com	Everything related to words	<a href="http://dictionary.reference.com">dictionary.reference.com</a>
DNS Glossary	DNS glossary	<a href="http://www.menandmice.com/online_docs_and_faq/glossary/glossarytoc.htm">www.menandmice.com/online_docs_and_faq/glossary/glossarytoc.htm</a>
FOLDOC (The Free On-Line Dictionary of Computing)	Computer terms	<a href="http://www.foldoc.org">www.foldoc.org</a>
The Jargon File	An online version of <i>The New Hacker's Dictionary</i>	<a href="http://www.catb.org/~esr/jargon">www.catb.org/~esr/jargon</a>
Merriam-Webster	English language	<a href="http://www.merriam-webster.com">www.merriam-webster.com</a>
OneLook	Multiple-site word search with a single query	<a href="http://www.onelook.com">www.onelook.com</a>
Webopedia	Commercial technical dictionary	<a href="http://www.webopedia.com">www.webopedia.com</a>
Wikipedia	An open-source (user-contributed) encyclopedia project	<a href="http://wikipedia.org">wikipedia.org</a>
Wordsmyth	Dictionary and thesaurus	<a href="http://www.wordsmyth.net">www.wordsmyth.net</a>
Yahoo Reference	Search multiple sources at the same time	<a href="http://education.yahoo.com/reference">education.yahoo.com/reference</a>

# SOFTWARE

There are many ways to learn about interesting software packages and their availability on the Internet. Table B-4 lists sites that you can download software from. For security-related programs, refer to Table C-1 on page 1058. Another way to learn about software packages is through a newsgroup (page 1037).

**Table B-4** Software

Site	About the site	URL
Apt	Apt installs, removes, and updates system software packages	<a href="http://apt.freshrpms.net">apt.freshrpms.net</a>

**Table B-4** Software (continued)

<b>Site</b>	<b>About the site</b>	<b>URL</b>
BitTorrent	BitTorrent efficiently distributes large amounts of static data	<a href="http://www.bittorrent.com">www.bittorrent.com</a>
CVS	CVS (Concurrent Versions System) is a version control system	<a href="http://www.nongnu.org/cvs">www.nongnu.org/cvs</a>
ddd	The ddd utility is a graphical front end for command-line debuggers such as gdb	<a href="http://www.gnu.org/software/ddd">www.gnu.org/software/ddd</a>
Firefox	Web browser	<a href="http://www.mozilla.com/firefox">www.mozilla.com/firefox</a>
Free Software Directory	Categorized, searchable lists of free software	<a href="http://directory.fsf.org">directory.fsf.org</a>
Freshmeat	A large index of UNIX and cross-platform software and themes	<a href="http://freshmeat.net">freshmeat.net</a>
gdb	The gdb utility is a command-line debugger	<a href="http://www.gnu.org/software/gdb">www.gnu.org/software/gdb</a>
GNOME Project	Links to all GNOME projects	<a href="http://www.gnome.org/projects">www.gnome.org/projects</a>
IceWALKERS	Categorized, searchable lists of free software	<a href="http://www.icewalkers.com">www.icewalkers.com</a>
kdbg	The kdbg utility is a graphical user interface to gdb	<a href="http://freshmeat.net/projects/kdbg">freshmeat.net/projects/kdbg</a>
Linux Software Map	A database of packages written for, ported to, or compiled for Linux	<a href="http://www.boutell.com/lsm">www.boutell.com/lsm</a>
Mtools	A collection of utilities to access DOS floppy diskettes from Linux without mounting the diskettes	<a href="http://www.gnu.org/software/mtools">www.gnu.org/software/mtools</a>
Network Calculators	Subnet mask calculator	<a href="http://www.subnetmask.info">www.subnetmask.info</a>
rpmfind.net	Searchable list of rpm files for various Linux distributions and versions	<a href="http://rpmfind.net/linux/RPM">rpmfind.net/linux/RPM</a>
Savannah	Central point for development, distribution, and maintenance of free software	<a href="http://savannah.gnu.org">savannah.gnu.org</a>
SourceForge	A development Web site with a large repository of open-source code and applications	<a href="http://sourceforge.net">sourceforge.net</a>

**Table B-4** Software (continued)

Site	About the site	URL
strace	The strace utility is a system call trace debugging tool	<a href="http://sourceforge.net/projects/strace">sourceforge.net/projects/strace</a>
Thunderbird	Mail application	<a href="http://www.mozilla.com/thunderbird">www.mozilla.com/thunderbird</a>
Tucows-Linux	Commercial, categorized, searchable list of software	<a href="http://www.tucows.com/Linux">www.tucows.com/Linux</a>
ups	The ups utility is a graphical source-level debugger	<a href="http://ups.sourceforge.net">ups.sourceforge.net</a>
yum	The yum utility installs, removes, and updates system software packages	<a href="http://wiki.linux.duke.edu/Yum">wiki.linux.duke.edu/Yum</a>

## OFFICE SUITES AND WORD PROCESSORS

Several office suites and many word processors are available for Linux. Table B-5 lists a few of them. If you are exchanging documents with people using Windows, make sure the import from/export to MS Word functionality covers your needs.

**Table B-5** Office suites and word processors

Product name	What it does	URL
AbiWord	Word processor	<a href="http://www.abisource.com">www.abisource.com</a>
KOffice	Integrated suite of office applications, including the KWord word processing program	<a href="http://www.koffice.org">www.koffice.org</a>
OpenOffice	A multiplatform and multilingual office suite	<a href="http://www.openoffice.org">www.openoffice.org</a> <a href="http://www.gnome.org/projects/ooo">www.gnome.org/projects/ooo</a>
Xcoral	A programmer's multiwindow mouse-based editor that runs under X	<a href="http://xcoral.free.fr">xcoral.free.fr</a>

## SPECIFYING A TERMINAL

Because vim, emacs, konsole, and other programs take advantage of features that are specific to various kinds of terminals and terminal emulators, you must tell these programs the name of the terminal you are using or the terminal that your terminal emulator is emulating. On many systems the terminal name is set for you. If the terminal name is not specified or is not specified correctly, the characters on the screen will be garbled or, when you start a program, the program will ask what type of terminal you are using.

Terminal names describe the functional characteristics of a terminal or terminal emulator to programs that require this information. Although terminal names are

referred to as either Terminfo or Termcap names, the difference relates to the method that each system uses to store the terminal characteristics internally, not the manner that you specify the name of a terminal. Terminal names that are often used with Linux terminal emulators and with graphical monitors while they are run in text mode include **ansi**, **linux**, **vt100**, **vt102**, **vt220**, and **xterm**.

When you are running a terminal emulator, you can specify the type of terminal you want to emulate. Set the emulator to either **vt100** or **vt220**, and then set **TERM** to the same value.

When you log in, you may be prompted to identify the type of terminal you are using:

```
TERM = (vt100)
```

You can respond to this prompt in one of two ways. First you can press RETURN to set your terminal type to the name in parentheses. If that name does not describe the terminal you are using, you can enter the correct name and then press RETURN.

```
TERM = (vt100) ansi
```

You may also receive the following prompt:

```
TERM = (unknown)
```

This prompt indicates that the system does not know what type of terminal you are using. If you plan to run programs that require this information, enter the name of the terminal or terminal emulator you are using before you press RETURN.

**TERM** If you do not receive a prompt, you can give the following command to display the value of the **TERM** variable and check whether the terminal type has been set:

```
$ echo $TERM
```

If the system responds with the wrong name, a blank line, or an error message, set or change the terminal name. From the Bourne Again Shell (**bash**), enter a command similar to the following to set the **TERM** variable so that the system knows which type of terminal you are using:

```
export TERM=name
```

Replace *name* with the terminal name for the terminal you are using, making sure that you do not put a SPACE before or after the equal sign. If you always use the same type of terminal, you can place this command in your **~/.bashrc** file (page 281), causing the shell to set the terminal type each time you log in. For example, give the following command to set your terminal name to **vt100**:

```
$ export TERM=vt100
```

**LANG** For some programs to display information correctly you may need to set the **LANG** variable (page 312). Frequently you can set this variable to **C**. Under **bash** use the command

```
$ export LANG=C
```

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# SECURITY

## IN THIS APPENDIX

Encryption . . . . .	1044
File Security . . . . .	1049
Email Security . . . . .	1049
Network Security . . . . .	1050
Host Security . . . . .	1053
Login Security . . . . .	1054
Remote Access Security . . . . .	1055
Viruses and Worms . . . . .	1056
Physical Security . . . . .	1056
Security Resources . . . . .	1058

Security is a major part of the foundation of any system that is not totally cut off from other machines and users. Some aspects of security have a place even on isolated machines. Examples of these measures include periodic system backups, BIOS or power-on passwords, and self-locking screensavers.

A system that is connected to the outside world requires other mechanisms to secure it: tools to check files (*tripwire*), audit tools (*tiger/cops*), secure access methods (*kerberos/ssh*), services that monitor logs and machine states (*swatch/watcher*), packet-filtering and routing tools (*ipfwadm/iptables/ipchains*), and more.

System security has many dimensions. The security of your system as a whole depends on the security of individual components, such as your email, files, network, login, and remote access policies, as well as the physical security of the host itself. These dimensions frequently overlap, and their borders are not always static or clear. For instance, email security is affected by the security of files and your network. If the medium (the network) over which you send and receive your email is not secure, then you must take extra steps to ensure the security of your

messages. If you save your secure email into a file on your local system, then you rely on the filesystem and host access policies for file security. A failure in any one of these areas can start a domino effect, diminishing reliability and integrity in other areas and potentially compromising system security as a whole.

This short appendix cannot cover all facets of system security in depth, but it does provide an overview of the complexity of setting up and maintaining a secure system. This appendix provides some specifics, concepts, guidelines to consider, and many pointers to security resources (Table C-1 on page 1058).

### Other sources of system security information

**security** Depending on how important system security is to you, you may want to purchase one or more of the books dedicated to system security, visit some of the Internet sites that are dedicated to security, or hire someone who is an expert in the field.

***Do not rely on this appendix as your sole source of information on system security.***

---

---

## ENCRYPTION

One of the building blocks of security is encryption, which provides a means of scrambling data for secure transmission to other parties. In cryptographic terms, the data or message to be encrypted is referred to as *plaintext*, and the resulting encrypted block of text as *ciphertext*. Processes exist for converting plaintext into ciphertext through the use of *keys*, which are essentially random numbers of a specified length used to *lock* and *unlock* data. This conversion is achieved by applying the keys to the plaintext according to a set of mathematical instructions, referred to as the *encryption algorithm*.

Developing and analyzing strong encryption software is extremely difficult. Many nuances exist, many standards govern encryption algorithms, and a background in mathematics is requisite. Also, unless an algorithm has undergone public scrutiny for a significant period of time, it is generally not considered secure; it is often impossible to know that an algorithm is completely secure but possible to know that one is not secure. Time is the best test of any algorithm. Also, a solid algorithm does not guarantee an effective encryption mechanism, as the fallibility of an encryption scheme frequently lies in problems with its implementation and distribution.

An encryption algorithm uses a key that is a certain number of bits long. Each bit you add to the length of a key effectively doubles the *key space* (the number of combinations allowed by the number of bits in the key—2 to the power of the length of the key in bits<sup>1</sup>) and means that it will take twice as long for an attacker to decrypt your message (assuming that the scheme lacks any inherent weaknesses or vulnerabilities to exploit). However, it is a mistake to compare algorithms based only on

---

1. A 2-bit key would have a key space of 4 ( $2^2$ ), a 3-bit key would have a key space of 8 ( $2^3$ ), and so on.



the number of bits used. In some cases an algorithm that uses a 64-bit key can be more secure than an algorithm that uses a 128-bit key.

The two primary classifications of encryption schemes are *public key encryption* and *symmetric key encryption*. Public key encryption, also called *asymmetric encryption*, uses two keys: a public key and a private key. These keys are uniquely associated with a specific individual user. Public key encryption schemes are used mostly to exchange keys and signatures. Symmetric key encryption, also called *symmetric encryption* or *secret key encryption*, uses one key that you and the person you are communicating with (hereafter referred to as your *friend*) share as a secret. Symmetric key encryption is typically used to encrypt large amounts of data. Public key algorithm keys typically have a length of 512 bits to 2,048 bits, whereas symmetric key algorithms use keys in the range of 64 bits to 512 bits.

When you are choosing an encryption scheme, realize that security comes at a price. There is usually a tradeoff between resilience of the cryptosystem and ease of administration.

### Hard to break? Hard to use!

**security** The more difficult an algorithm is to crack, the more difficult it is to maintain and to get people to use properly. The paramount limitations of most respectable cryptosystems lie not in weak algorithms but rather in users' failure to transmit and store keys in a secure manner.

The practicality of a security solution is a far greater factor in encryption, and in security in general, than most people realize. With enough time and effort, nearly every algorithm can be broken. In fact, you can often unearth the mathematical instructions for a widely used algorithm by flipping through a cryptography book, reviewing a vendor's product specifications, or performing a quick search on the Internet. The challenge is to ensure that the effort required to follow the twists and turns taken by an encryption algorithm and its resulting encryption solution outweighs the worth of the information it is protecting.

### How much time and money should you spend on encryption?

**tip** When the cost of obtaining the information exceeds the value realized by its possession, the solution is an effective one.

## PUBLIC KEY ENCRYPTION

To use public key encryption, you must generate two keys: a public key and a private key. You keep the private key for yourself and give the public key to the world. In a similar manner, your friends will generate a pair of keys and give you their public keys. Public key encryption is marked by two distinct features:

1. When you encrypt data with someone's public key, only that person's private key can decrypt it.
2. When you encrypt data with your private key, anyone else can decrypt it with your public key.

You may wonder why the second point is useful: Why would you want everybody else to be able to decrypt something you just encrypted? The answer lies in the purpose of the encryption. Although encryption changes the original message into unreadable ciphertext, its purpose is to provide a *digital signature*. If the message can be properly decrypted with your public key, *only you* could have encrypted it with your private key, proving that the message is authentic. Combining these two modes of operation yields privacy and authenticity. You can sign something with your private key so that it is verified as authentic, and then you can encrypt it with your friend's public key so that only your friend can decrypt it.

Public key encryption has three major shortcomings:

1. Public key encryption algorithms are generally much slower than symmetric key algorithms and usually require a much larger key size and a way to generate large prime numbers to use as components of the key, making them more resource intensive.
2. The private key must be stored securely and its integrity safeguarded. If a person's private key is obtained by another party, that party can encrypt, decrypt, and sign messages while impersonating the original owner of the key. If the private key is lost or becomes corrupted, any messages previously encrypted with it are also lost, and a new keypair must be generated.
3. It is difficult to authenticate the origin of a key—that is, to prove whom it originally came from. This so-called key-distribution problem is the *raison d'être* for such companies as VeriSign ([www.verisign.com](http://www.verisign.com)).

Algorithms such as RSA, Diffie-Hellman, and El-Gamal implement public key encryption methodology. Today a 512-bit key is considered barely adequate for RSA encryption and offers marginal protection; 1,024-bit keys are expected to withhold determined attackers for several more years. Keys that are 2,048 bits long are now becoming commonplace and are rated as *espionage strength*. A mathematical paper published in late 2001 and reexamined in spring 2002 describes how a machine can be built—for a very large sum of money—that could break 1,024-bit RSA encryption in seconds to minutes (this point is debated in an article at [www.schneier.com/crypto-gram-0203.html#6](http://www.schneier.com/crypto-gram-0203.html#6)). Although the cost of such a machine exceeds the resources available to most individuals and smaller corporations, it is well within the reach of large corporations and governments.

## SYMMETRIC KEY ENCRYPTION

Symmetric key encryption is generally fast and simple to deploy. First you and your friend agree on which algorithm to use and a key that you will share. Then either of you can decrypt or encrypt a file with the same key. Behind the scenes, symmetric key encryption algorithms are most often implemented as a network of black boxes, which can involve hardware components, software, or a combination of the two. Each box imposes a reversible transformation on the plaintext and passes it on to the next box, where another reversible transformation further alters the data. The

security of a symmetric key algorithm relies on the difficulty of determining which boxes were used and the number of times the data was fed through the set of boxes. A good algorithm will cycle the plaintext through a given set of boxes many times before yielding the result, and there will be no obvious mapping from plaintext to ciphertext.

The disadvantage of symmetric key encryption is that it depends heavily on the availability of a secure channel through which to send the key to your friend. For example, you would not use email to send your key; if your email is intercepted, a third party is in possession of your secret key, and your encryption is useless. You could relay the key over the phone, but your call could be intercepted if your phone were tapped or someone overheard your conversation.

Common implementations of symmetric key algorithms include DES (Data Encryption Standard), 3-DES (triple DES), IDEA, RC5, Blowfish, and AES (Advanced Encryption Standard). AES is the new Federal Information Processing Standard (FIPS-197) algorithm endorsed for governmental use and has been selected to replace DES as the de facto encryption algorithm. AES uses the Rijndael algorithm ([www.rijndael.com](http://www.rijndael.com)), chosen after a thorough evaluation of 15 candidate algorithms by the cryptographic research community.

None of the aforementioned algorithms has undergone more scrutiny than DES, which has been in use since the late 1970s. However, the use of DES has drawbacks and it is no longer considered secure, as the weakness of its 56-bit key makes it unreasonably easy to break. Because of the advances in computing power and speed since DES was developed, the small size of this algorithm's key renders it inadequate for operations requiring more than basic security for a relatively short period of time. For a few thousand dollars, you can link off-the-shelf computer systems so that they can crack DES keys in a few hours.

The 3-DES application of DES is intended to combat its degenerating resilience by running the encryption three times; it is projected to be secure for years to come. DES is probably sufficient for such tasks as sending email to a friend when you need it to be confidential or secure for only a few days (for example, to send a notice of a meeting that will take place in a few hours). It is unlikely that anyone is sufficiently interested in your email to invest the time and money to decrypt it. Because of 3-DES's wide availability and ease of use, it is advisable to use it instead of DES.

## ENCRYPTION IMPLEMENTATION

Most of today's commercial software packages use both public and symmetric key encryption algorithms, taking advantage of the strengths of each and avoiding their weaknesses. The public key algorithm is used first, as a means of negotiating a randomly generated secret key and providing for message authenticity. Then a secret key algorithm, such as 3-DES, IDEA, AES, or Blowfish, encrypts and decrypts the data on both ends for speed. Finally a hash algorithm, such as DSA (Digital Signature Algorithm), generates a message digest that provides a signature that can alert you to tampering. The digest is digitally signed with the sender's private key.

## GNUPG/PGP

The most popular personal encryption packages available today are GnuPG (GNU Privacy Guard, also called GPG; [www.gnupg.org](http://www.gnupg.org)) and PGP (Pretty Good Privacy; [www.pgp.com](http://www.pgp.com)). GNU Privacy Guard was designed as a free replacement for PGP, a security tool that made its debut during the early 1990s. Phil Zimmerman developed PGP as a Public Key Infrastructure (PKI), featuring a convenient interface, ease of use and management, and the security of digital certificates. One critical characteristic set PGP apart from the majority of cryptosystems then available: PGP functions entirely without certification authorities (CAs). Until the introduction of PGP, PKI implementations were built around the concept of CAs and centralized key management controls.

PGP and GnuPG rely on the notion of a ring of trust:<sup>2</sup> If you trust someone and that person trusts someone else, the person you trust can provide an introduction to the third party. When you trust someone, you perform an operation called *key signing*. By signing someone else's key, you verify that the person's public key is authentic and safe for you to use to send email. When you sign a key, you are asked whether you trust this person to introduce other keys to you. It is common practice to assign this trust based on several criteria, including your knowledge of a person's character or a lasting professional relationship with the person. The best practice is to sign someone's key only after you have met face to face to avert any chance of a man-in-the-middle<sup>3</sup> scenario. The disadvantage of this scheme is the lack of a central registry for associating with people you do not already know.

PGP is available without cost for personal use, but its deployment in a commercial environment requires the purchase of a license. This was not always the case: Soon after its introduction, PGP was available on many bulletin board systems, and users could implement it in any manner they chose. PGP rapidly gained popularity in the networking community, which capitalized on its encryption and key management capabilities for secure transmission of email.

After a time, attention turned to the two robust cryptographic algorithms, RSA and IDEA, which form an integral part of PGP's code. These algorithms are privately owned. The wide distribution of and growing user base for PGP sparked battles over patent violation and licenses, resulting in the eventual restriction of PGP's use.

Enter GnuPG, which supports most of the features and implementations made available by PGP and complies with the OpenPGP Message Format standard.

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2. For more information, see the section of *The GNU Privacy Handbook* ([www.gnupg.org/docs.html](http://www.gnupg.org/docs.html)) titled "Validating Other Keys on Your Public Keyring."

3. Man-in-the-middle: If Alex and Jenny try to carry on a secure email exchange over a network, Alex first sends Jenny his public key. However, suppose that Mr. X sits between Alex and Jenny on the network and intercepts Alex's public key. Mr. X then sends *his own* public key to Jenny. Jenny then sends her public key to Alex, but once again Mr. X intercepts it and substitutes *his own* public key and sends that to Alex. Without some kind of active protection (a piece of shared information), Mr. X, the *man-in-the-middle*, can decrypt all traffic between Alex and Jenny, reencrypt it, and send it on to the other party.

Because GnuPG does not use the patented IDEA algorithm but rather relies on BUGS ([www.gnu.org/directory/bugs.html](http://www.gnu.org/directory/bugs.html)), you can use it almost without restriction: It is released under the GNU GPL (refer to “The Code Is Free” on page 4). PGP and GnuPG are considered to be interchangeable and interoperable. The command sequences for and internal workings of these two tools are very similar.

### The GnuPG system includes the gpg program

**tip** GnuPG is frequently referred to as gpg, but gpg is actually the main program for the GnuPG system.

GNU offers a good introduction to privacy, *The GNU Privacy Handbook*, which is available in several languages and listed at [www.gnupg.org](http://www.gnupg.org) (click **Documentation⇒Guides**). Click **Documentation⇒HOWTOs** on the same Web page to view the *GNU Privacy Guard (GnuPG) Mini Howto*, which steps through the setup and use of gpg. And, of course, there is a gpg info page.

In addition to encryption, gpg is useful for authentication. For example, you can use it to verify that the person who signed a piece of email is the person who actually sent it.

## FILE SECURITY

From an end user’s perspective, file security is one of the most critical areas of security. Some file security is built into Linux: `chmod` (page 204) gives you basic security control. ACLs (Access Control Lists) allow for more fine-grained control of file access permissions. ACLs are part of Solaris, Windows NT/2000/XP, VAX/VMS, and mainframe operating systems. Fedora/RHEL supports ACLs (page 207). Even these tools are insufficient, however, when your account is compromised (for example, by someone watching your fingers on the keyboard as you type your password). To provide maximum file security, you must encrypt your files. Then even someone who knows your password cannot read your files. (Of course, if someone knows your key, that person can decrypt your files if he or she can get to them.)

## EMAIL SECURITY

Email security overlaps with file security and, as discussed later, with network security. GnuPG is the tool most frequently used for email security, although you can also use PGP. PEM (Privacy Enhanced Mail) is a standard rather than an algorithm and is used less frequently.

## MTAS (MAIL TRANSFER AGENTS)

An increasingly commonplace MTA is STARTTLS (Start Transport Layer Security; [www.sendmail.org/~ca/email/starttls.html](http://www.sendmail.org/~ca/email/starttls.html)). TLS itself usually refers to SSL (Secure

Sockets Layer) and has become the de facto method for encrypting TCP/IP traffic on the Internet. The **sendmail** daemon can be built to support STARTTLS, and much documentation exists on how to do so. STARTTLS enhancements also exist for **qmail** and **postfix** and other popular MTAs. It is important to recognize that this capability provides encryption between two mail servers but not necessarily between your machine and the mail server. Also, the advantages of using TLS are negated if the email must pass through a relay that does not support TLS.

## MUAs (MAIL USER AGENTS)

Many popular mail user agents, such as **mutt**, **elm**, and **emacs**, include the ability to use PGP or GnuPG for encryption. This approach has become the default way to exchange secure email.

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## NETWORK SECURITY

Network security is a vital component for ensuring the security of a computing site. However, without the right infrastructure, providing network security is difficult, if not impossible. For example, if you run a shared network topology,<sup>4</sup> such as Ethernet, and have in public locations jacks that allow anyone to plug in to the network at will, how can you prevent someone from plugging in a machine and capturing all the *packets* (page 1098) that traverse the network?<sup>5</sup> You cannot, so you have a potential security hole. Another common security hole relates to the use of **telnet** for logins. Because **telnet** sends and receives cleartext, anyone “listening in” on the line can easily capture usernames and passwords, compromising security.

Do not allow any unauthenticated PC (any PC that does not require users to supply a local name and password) on your network. With a Windows 9x PC, any user on the network is effectively Superuser for the following reasons:

- A PC does not recognize the concept of **root**. All users, by default, have access to and can watch the network, capture packets, and send packets.
- On UNIX/Linux, only Superuser can put the network interface in promiscuous mode and collect packets. On UNIX and Linux, ports numbered less than 1024<sup>6</sup> are privileged—that is, normal user protocols cannot bind to these ports. This is an important but regrettable means of security for some protocols, such as NIS, NFS, RSH, and LPD. Normally a data switch on your LAN automatically protects your machines from people snooping

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4. Shared network topology: A network in which each packet may be seen by machines other than its destination. “Shared” means that the 100 megabits per second bandwidth is shared by all users.

5. Do not make the mistake of assuming that you have security just because you have a switch. Switches are designed to allocate bandwidth, not to guarantee security.

6. The term *port* has many meanings. Here it is a number assigned to a program. The number links incoming data with a specific service. For example, port 21 is used by **ftp** traffic, and port 23 is used by **telnet**.

on your network for data. In high-load situations, switches have been known to behave unpredictably, directing packets to the wrong ports. Certain programs can overload the switch tables that hold information about which machine is on which port. When these tables are overloaded, the switch becomes a repeater and broadcasts all packets to all ports. The attacker on the same switch as you can potentially see all the traffic your system sends and receives.

## NETWORK SECURITY SOLUTIONS

One solution to shared-network problems is to encrypt messages that travel between machines. IPSec (Internet Protocol Security Protocol) provides just such a technology. IPSec is commonly used to establish a secure point-to-point virtual network (VPN, page 1114) that allows two hosts to communicate securely over an insecure channel, such as the Internet. This protocol provides integrity, confidentiality, authenticity, and flexibility of implementation that supports multiple vendors.

IPSec is an amalgamation of protocols (IPSec = AH + ESP + IPComp + IKE):

- **Authentication Header (AH)**—A cryptographically secure, irreversible *checksum* (page 1074) for an entire packet. AH guarantees that the packet is authentic.
- **Encapsulating Security Payload (ESP)**—Encrypts a packet to make the data unreadable.
- **IP Payload Compression (IPComp)**—Compresses a packet. Encryption can increase the size of a packet, and IPComp counteracts this increase in size.
- **Internet Key Exchange (IKE)**—Provides a way for the endpoints to negotiate a common key securely. For AH to work, both ends of the exchange must use the same key to prevent a “man-in-the-middle” (see footnote 3 on page 1048) from spoofing the connection.

While IPSec is an optional part of IPv4, IPv6 (page 373) mandates its use. However, it may be quite some time before IPv6 is widely implemented.

## NETWORK SECURITY GUIDELINES

Some general guidelines for establishing and maintaining a secure system follow. This list is not complete but meant rather only as a guide.

- **Fiberoptic cable is more secure than copper cable.** Copper is subject to both active and passive eavesdropping. With access to copper cable, all a data thief needs to monitor your network traffic is a passive device for measuring magnetic fields. In contrast, it is much more difficult to tap a fiberoptic cable without interrupting the signal. Sites requiring top security keep fiberoptic cable in pressurized conduits, where a change in pressure signals that the physical security of the cable has been breached.

- Avoid leaving unused ports available in public areas. If a malicious user can plug a laptop into the network without being detected, you are at risk of a serious security problem. Network drops that will remain unused for extended periods should be disabled at the switch, preventing them from accepting or passing network traffic.
- Many network switches have provisions for binding a hardware address to a port for enhanced security. If someone unplugs one machine and plugs in another machine to capture traffic, chances are that the second machine will have a different hardware address. When it detects a device with a different hardware address, the switch can disable the port. Even this solution is no guarantee, however, as there are programs that enable you to change or mask the hardware address of a network interface.

**Install a small kernel and run only the programs you need**

**security** Linux systems contain a huge number of programs that, although useful, significantly reduce the security of the host. Install the smallest operating system kernel that meets your needs. For Web and FTP servers, install only the needed components. Users usually require additional packages.

- Do not allow NFS or NIS access outside of your network. Otherwise, it is a simple matter for a malicious user to steal your entire password map. Default NFS security is marginal to nonexistent (a common joke is that NFS stands for No File Security) so such access should not be allowed outside your network to machines that you do not trust. Experimental versions of NFS for Linux that support much better authentication algorithms are now becoming available. Use IPSec, an experimental NFSv4 with improved authentication, or firewalls to provide access outside of your domain.
- Support for VPN configuration is often built into new firewalls or provided as a separate product, enabling your system to join securely with those of your customers or partners. If you must allow business partners, contractors, or other outside parties to access your files, consider using a secure filesystem, such as NFS with *Kerberos* (page 1090), secure NFS (encrypts authentication, not traffic), NFS over a VPN such as IPSec, or cfs (cryptographic filesystem).
- Specify `/usr` as readonly (`ro`) in `/etc/fstab`. Following is an example of such a configuration.

```
/dev/sda6      /usr      ext2      ro        0        0
```

This approach may make your machine difficult to update, so use this tactic with care.

- Mount filesystems other than `/` and `/usr` **nosuid** to prevent setuid programs from executing on this filesystem. For example,

```
/dev/sda4      /var      ext3      nosuid    0        0
/dev/sda5      /usr/local ext3      nosuid    0        0
```



- Use a barrier or firewall product between your network and the Internet. Several valuable mailing lists cover firewalls, including the **comp.security.firewalls** newsgroup and the free firewalls Web site, [www.freefire.org](http://www.freefire.org). Fedora/RHEL includes `iptables` (page 819), which allows you to implement a firewall.

## HOST SECURITY

Your host must be secure. Simple security steps include preventing remote logins and leaving the `/etc/hosts.equiv` and individual users' `~/.rhosts` files empty (or not having them at all). Complex security steps include installing IPSec for VPNs between hosts. Many common security measures fall somewhere in between these two extremes. A few of these follow. See Table C-1 on page 1058 for relevant URLs.

- Although potentially tricky to implement and manage, intrusion detection systems (IDSs) are an excellent way to keep an eye on the integrity of a device. An IDS can warn of possible attempts to subvert security on the host on which it runs. The great-granddaddy of intrusion detection systems is `tripwire`. This host-based system checks modification times and integrity of files by using strong algorithms (cryptographic checksums or signatures) that can detect even the most minor modifications. A commercial version of `tripwire` is also available. Another commercial IDS is `DragonSquire`. Other free, popular, and flexible IDSs include `samhain` and `AIDE`. The last two IDSs offer even more features and means of remaining invisible to users than `tripwire` does. Commercial IDSs that are popular in enterprise environments include Cisco Secure IDS (formerly `NetRanger`), Enterasys `Dragon`, and ISS `RealSecure`.
- Keep Fedora systems up-to-date by downloading and installing the latest updates. Use `yum` to update the system regularly (page 500) or set up the system to update itself every night automatically (page 504). Go to [fedora.redhat.com/download/updates.html](http://fedora.redhat.com/download/updates.html) for more information.
- Red Hat Network (RHN, page 516) can automatically or semiautomatically keep one or more systems up-to-date, preventing the system from becoming prey to fixed security bugs.
- Complementing host-based IDSs are network-based IDSs. The latter programs monitor the network and nodes on the network and report suspicious occurrences (attack signatures) via user-defined alerts. These signatures can be matched based on known worms, overflow attacks against programs, or unauthorized scans of network ports. Such programs as `snort`, `klaxon`, and `NFR` are used in this capacity. Commercial programs, such as `DragonSentry`, also fill this role.
- Provided with Fedora/RHEL is PAM, which allows you to set up different methods and levels of authentication in many ways (page 458).

- Process accounting—a good supplement to system security—can provide a continuous record of user actions on your system. See the `accton` man page for more information.
- Emerging standards for such things as Role Based Access Control (RBAC) allow tighter delegation of privileges along defined organizational boundaries. You can delegate a role or roles to each user as appropriate to the access required.
- General mailing lists and archives are extremely useful repositories of security information, statistics, and papers. The most useful are the bugtraq mailing list and CERT.<sup>7</sup> The bugtraq site and email service offer immediate notifications about specific vulnerabilities, whereas CERT provides notice of widespread vulnerabilities and useful techniques to fix them, as well as links to vendor patches.
- The `rsyslog` facility (provided with Fedora/RHEL) can direct messages from system daemons to specific files such as those in `/var/log`. On larger groups of systems, you can send all important `rsyslog` information to a secure host, where that host's only function is to store `rsyslog` data so that it cannot be tampered with. See page 390 and the `rsyslogd` man page for more information.

## LOGIN SECURITY

Without a secure host, good login security cannot add much protection. Table C-1 lists some of the best login security tools, including replacement daemons for `telnetd`, `rlogind`, and `rshd`. The current choice of most sites is `ssh`, which comes as both freeware and a commercially supported package that works on UNIX/Linux, Windows, and Macintosh platforms.

The PAM facility (page 458) allows you to set up multiple authentication methods for users in series or in parallel. In-series PAM requires multiple methods of authentication for a user. In-parallel PAM uses any one of a number of methods for authentication.

Although it is not the most popular choice, you can configure your system to take advantage of one-time passwords. S/Key is the original implementation of one-time passwords by Bellcore. OPIE (one-time passwords in everything), which was developed by the U.S. Naval Research Labs, is an improvement over the original Bellcore system. In one permutation of one-time passwords, the user gets a piece of paper listing a set of one-time passwords. Each time a user logs in, she enters a password from the piece of paper. Once used, a password becomes obsolete, and the next password in the list is the only one that will work. Even if a malicious user compromises the network and sees your password, the information will be of no use

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7. CERT is slow but useful as a medium for coordination between sites. It acts as a tracking agency to document the spread of security problems.

because the password can be used only once. This setup makes it very difficult for someone to log in as you but does nothing to protect the data you type at the keyboard. One-time passwords are a good solution if you are at a site where no encrypted login is available. A truly secure (or paranoid) site will combine one-time passwords and encrypted logins.

Another type of secure login that is becoming more common is facilitated by a token or a *smartcard*. Smartcards are credit-card-like devices that use a challenge–response method of authentication. Smartcard and token authentication rely on something you have (the card) and something you know (a pass phrase, user ID, or PIN). For example, you might enter your username in response to the login prompt and get a password prompt. You would then enter your PIN and the number displayed on the access token. The token has a unique serial number that is stored in a database on the authentication server. The token and the authentication server use this serial number as a means of computing a challenge every 30 to 60 seconds. If the PIN and token number you enter match what they should be as computed by the access server, you are granted access to the system.

## REMOTE ACCESS SECURITY

Issues and solutions surrounding remote access security overlap with those pertaining to login and host security. Local logins may be secure with simply a username and password, whereas remote logins (and all remote access) should be made more secure. Many breakins can be traced back to reusable passwords. It is a good idea to use an encrypted authentication client, such as `ssh` or `kerberos`. You can also use smartcards for remote access authentication.

Modem pools can also be an entry point into a system. Most people are aware of how easy it is to monitor a network line. However, they may take for granted the security of the public switched telephone network (PSTN, also known as POTS—plain old telephone service). You may want to set up an encrypted channel after dialing in to a modem pool. One way to do so is by running `ssh` over PPP.

There are ways to implement stringent modem authentication policies so that unauthorized users are not able to use your modems. The most common techniques are PAP (Password Authentication Protocol), CHAP (Challenge Handshake Authentication Protocol), and Radius. PAP and CHAP are relatively weak when compared with Radius, so the latter has rapidly gained in popularity. Cisco also provides a method of authentication called TACACS/TACACS+ (Terminal Access Controller Access Control System).

One or more of these authentication techniques are available in a RAS (remote access server)—in a network a computer that provides network access to remote users via modem). Before purchasing a RAS, check what kind of security it provides and decide whether that level of security meets your needs.

Two other techniques for remote access security can be built into a modem (or RAS if it has integrated modems). One is callback: After you dial in, you get a password

prompt. Once you type in your password, the modem hangs up and calls you back at a phone number it has stored internally. Unfortunately this technique is not fool-proof. Some modems have a built-in callback table that holds about ten entries, so this strategy works for small sites with only a few modems. If you use more modems, the RAS software must provide the callback.

The second technique is to use CLID (caller line ID) or ANI (automatic number identification) to decide whether to answer the call. Depending on your wiring and the local phone company, you may or may not be able to use ANI. ANI information is provided before the call, whereas CLID information is provided along with the call.

## VIRUSES AND WORMS

Examples of UNIX/Linux viruses include the Bliss virus/worm released in 1997 and the RST.b virus discovered in December 2001. Both are discussed in detail in articles on the Web. Viruses spread through systems by infecting executable files. In the cases of Bliss and RST.b, the Linux native executable format, ELF, was used as a propagation vector.

Just after 5 PM on November 2, 1988, Robert T. Morris, Jr., a graduate student at Cornell University, released the first big virus onto the Internet. Called an Internet worm, this virus was designed to propagate copies of itself over many machines on the Internet. The worm was a piece of code that exploited four vulnerabilities, including one in `finger`, to get a buffer to overflow on a system. Once the buffer overflowed, the code was able to get a shell and then recompile itself on the remote machine. The worm spread around the Internet very quickly and was not disabled, despite many people's efforts, for 36 hours.

The chief characteristic of any worm is propagation over a public network, such as the Internet. A virus propagates by infecting executables on the machine, whereas a worm tends to prefer exploiting known security holes in network servers to gain `root` access and then tries to infect other machines in the same way.

UNIX/Linux file permissions help to inoculate systems against many viruses. Windows NT is resistant for similar reasons. You can easily protect your system against many viruses and worms by keeping your system patches up-to-date, not executing untrusted binaries from the Internet, limiting your path to include only necessary system directories, and doing as little as possible while enabled with Superuser privileges. You can prevent a disaster in case a virus strikes by backing up your system frequently.

## PHYSICAL SECURITY

Often overlooked as a defense against intrusion, physical security covers access to the computer itself and to the console or terminal attached to the machine. If the machine is unprotected in an unlocked room, there is very little hope for physical security. (A simple example of physical vulnerability is someone walking into the room where the computer is, removing the hard drive from the computer, taking it

home, and analyzing it.) You can take certain steps to improve the physical security of your computer.

- Keep servers in a locked room with limited access. A key, a combination, or a swipe card should be required to gain access. Protect windows as well as doors. Maintain a single point of entry. (Safety codes may require multiple exits, but only one must be an entry.)
- For public machines, use a security system, such as a fiberoptic security system, that can secure a lab full of machines. With such a system, you run a fiberoptic cable through each machine such that the machine cannot be removed (or opened) without cutting the cable. When the cable is cut, an alarm goes off. Some machines—for example, PCs with plastic cases—are much more difficult to secure than others. Although it is not a perfect solution, a fiberoptic security system may improve local security enough to persuade a would-be thief to go somewhere else.
- Most modern PCs have a BIOS password. You can set the order in which a PC searches for a boot device, preventing the PC from being booted from a floppy disk or CD. Some BIOSs can prevent the machine from booting altogether without a proper password. The password protects the BIOS from unauthorized modification. Beware, however: Many BIOSs have well-known *back doors* (page 1070). Research this issue if the BIOS password is an important feature for you. In addition, you can blank the BIOS password by setting the clear-CMOS jumper on a PC motherboard; if you are relying on a BIOS password, lock the case.
- Run only fiberoptic cable between buildings. This strategy is not only more secure but also safer in the event of lightning strikes and is required by many commercial building codes.
- Maintain logs of who goes in and out of secure areas. Sign-in/out sheets are useful only if everyone uses them. Sometimes a guard is warranted. Often a simple proximity badge or smartcard can tell when anyone has entered or left an area and keep logs of these events, although these can be expensive to procure and install.
- Anyone who has access to the physical hardware has the keys to the palace. Someone with direct access to a computer system can do such things as swap components and insert boot media, all of which are security threats.
- Avoid having activated, unused network jacks in public places. Such jacks provide unnecessary risk.
- Many modern switches can lock a particular switch port so that it accepts only traffic from an NIC (network interface card) with a particular hardware address and shuts down the port if another address is seen. However, commonly available programs can enable someone to reset this address.

- Make periodic security sweeps. Check doors for proper locking. If you must have windows, make sure that they are locked or are permanently sealed.
- Waste receptacles are often a source of information for intruders. Have policies for containment and disposal of sensitive documents.
- Use a UPS (uninterruptable power supply). Without a clean source of power, your system is vulnerable to corruption.

# SECURITY RESOURCES

Many free and commercial programs can enhance system security. Some of these are listed in Table C-1. Many of these sites have links to other, interesting sites that are worth looking at.

**Table C-1** Security resources

Tool	What it does	Where to get it
AIDE	Advanced Intrusion Detection Environment. Similar to trip-wire with extensible verification algorithms.	<a href="http://sourceforge.net/projects/aide">sourceforge.net/projects/aide</a>
bugtraq	A moderated mailing list for the announcement and detailed discussion of all aspects of computer security vulnerabilities.	<a href="http://www.securityfocus.com/archive/1">www.securityfocus.com/archive/1</a>
CERT	Computer Emergency Response Team. A repository of papers and data about major security events and a list of security tools.	<a href="http://www.cert.org">www.cert.org</a>
chkrootkit	Checks for signs of a rootkit indicating that the machine has been compromised.	<a href="http://www.chkrootkit.org">www.chkrootkit.org</a>
dsniff	Sniffing and network audit tool suite. Free.	<a href="http://monkey.org/~dugsong/dsniff">monkey.org/~dugsong/dsniff</a>
ethereal	Network protocol analyzer. Free.	<a href="http://www.ethereal.com">www.ethereal.com</a>
freefire	Supplies free security solutions and supports developers of free security solutions.	<a href="http://www.freefire.org">www.freefire.org</a>

**Table C-1** Security resources (continued)

<b>Tool</b>	<b>What it does</b>	<b>Where to get it</b>
fwtk	Firewall toolkit. A set of proxies that can be used to construct a firewall.	<a href="http://www.fwtk.org">www.fwtk.org</a>
GIAC	A security certification and training Web site.	<a href="http://www.giac.org">www.giac.org</a>
hping	Multipurpose network auditing and packet analysis tool. Free.	<a href="http://www.hping.org">www.hping.org</a>
ISC <sup>2</sup>	Educates and certifies industry professionals and practitioners under an international standard.	<a href="http://www.isc2.org">www.isc2.org</a>
John	John the Ripper: a fast, flexible, weak password detector.	<a href="http://www.openwall.com/john">www.openwall.com/john</a>
Kerberos	Complete, secure network authentication system.	<a href="http://web.mit.edu/kerberos/www">web.mit.edu/kerberos/www</a>
LIDS	Intrusion detection and active defense system.	<a href="http://www.lids.org">www.lids.org</a>
LinuxSecurity.com	A solid news site dedicated to Linux security issues.	<a href="http://www.linuxsecurity.com">www.linuxsecurity.com</a>
LWN.net	Security alert database for all major Linux distributions.	<a href="http://lwn.net/Alerts">lwn.net/Alerts</a>
Microsoft Security	Microsoft security information.	<a href="http://www.microsoft.com/security">www.microsoft.com/security</a>
nessus	A plugin-based remote security scanner that can perform more than 370 security checks. Free.	<a href="http://www.nessus.org">www.nessus.org</a>
netcat	Explores, tests, and diagnoses networks.	<a href="http://freshmeat.net/projects/netcat">freshmeat.net/projects/netcat</a>
nmap	Scans hosts to see which ports are available. It can perform stealth scans, determine operating system type, find open ports, and more.	<a href="http://nmap.org">nmap.org</a>
RBAC	Role Based Access Control. Assigns roles and privileges associated with the roles.	<a href="http://csrc.nist.gov/groups/SNS/rbac">csrc.nist.gov/groups/SNS/rbac</a>

**Table C-1** Security resources (continued)

<b>Tool</b>	<b>What it does</b>	<b>Where to get it</b>
Red Hat Security	Red Hat security information.	<a href="http://www.redhat.com/security">www.redhat.com/security</a>
SAINT	Security Administrator's Integrated Network Tool. Assesses and analyzes network vulnerabilities. This tool follows <i>satan</i> .	<a href="http://www.saintcorporation.com">www.saintcorporation.com</a>
samhain	A file integrity checker. Has a GUI configurator, client/server capability, and real-time reporting capability.	<a href="http://www.la-samhna.de/samhain">www.la-samhna.de/samhain</a>
SANS	Security training and certification.	<a href="http://sans.org">sans.org</a>
SARA	The Security Auditor's Research Assistant security analysis tool.	<a href="http://www-arc.com/sara">www-arc.com/sara</a>
Schneier, Bruce	Security visionary.	<a href="http://www.schneier.com">www.schneier.com</a>
Secunia	Monitors a broad spectrum of vulnerabilities.	<a href="http://secunia.com">secunia.com</a>
SecurityFocus	Home for security tools, mail lists, libraries, and cogent analysis.	<a href="http://www.securityfocus.com">www.securityfocus.com</a>
snort	A flexible IDS.	<a href="http://www.snort.org">www.snort.org</a>
srp	Secure Remote Password. Upgrades common protocols, such as TELNET and FTP, to use secure password exchange.	<a href="http://srp.stanford.edu">srp.stanford.edu</a>
ssh	A secure rsh, ftp, and rlogin replacement with encrypted sessions and other options. Supplied with Fedora/RHEL.	<a href="http://www.ssh.org">www.ssh.org</a> <a href="http://openssh.org">openssh.org</a>
swatch	A Perl-based log parser and analyzer.	<a href="http://sourceforge.net/projects/swatch">sourceforge.net/projects/swatch</a>
Treachery	A collection of tools for security and auditing.	<a href="http://www.treachery.net/tools">www.treachery.net/tools</a>
tripwire	Checks for possible signs of intruder activity. Supplied with Fedora/RHEL.	<a href="http://www.tripwire.com">www.tripwire.com</a>



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## APPENDIX SUMMARY

Security is inversely proportional to usability. There must be a balance between your users' requirements to get their work done and the amount of security that is implemented. It is often unnecessary to provide top security for a small business with only a few employees. By contrast, if you work for a government military contractor, you are bound to have extreme security constraints and an official audit policy to determine whether your security policies are being implemented correctly.

Review your own security requirements periodically. Several of the tools mentioned in this appendix are designed to help you monitor your system's security measures. Such tools as *nessus*, *samhain*, and *SAINT* all provide auditing mechanisms.

Some companies specialize in security and auditing. Hiring one of them to examine your site can be costly but may yield specific recommendations for areas that you may have overlooked in your initial setup. When you hire someone to audit your security, recognize that you may be providing both physical and Superuser access to your systems. Make sure the company that you hire has a good history, has been in business for several years, and has impeccable references. Check up on the company periodically: Things change over time. Avoid the temptation to hire former system crackers as consultants. Security consultants should have an irreproachable ethical background, or you will always have doubts about their intentions.

Your total security package is based on your risk assessment of your vulnerabilities. Strengthen those areas that are most important for your business. For example, many sites rely on a firewall to protect them from the Internet, whereas internal hosts receive little or no security attention. Crackers refer to this setup as "the crunchy outside surrounding the soft chewy middle." Yet this is entirely sufficient to protect some sites. Perform your own risk assessment and address your needs accordingly. If need be, hire a full-time security administrator whose job it is to design and audit your security policies.

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# THE FREE SOFTWARE DEFINITION<sup>1</sup>

We maintain this free software definition to show clearly what must be true about a particular software program for it to be considered free software.

“Free software” is a matter of liberty, not price. To understand the concept, you should think of “free” as in “free speech,” not as in “free beer.”

Free software is a matter of the users’ freedom to run, copy, distribute, study, change and improve the software. More precisely, it refers to four kinds of freedom, for the users of the software:

- The freedom to run the program, for any purpose (freedom 0).

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1. This material is at [www.gnu.org/philosophy/free-sw.html](http://www.gnu.org/philosophy/free-sw.html) on the GNU Web site. Because GNU requests a verbatim copy, links remain in place (underlined). View the document on the Web to ensure you are reading the latest copy and to follow the links.

- The freedom to study how the program works, and adapt it to your needs (freedom 1). Access to the source code is a precondition for this.
- The freedom to redistribute copies so you can help your neighbor (freedom 2).
- The freedom to improve the program, and release your improvements to the public, so that the whole community benefits (freedom 3). Access to the source code is a precondition for this.

A program is free software if users have all of these freedoms. Thus, you should be free to redistribute copies, either with or without modifications, either gratis or charging a fee for distribution, to anyone anywhere. Being free to do these things means (among other things) that you do not have to ask or pay for permission.

You should also have the freedom to make modifications and use them privately in your own work or play, without even mentioning that they exist. If you do publish your changes, you should not be required to notify anyone in particular, or in any particular way.

The freedom to use a program means the freedom for any kind of person or organization to use it on any kind of computer system, for any kind of overall job, and without being required to communicate subsequently with the developer or any other specific entity.

The freedom to redistribute copies must include binary or executable forms of the program, as well as source code, for both modified and unmodified versions. (Distributing programs in runnable form is necessary for conveniently installable free operating systems.) It is ok if there is no way to produce a binary or executable form for a certain program (since some languages don't support that feature), but you must have the freedom to redistribute such forms should you find or develop a way to make them.

In order for the freedoms to make changes, and to publish improved versions, to be meaningful, you must have access to the source code of the program. Therefore, accessibility of source code is a necessary condition for free software.

One important way to modify a program is by merging in available free subroutines and modules. If the program's license says that you cannot merge in an existing module, such as if it requires you to be the copyright holder of any code you add, then the license is too restrictive to qualify as free.

In order for these freedoms to be real, they must be irrevocable as long as you do nothing wrong; if the developer of the software has the power to revoke the license, without your doing anything to give cause, the software is not free.

However, certain kinds of rules about the manner of distributing free software are acceptable, when they don't conflict with the central freedoms. For example, copy-left (very simply stated) is the rule that when redistributing the program, you cannot add restrictions to deny other people the central freedoms. This rule does not conflict with the central freedoms; rather it protects them.

You may have paid money to get copies of free software, or you may have obtained copies at no charge. But regardless of how you got your copies, you always have the freedom to copy and change the software, even to sell copies.

“Free software” does not mean “non-commercial”. A free program must be available for commercial use, commercial development, and commercial distribution. Commercial development of free software is no longer unusual; such free commercial software is very important.

Rules about how to package a modified version are acceptable, if they don’t substantively block your freedom to release modified versions, or your freedom to make and use modified versions privately. Rules that “if you make your version available in this way, you must make it available in that way also” can be acceptable too, on the same condition. (Note that such a rule still leaves you the choice of whether to publish your version at all.) Rules that require release of source code to the users for versions that you put into public use are also acceptable. It is also acceptable for the license to require that, if you have distributed a modified version and a previous developer asks for a copy of it, you must send one, or that you identify yourself on your modifications.

In the GNU project, we use “copyleft” to protect these freedoms legally for everyone. But non-copylefted free software also exists. We believe there are important reasons why it is better to use copyleft, but if your program is non-copylefted free software, we can still use it.

See Categories of Free Software for a description of how “free software,” “copylefted software” and other categories of software relate to each other.

Sometimes government export control regulations and trade sanctions can constrain your freedom to distribute copies of programs internationally. Software developers do not have the power to eliminate or override these restrictions, but what they can and must do is refuse to impose them as conditions of use of the program. In this way, the restrictions will not affect activities and people outside the jurisdictions of these governments.

Most free software licenses are based on copyright, and there are limits on what kinds of requirements can be imposed through copyright. If a copyright-based license respects freedom in the ways described above, it is unlikely to have some other sort of problem that we never anticipated (though this does happen occasionally). However, some free software licenses are based on contracts, and contracts can impose a much larger range of possible restrictions. That means there are many possible ways such a license could be unacceptably restrictive and non-free.

We can’t possibly list all the ways that might happen. If a contract-based license restricts the user in an unusual way that copyright-based licenses cannot, and which isn’t mentioned here as legitimate, we will have to think about it, and we will probably conclude it is non-free.

When talking about free software, it is best to avoid using terms like “give away” or “for free”, because those terms imply that the issue is about price, not freedom. Some common terms such as “piracy” embody opinions we hope you won’t endorse. See Confusing Words and Phrases that are Worth Avoiding for a discussion of these terms. We also have a list of translations of “free software” into various languages.

Finally, note that criteria such as those stated in this free software definition require careful thought for their interpretation. To decide whether a specific software license qualifies as a free software license, we judge it based on these criteria to determine whether it fits their spirit as well as the precise words. If a license includes unconscionable restrictions, we reject it, even if we did not anticipate the issue in these criteria. Sometimes a license requirement raises an issue that calls for extensive thought, including discussions with a lawyer, before we can decide if the requirement is acceptable. When we reach a conclusion about a new issue, we often update these criteria to make it easier to see why certain licenses do or don't qualify.

If you are interested in whether a specific license qualifies as a free software license, see our [list of licenses](#). If the license you are concerned with is not listed there, you can ask us about it by sending us email at [licensing@gnu.org](mailto:licensing@gnu.org).

If you are contemplating writing a new license, please contact the FSF by writing to that address. The proliferation of different free software licenses means increased work for users in understanding the licenses; we may be able to help you find an existing Free Software license that meets your needs.

If that isn't possible, if you really need a new license, with our help you can ensure that the license really is a Free Software license and avoid various practical problems.

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Another group has started using the term “open source” to mean something close (but not identical) to “free software”. We prefer the term “free software” because, once you have heard it refers to freedom rather than price, [it calls to mind freedom](#). The word “open” never does that.

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- Updated: \$Date: 2005/11/26 13:16:40 \$ \$Author: rms \$

# GLOSSARY

All entries marked with FOLDOC are based on definitions in the Free On-line Dictionary of Computing ([www.foldoc.org](http://www.foldoc.org)), Denis Howe, editor. Used with permission.

10.0.0.0	See <i>private address space</i> on page 1100.
172.16.0.0	See <i>private address space</i> on page 1100.
192.168.0.0	See <i>private address space</i> on page 1100.
802.11	A family of specifications developed by IEEE for wireless LAN technology, including 802.11 (1–2 megabits per second), 802.11a (54 megabits per second), 802.11b (11 megabits per second), and 802.11g (54 megabits per second).
<b>absolute pathname</b>	A pathname that starts with the root directory (represented by /). An absolute pathname locates a file without regard to the working directory.
<b>access</b>	In computer jargon, a verb meaning to use, read from, or write to. To access a file means to read from or write to the file.
<b>Access Control List</b>	See <i>ACL</i> .
<b>access permissions</b>	Permission to read from, write to, or execute a file. If you have write access permission to a file (usually just called <i>write permission</i> ), you can write to the file. Also <i>access privilege</i> .
<b>ACL</b>	Access Control List. A system that performs a function similar to file permissions but with much finer-grain control.
<b>active window</b>	On a desktop, the window that receives the characters you type on the keyboard. Same as <i>focus</i> , <i>desktop</i> (page 1083).
<b>address mask</b>	See <i>subnet mask</i> on page 1109.
<b>alias</b>	A mechanism of a shell that enables you to define new commands.
<b>alphanumeric character</b>	One of the characters, either uppercase or lowercase, from A to Z and 0 to 9, inclusive.
<b>ambiguous file reference</b>	A reference to a file that does not necessarily specify any one file but can be used to specify a group of files. The shell expands an ambiguous file reference into a list of filenames. Special characters represent single characters (?), strings of zero or more characters (*), and character classes ([ ]) within ambiguous file references. An ambiguous file reference is a type of <i>regular expression</i> (page 1103).
<b>angle bracket</b>	A left angle bracket (<) and a right angle bracket (>). The shell uses < to redirect a command's standard input to come from a file and > to redirect the standard output. The shell uses the characters << to signify the start of a Here document and >> to append output to a file.
<b>animate</b>	When referring to a window action, means that the action is slowed down so the user can view it. For example, when you minimize a window, it can disappear all at once (not animated) or it can slowly telescope into the panel so you can get a visual feel for what is happening (animated).



- anti-aliasing** Adding gray pixels at the edge of a diagonal line to get rid of the jagged appearance and thereby make the line look smoother. Anti-aliasing sometimes makes type on a screen look better and sometimes worse; it works best on small and large fonts and is less effective on fonts from 8 to 15 points. See also *subpixel hinting* (page 1109).
- API** Application program interface. The interface (calling conventions) by which an application program accesses an operating system and other services. An API is defined at the source code level and provides a level of abstraction between the application and the kernel (or other privileged utilities) to ensure the portability of the code.<sup>FOLDOC</sup>
- append** To add something to the end of something else. To append text to a file means to add the text to the end of the file. The shell uses `>>` to append a command's output to a file.
- applet** A small program that runs within a larger program. Examples are Java applets that run in a browser and panel applets that run from a desktop panel.
- archive** A file that contains a group of smaller, typically related, files. Also, to create such a file. The tar and cpio utilities can create and read archives.
- argument** A number, letter, filename, or another string that gives some information to a command and is passed to the command when it is called. A command-line argument is anything on a command line following the command name that is passed to the command. An option is a kind of argument.
- arithmetic expression** A group of numbers, operators, and parentheses that can be evaluated. When you evaluate an arithmetic expression, you end up with a number. The Bourne Again Shell uses the `expr` command to evaluate arithmetic expressions; the TC Shell uses `@`, and the Z Shell uses `let`.
- array** An arrangement of elements (numbers or strings of characters) in one or more dimensions. The Bourne Again, TC, and Z Shells and `awk/mawk/gawk` can store and process arrays.
- ASCII** American Standard Code for Information Interchange. A code that uses seven bits to represent both graphic (letters, numbers, and punctuation) and `CONTROL` characters. You can represent textual information, including program source code and English text, in ASCII code. Because ASCII is a standard, it is frequently used when exchanging information between computers. See the file `/usr/pub/ascii` or give the command `man ascii` to see a list of ASCII codes.
- Extensions of the ASCII character set use eight bits. The seven-bit set is common; the eight-bit extensions are still coming into popular use. The eighth bit is sometimes referred to as the metabit.
- ASCII terminal** A textual terminal. Contrast with *graphical display* (page 1084).
- ASP** Application service provider. A company that provides applications over the Internet.

- asynchronous event** An event that does not occur regularly or synchronously with another event. Linux system signals are asynchronous; they can occur at any time because they can be initiated by any number of nonregular events.
- attachment** A file that is attached to, but is not part of, a piece of email. Attachments are frequently opened by programs (including your Internet browser) that are called by your mail program so you may not be aware that they are not an integral part of an email message.
- authentication** The verification of the identity of a person or process. In a communication system, authentication verifies that a message comes from its stated source. Methods of authentication on a Linux system include the `/etc/passwd` and `/etc/shadow` files, LDAP, Kerberos 5, and SMB authentication.<sup>FOLDOC</sup>
- automatic mounting** A way of demand mounting directories from remote hosts without having them hard configured into `/etc/fstab`. Also called *automounting*.
- avoided** An object, such as a panel, that should not normally be covered by another object, such as a window.
- back door** A security hole deliberately left in place by the designers or maintainers of a system. The motivation for creating such holes is not always sinister; some operating systems, for example, come out of the box with privileged accounts intended for use by field service technicians or the vendor's maintenance programmers.
- Ken Thompson's 1983 Turing Award lecture to the ACM revealed the existence, in early UNIX versions, of a back door that may be the most fiendishly clever security hack of all time. The C compiler contained code that would recognize when the **login** command was being recompiled and would insert some code recognizing a password chosen by Thompson, giving him entry to the system whether or not an account had been created for him.
- Normally such a back door could be removed by removing it from the source code for the compiler and recompiling the compiler. But to recompile the compiler, you have to *use* the compiler, so Thompson arranged that the compiler would *recognize when it was compiling a version of itself*. It would insert into the recompiled compiler the code to insert into the recompiled **login** the code to allow Thompson entry, and, of course, the code to recognize itself and do the whole thing again the next time around. Having done this once, he was then able to recompile the compiler from the original sources; the hack perpetuated itself invisibly, leaving the back door in place and active but with no trace in the sources.
- Sometimes called a wormhole. Also *trap door*.<sup>FOLDOC</sup>
- background process** A process that is not run in the foreground. Also called a *detached process*, a background process is initiated by a command line that ends with an ampersand (&). You do not have to wait for a background process to run to completion before giving the shell additional commands. If you have job control, you can move background processes to the foreground, and vice versa.

<b>basename</b>	The name of a file that, in contrast with a <i>pathname</i> , does not mention any of the directories containing the file (and therefore does not contain any slashes [/]). For example, <b>hosts</b> is the <i>basename</i> of <i>/etc/hosts</i> . <sup>FOLDOC</sup>
<b>baud</b>	The maximum information-carrying capacity of a communication channel in symbols (state transitions or level transitions) per second. It coincides with bits per second only for two-level modulation with no framing or stop bits. A symbol is a unique state of the communication channel, distinguishable by the receiver from all other possible states. For example, it may be one of two voltage levels on a wire for a direct digital connection, or it might be the phase or frequency of a carrier. <sup>FOLDOC</sup>  Baud is often mistakenly used as a synonym for bits per second.
<b>baud rate</b>	Transmission speed. Usually used to measure terminal or modem speed. Common baud rates range from 110 to 38,400 baud. See <i>baud</i> .
<b>Berkeley UNIX</b>	One of the two major versions of the UNIX operating system. Berkeley UNIX was developed at the University of California at Berkeley by the Computer Systems Research Group and is often referred to as <i>BSD</i> (Berkeley Software Distribution).
<b>BIND</b>	Berkeley Internet Name Domain. An implementation of a <i>DNS</i> (page 1079) server developed and distributed by the University of California at Berkeley.
<b>BIOS</b>	Basic Input/Output System. On PCs, <i>EEPROM</i> -based (page 1081) system software that provides the lowest-level interface to peripheral devices and controls the first stage of the <i>bootstrap</i> (page 1072) process, which loads the operating system. The BIOS can be stored in different types of memory. The memory must be nonvolatile so that it remembers the system settings even when the system is turned off. Also BIOS ROM.
<b>bit</b>	The smallest piece of information a computer can handle. A <i>bit</i> is a binary digit: either 1 or 0 ( <i>on</i> or <i>off</i> ).
<b>bit depth</b>	Same as <i>color depth</i> (page 1075).
<b>bit-mapped display</b>	A graphical display device in which each pixel on the screen is controlled by an underlying representation of zeros and ones.
<b>blank character</b>	Either a <i>SPACE</i> or a <i>TAB</i> character, also called <i>whitespace</i> (page 1115). In some contexts, <i>NEWLINES</i> are considered blank characters.
<b>block</b>	A section of a disk or tape (usually 1,024 bytes long but shorter or longer on some systems) that is written at one time.
<b>block device</b>	A disk or tape drive. A block device stores information in blocks of characters. A block device is represented by a block device (block special) file. Contrast with <i>character device</i> (page 1074).
<b>block number</b>	Disk and tape <i>blocks</i> are numbered so that Linux can keep track of the data on the device.

<b>blocking factor</b>	The number of logical blocks that make up a physical block on a tape or disk. When you write 1K logical blocks to a tape with a physical block size of 30K, the blocking factor is 30.
<b>Boolean</b>	The type of an expression with two possible values: <i>true</i> and <i>false</i> . Also, a variable of Boolean type or a function with Boolean arguments or result. The most common Boolean functions are AND, OR, and NOT. <sup>FOLDOC</sup>
<b>boot</b>	See <i>bootstrap</i> .
<b>boot loader</b>	A very small program that takes its place in the <i>bootstrap</i> process that brings a computer from off or reset to a fully functional state. See
<b>bootstrap</b>	Derived from “Pull oneself up by one’s own bootstraps,” the incremental process of loading an operating system kernel into memory and starting it running without any outside assistance. Frequently shortened to <i>boot</i> .
<b>Bourne Again Shell</b>	<b>bash</b> . GNU’s command interpreter for UNIX, <b>bash</b> is a POSIX-compliant shell with full Bourne Shell syntax and some C Shell commands built in. The Bourne Again Shell supports <b>emacs</b> -style command-line editing, job control, functions, and online help. <sup>FOLDOC</sup>
<b>Bourne Shell</b>	<b>sh</b> . This UNIX command processor was developed by Steve Bourne at AT&T Bell Laboratories.
<b>brace</b>	A left brace ( { ) and a right brace ( } ). Braces have special meanings to the shell.
<b>bracket</b>	A <i>square bracket</i> (page 1108) or an <i>angle bracket</i> (page 1068).
<b>branch</b>	In a tree structure, a branch connects nodes, leaves, and the root. The Linux file-system hierarchy is often conceptualized as an upside-down tree. The branches connect files and directories. In a source code control system, such as SCCS or RCS, a branch occurs when a revision is made to a file and is not included in subsequent revisions to the file.
<b>bridge</b>	Typically a two-port device originally used for extending networks at layer 2 (data link) of the Internet Protocol model.
<b>broadcast</b>	A transmission to multiple, unspecified recipients. On Ethernet a broadcast packet is a special type of multicast packet that has a special address indicating that all devices that receive it should process it. Broadcast traffic exists at several layers of the network stack, including Ethernet and IP. Broadcast traffic has one source but indeterminate destinations (all hosts on the local network).
<b>broadcast address</b>	The last address on a subnet (usually 255), reserved as shorthand to mean all hosts.
<b>broadcast network</b>	A type of network, such as Ethernet, in which any system can transmit information at any time, and all systems receive every message.
<b>BSD</b>	See <i>Berkeley UNIX</i> on page 1071.

<b>buffer</b>	An area of memory that stores data until it can be used. When you write information to a file on a disk, Linux stores the information in a disk buffer until there is enough to write to the disk or until the disk is ready to receive the information.
<b>bug</b>	An unwanted and unintended program property, especially one that causes the program to malfunction. <sup>FOLDOC</sup>
<b>builtin (command)</b>	A command that is built into a shell. Each of the three major shells—the Bourne Again, TC, and Z Shells—has its own set of builtins.
<b>byte</b>	A component in the machine data hierarchy, usually larger than a bit and smaller than a word; now most often eight bits and the smallest addressable unit of storage. A byte typically holds one character. <sup>FOLDOC</sup>
<b>C programming language</b>	A modern systems language that has high-level features for efficient, modular programming as well as lower-level features that make it suitable for use as a systems programming language. It is machine independent so that carefully written C programs can be easily transported to run on different machines. Most of the Linux operating system is written in C, and Linux provides an ideal environment for programming in C.
<b>C Shell</b>	<code>csh</code> . The C Shell command processor was developed by Bill Joy for BSD UNIX. It was named for the C programming language because its programming constructs are similar to those of C. See <i>shell</i> on page 1105.
<b>cable modem</b>	A type of modem that allows you to access the Internet by using your cable television connection.
<b>cache</b>	Holding recently accessed data, a small, fast memory designed to speed up subsequent access to the same data. Most often applied to processor-memory access but also used for a local copy of data accessible over a network, from a hard disk, and so on. <sup>FOLDOC</sup>
<b>calling environment</b>	A list of variables and their values that is made available to a called program. Refer to “Executing a Command” on page 316.
<b>cascading stylesheet</b>	See <i>CSS</i> on page 1077.
<b>cascading windows</b>	An arrangement of windows such that they overlap, generally with at least part of the title bar visible. Opposite of <i>tiled windows</i> (page 1111).
<b>case sensitive</b>	Able to distinguish between uppercase and lowercase characters. Unless you set the <code>ignorecase</code> parameter, <code>vim</code> performs case-sensitive searches. The <code>grep</code> utility performs case-sensitive searches unless you use the <code>-i</code> option.
<b>catenate</b>	To join sequentially, or end to end. The Linux <code>cat</code> utility catenates files: It displays them one after the other. Also <i>concatenate</i> .

- chain loading** The technique used by a boot loader to load unsupported operating systems. Used for loading such operating systems as DOS or Windows, it works by loading another boot loader.
- character-based** A program, utility, or interface that works only with *ASCII* (page 1069) characters. This set of characters includes some simple graphics, such as lines and corners, and can display colored characters. It cannot display true graphics. Contrast with *GUI* (page 1084).
- character-based terminal** A terminal that displays only characters and very limited graphics. See *character-based*.
- character class** In a regular expression, a group of characters that defines which characters can occupy a single character position. A character-class definition is usually surrounded by square brackets. The character class defined by `[abcr]` represents a character position that can be occupied by `a`, `b`, `c`, or `r`. Also *list operator*.
- In POSIX, used to refer to sets of characters with a common characteristic, denoted by the notation `[:class:];` for example, `[:upper:]` denotes the set of uppercase letters.
- This book uses the term character class as explained under “Brackets” on page 1025.
- character device** A terminal, printer, or modem. A character device stores or displays characters one at a time. A character device is represented by a character device (character special) file. Contrast with *block device* (page 1071).
- check box** A GUI widget, usually the outline of a square box with an adjacent caption, that a user can click to display or remove a *tick* (page 1111). When the box holds a tick, the option described by the caption is on or true. Also *tick box*.
- checksum** A computed value that depends on the contents of a block of data and is transmitted or stored along with the data to detect corruption of the data. The receiving system recomputes the checksum based on the received data and compares this value with the one sent with the data. If the two values are the same, the receiver has some confidence that the data was received correctly.
- The checksum may be 8, 16, or 32 bits, or some other size. It is computed by summing the bytes or words of the data block, ignoring overflow. The checksum may be negated so that the total of the data words plus the checksum is zero.
- Internet packets use a 32-bit checksum.<sup>FOLDOC</sup>
- child process** A process that is created by another process, the parent process. Every process is a child process except for the first process, which is started when Linux begins execution. When you run a command from the shell, the shell spawns a child process to run the command. See *process* on page 1100.
- CIDR** Classless Inter-Domain Routing. A scheme that allocates blocks of Internet addresses in a way that allows summarization into a smaller number of routing table entries. A CIDR block is a block of Internet addresses assigned to an ISP by the Internic. Refer to “CIDR: Classless Inter-Domain Routing” on page 371.<sup>FOLDOC</sup>

<b>CIFS</b>	Common Internet File System. An Internet filesystem protocol based on <i>SMB</i> (page 1106). CIFS runs on top of TCP/IP, uses DNS, and is optimized to support slower dial-up Internet connections. SMB and CIFS are used interchangeably. <sup>FOLDOC</sup>
<b>CIPE</b>	Crypto IP <i>Encapsulation</i> (page 1081). This <i>protocol</i> (page 1100) <i>tunnels</i> (page 1112) IP packets within encrypted <i>UDP</i> (page 1112) packets, is lightweight and simple, and works over dynamic addresses, <i>NAT</i> (page 1095), and <i>SOCKS</i> (page 1107) <i>proxies</i> (page 1101).
<b>cipher (cypher)</b>	A cryptographic system that uses a key to transpose/substitute characters within a message, the key itself, or the message.
<b>ciphertext</b>	Text that is encrypted. Contrast with <i>plaintext</i> (page 1099). See also “Encryption” on page 1044.
<b>Classless Inter-Domain Routing</b>	See <i>CIDR</i> on page 1074.
<b>cleartext</b>	Text that is not encrypted. Also <i>plaintext</i> . Contrast with <i>ciphertext</i> .
<b>CLI</b>	Command-line interface. See also <i>character-based</i> (page 1074). Also <i>textual interface</i> .
<b>client</b>	A computer or program that requests one or more services from a server.
<b>CODEC</b>	Coder/decoder or compressor/decompressor. A hardware and/or software technology that codes and decodes data. MPEG is a popular CODEC for computer video.
<b>color depth</b>	The number of bits used to generate a pixel—usually 8, 16, 24, or 32. The color depth is directly related to the number of colors that can be generated. The number of colors that can be generated is 2 raised to the color-depth power. Thus a 24-bit video adapter can generate about 16.7 million colors.
<b>color quality</b>	See <i>color depth</i> .
<b>combo box</b>	A combination of a <i>drop-down list</i> (page 1080) and <i>text box</i> (page 1110). You can enter text in a combo box. Or, you can click a combo box, cause it to expand and display a static list of selections for you to choose from.
<b>command</b>	What you give the shell in response to a prompt. When you give the shell a command, it executes a utility, another program, a builtin command, or a shell script. Utilities are often referred to as commands. When you are using an interactive utility, such as <i>vim</i> or <i>mail</i> , you use commands that are appropriate to that utility.
<b>command line</b>	A line containing instructions and arguments that executes a command. This term usually refers to a line that you enter in response to a shell prompt on a character-based terminal or terminal emulator.
<b>command substitution</b>	Replacing a command with its output. The shells perform command substitution when you enclose a command between \$( and ) or between a pair of back ticks (` `), also called grave accent marks.

- component architecture** A notion in object-oriented programming where “components” of a program are completely generic. Instead of having a specialized set of methods and fields, they have generic methods through which the component can advertise the functionality it supports to the system into which it is loaded. This strategy enables completely dynamic loading of objects. JavaBeans is an example of a component architecture.<sup>FOLDOC</sup>
- concatenate** See *catenate* on page 1073.
- condition code** See *exit status* on page 1081.
- connection-oriented protocol** A type of transport layer data communication service that allows a host to send data in a continuous stream to another host. The transport service guarantees that all data will be delivered to the other end in the same order as sent and without duplication. Communication proceeds through three well-defined phases: connection establishment, data transfer, and connection release. The most common example is *TCP* (page 1110).  
  
Also called connection-based protocol and stream-oriented protocol. Contrast with *connectionless protocol* and *datagram* (page 1078).<sup>FOLDOC</sup>
- connectionless protocol** The data communication method in which communication occurs between hosts with no previous setup. Packets sent between two hosts may take different routes. There is no guarantee that packets will arrive as transmitted or even that they will arrive at the destination at all. *UDP* (page 1112) is a connectionless protocol. Also called packet switching. Contrast with circuit switching and *connection-oriented protocol*.<sup>FOLDOC</sup>
- console** The main system terminal, usually directly connected to the computer and the one that receives system error messages. Also *system console* and *console terminal*.
- console terminal** See *console*.
- control character** A character that is not a graphic character, such as a letter, number, or punctuation mark. Such characters are called control characters because they frequently act to control a peripheral device. *RETURN* and *FORMFEED* are control characters that control a terminal or printer.  
  
The word *CONTROL* is shown in this book in THIS FONT because it is a key that appears on most terminal keyboards. Control characters are represented by ASCII codes less than 32 (decimal). See also *nonprinting character* on page 1097.
- control structure** A statement used to change the order of execution of commands in a shell script or other program. Each shell provides control structures (for example, *if* and *while*) as well as other commands that alter the order of execution (for example, *exec*). Also *control flow commands*.
- cookie** Data stored on a client system by a server. The client system browser sends the cookie back to the server each time it accesses that server. For example, a catalog shopping service may store a cookie on your system when you place your first



order. When you return to the site, it knows who you are and can supply your name and address for subsequent orders. You may consider cookies to be an invasion of privacy.

<b>CPU</b>	Central processing unit. The part of a computer that controls all the other parts. The CPU includes the control unit and the arithmetic and logic unit (ALU). The control unit fetches instructions from memory and decodes them to produce signals that control the other parts of the computer. These signals can cause data to be transferred between memory and ALU or peripherals to perform input or output. A CPU that is housed on a single chip is called a microprocessor. Also <i>processor</i> and <i>central processor</i> .
<b>cracker</b>	An individual who attempts to gain unauthorized access to a computer system. These individuals are often malicious and have many means at their disposal for breaking into a system. Contrast with <i>hacker</i> (page 1084). <sup>FOLDOC</sup>
<b>crash</b>	The system suddenly and unexpectedly stops or fails. Derived from the action of the hard disk heads on the surface of the disk when the air gap between the two collapses.
<b>cryptography</b>	<p>The practice and study of encryption and decryption—encoding data so that only a specific individual or machine can decode it. A system for encrypting and decrypting data is a cryptosystem. Such systems usually rely on an algorithm for combining the original data (plaintext) with one or more keys—numbers or strings of characters known only to the sender and/or recipient. The resulting output is called <i>ciphertext</i> (page 1075).</p> <p>The security of a cryptosystem usually depends on the secrecy of keys rather than on the supposed secrecy of an algorithm. Because a strong cryptosystem has a large range of keys, it is not possible to try all of them. Ciphertext appears random to standard statistical tests and resists known methods for breaking codes.<sup>FOLDOC</sup></p>
<b>.cshrc file</b>	In your home directory, a file that the TC Shell executes each time you invoke a new TC Shell. You can use this file to establish variables and aliases.
<b>CSS</b>	Cascading stylesheet. Describes how documents are presented on screen and in print. Attaching a stylesheet to a structured document can affect the way it looks without adding new HTML (or other) tags and without giving up device independence. Also <i>stylesheet</i> .
<b>current (process, line, character, directory, event, etc.)</b>	The item that is immediately available, working, or being used. The current process is the program you are running, the current line or character is the one the cursor is on, and the current directory is the working directory.
<b>cursor</b>	A small lighted rectangle, underscore, or vertical bar that appears on a terminal screen and indicates where the next character will appear. Differs from the <i>mouse pointer</i> (page 1094).

<b>daemon</b>	A program that is not invoked explicitly but lies dormant, waiting for some condition(s) to occur. The perpetrator of the condition need not be aware that a daemon is lurking (although often a program will commit an action only because it knows that it will implicitly invoke a daemon). From the mythological meaning, later rationalized as the acronym Disk And Execution MONitor. <sup>FOLDOC</sup>
<b>data structure</b>	A particular format for storing, organizing, working with, and retrieving data. Frequently, data structures are designed to work with specific algorithms that facilitate these tasks. Common data structures include trees, files, records, tables, arrays, etc.
<b>datagram</b>	A self-contained, independent entity of data carrying sufficient information to be routed from the source to the destination computer without reliance on earlier exchanges between this source and destination computer and the transporting network. <i>UDP</i> (page 1112) uses datagrams; <i>IP</i> (page 1088) uses <i>packets</i> (page 1098). Packets are indivisible at the network layer; datagrams are not. <sup>FOLDOC</sup> See also <i>frame</i> (page 1083).
<b>dataless</b>	A computer, usually a workstation, that uses a local disk to boot a copy of the operating system and access system files but does not use a local disk to store user files.
<b>dbm</b>	A standard, simple database manager. Implemented as <b>gdbm</b> (GNU database manager), it uses hashes to speed searching. The most common versions of the <b>dbm</b> database are <b>dbm</b> , <b>ndbm</b> , and <b>gdbm</b> .
<b>DDoS attack</b>	Distributed denial of service attack. A <i>DoS attack</i> (page 1080) from many systems that do not belong to the perpetrator of the attack.
<b>debug</b>	To correct a program by removing its bugs (that is, errors).
<b>default</b>	Something that is selected without being explicitly specified. For example, when used without an argument, <b>ls</b> displays a list of the files in the working directory by default.
<b>delta</b>	A set of changes made to a file that has been encoded by the Source Code Control System (SCCS).
<b>denial of service</b>	See <i>DoS attack</i> on page 1080.
<b>dereference</b>	When speaking of symbolic links, follow the link rather than working with the reference to the link. For example, the <b>-L</b> or <b>--dereference</b> option causes <b>ls</b> to list the entry that a symbolic link points to rather than the symbolic link (the reference) itself.
<b>desktop</b>	A collection of windows, toolbars, icons, and buttons, some or all of which appear on your display. A desktop comprises one or more <i>workspaces</i> (page 1116).
<b>desktop manager</b>	An icon- and menu-based user interface to system services that allows you to run applications and use the filesystem without using the system's command-line interface.

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<b>detached process</b>	See <i>background process</i> on page 1070.
<b>device</b>	A disk drive, printer, terminal, plotter, or other input/output unit that can be attached to the computer. Short for <i>peripheral device</i> .
<b>device driver</b>	Part of the Linux kernel that controls a device, such as a terminal, disk drive, or printer.
<b>device file</b>	A file that represents a device. Also <i>special file</i> .
<b>device filename</b>	The pathname of a device file. All Linux systems have two kinds of device files: block and character device files. Linux also has FIFOs (named pipes) and sockets. Device files are traditionally located in the <i>/dev</i> directory.
<b>device number</b>	See <i>major device number</i> (page 1092) and <i>minor device number</i> (page 1094).
<b>DHCP</b>	Dynamic Host Configuration Protocol. A protocol that dynamically allocates IP addresses to computers on a LAN. <sup>FOLDOC</sup>
<b>dialog box</b>	In a GUI, a special window, usually without a titlebar, that displays information. Some dialog boxes accept a response from the user
<b>directory</b>	Short for <i>directory file</i> . A file that contains a list of other files.
<b>directory hierarchy</b>	A directory, called the root of the directory hierarchy, and all the directory and ordinary files below it (its children).
<b>directory service</b>	A structured repository of information on people and resources within an organization, facilitating management and communication. <sup>FOLDOC</sup>
<b>disk partition</b>	See <i>partition</i> on page 1098.
<b>diskless</b>	A computer, usually a workstation, that has no disk and must contact another computer (a server) to boot a copy of the operating system and access the necessary system files.
<b>distributed computing</b>	A style of computing in which tasks or services are performed by a network of cooperating systems, some of which may be specialized.
<b>DMZ</b>	Demilitarized zone. A host or small network that is a neutral zone between a LAN and the Internet. It can serve Web pages and other data to the Internet and allow local systems access to the Internet while preventing LAN access to unauthorized Internet users. Even if a DMZ is compromised, it holds no data that is private and none that cannot be easily reproduced.
<b>DNS</b>	Domain Name Service. A distributed service that manages the correspondence of full hostnames (those that include a domain name) to IP addresses and other system characteristics.
<b>DNS domain name</b>	See <i>domain name</i> .

document object model	See <i>DOM</i> .
DOM	Document Object Model. A platform-/language-independent interface that enables a program to update the content, structure, and style of a document dynamically. The changes can then be made part of the displayed document. Go to <a href="http://www.w3.org/DOM">www.w3.org/DOM</a> for more information.
domain name	A name associated with an organization, or part of an organization, to help identify systems uniquely. Technically, the part of the <i>FQDN</i> (page 1083) to the right of the leftmost period. Domain names are assigned hierarchically. The domain <i>berkeley.edu</i> refers to the University of California at Berkeley, for example; it is part of the top-level <i>edu</i> (education) domain. Also DNS domain name. Different than <i>NIS domain name</i> (page 1096).
Domain Name Service	See <i>DNS</i> .
door	An evolving filesystem-based <i>RPC</i> (page 1104) mechanism.
DoS attack	Denial of service attack. An attack that attempts to make the target host or network unusable by flooding it with spurious traffic.
DPMS	Display Power Management Signaling. A standard that can extend the life of CRT monitors and conserve energy. DPMS supports four modes for a monitor: Normal, Standby (power supply on, monitor ready to come to display images almost instantly), Suspend (power supply off, monitor takes up to ten seconds to display an image), and Off.
drag	The motion part of <i>drag-and-drop</i> .
drag-and-drop	To move an object from one position or application to another within a GUI. To drag an object, the user clicks a mouse button (typically the left one) while the mouse pointer <i>hovers</i> (page 1086) over the object. Then, without releasing the mouse button, the user drags the object, which stays attached to the mouse pointer, to a different location. The user can then drop the object at the new location by releasing the mouse button.
drop-down list	A <i>widget</i> (page 1115) that displays a static list for a user to choose from. When the list is not active, it appears as text in a box, displaying the single selected entry. When a user clicks the box, a list appears; the user can move the mouse cursor to select an entry from the list. Different from a <i>list box</i> (page 1091).
druid	In role-playing games, a character that represents a magical user. Red Hat uses the term <i>druid</i> at the ends of names of programs that guide you through a task-driven chain of steps. Other operating systems call these types of programs <i>wizards</i> .
DSA	Digital Signature Algorithm. A public key cipher used to generate digital signatures.

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DSL	Digital Subscriber Line/Loop. Provides high-speed digital communication over a specialized, conditioned telephone line. See also <i>xDSL</i> (page 1116).
Dynamic Host Configuration Protocol	See <i>DHCP</i> on page 1079.
editor	A utility, such as <i>vim</i> or <i>emacs</i> , that creates and modifies text files.
EEPROM	Electrically erasable, programmable, readonly memory. A <i>PROM</i> (page 1100) that can be written to.
effective user ID	The user ID that a process appears to have; usually the same as the user ID. For example, while you are running a <i>setuid</i> program, the effective user ID of the process running the program is that of the owner of the program.
element	One thing; usually a basic part of a group of things. An element of a numeric array is one of the numbers stored in the array.
emoticon	See <i>smiley</i> on page 1106.
encapsulation	See <i>tunneling</i> on page 1112.
environment	See <i>calling environment</i> on page 1073.
EOF	End of file.
EPROM	Erasable programmable readonly memory. A <i>PROM</i> (page 1100) that can be written to by applying a higher than normal voltage.
escape	See <i>quote</i> on page 1101.
Ethernet	A type of <i>LAN</i> (page 1090) capable of transfer rates as high as 1,000 megabits per second.
event	An occurrence, or happening, of significance to a task or program—for example, the completion of an asynchronous input/output operation, such as a keypress or mouse click. <sup>FOLDOC</sup>
exabyte	2 <sup>60</sup> bytes or about 10 <sup>18</sup> bytes. See also <i>large number</i> (page 1090).
exit status	The status returned by a process; either successful (usually 0) or unsuccessful (usually 1).
exploit	A security hole or an instance of taking advantage of a security hole. <sup>FOLDOC</sup>
expression	See <i>logical expression</i> (page 1092) and <i>arithmetic expression</i> (page 1069).
extranet	A network extension for a subset of users (such as students at a particular school or engineers working for the same company). An extranet limits access to private information even though it travels on the public Internet.

<b>failsafe session</b>	A session that allows you to log in on a minimal desktop in case your standard login does not work well enough to allow you to log in to fix a login problem.
<b>FDDI</b>	Fiber Distributed Data Interface. A type of <i>LAN</i> (page 1090) designed to transport data at the rate of 100 million bits per second over fiberoptic cable.
<b>file</b>	A collection of related information referred to with a <i>filename</i> and frequently stored on a disk. Text files typically contain memos, reports, messages, program source code, lists, or manuscripts. Binary or executable files contain utilities or programs that you can run. Refer to “Directory Files and Ordinary Files” on page 188.
<b>filename</b>	The name of a file. A filename refers to a file.
<b>filename completion</b>	Automatic completion of a filename after you specify a unique prefix.
<b>filename extension</b>	The part of a filename following a period.
<b>filename generation</b>	What occurs when the shell expands ambiguous file references. See <i>ambiguous file reference</i> on page 1068.
<b>filesystem</b>	A <i>data structure</i> (page 1078) that usually resides on part of a disk. All Linux systems have a root filesystem, and many have other filesystems. Each filesystem is composed of some number of blocks, depending on the size of the disk partition that has been assigned to the filesystem. Each filesystem has a control block, named the superblock, that contains information about the filesystem. The other blocks in a filesystem are inodes, which contain control information about individual files, and data blocks, which contain the information in the files.
<b>filling</b>	A variant of maximizing in which window edges are pushed out as far as they can go without overlapping another window.
<b>filter</b>	A command that can take its input from standard input and send its output to standard output. A filter transforms the input stream of data and sends it to standard output. A pipe usually connects a filter’s input to standard output of one command, and a second pipe connects the filter’s output to standard input of another command. The <i>grep</i> and <i>sort</i> utilities are commonly used as filters.
<b>firewall</b>	<p>A device for policy-based traffic management used to keep a network secure. A firewall can be implemented in a single router that filters out unwanted packets, or it can rely on a combination of routers, proxy servers, and other devices. Firewalls are widely used to give users access to the Internet in a secure fashion and to separate a company’s public WWW server from its internal network. They are also employed to keep internal network segments more secure.</p> <p>Recently the term has come to be defined more loosely to include a simple packet filter running on an endpoint machine.</p> <p>See also <i>proxy server</i> on page 1101.</p>

<b>firmware</b>	Software built into a computer, often in <i>ROM</i> (page 1103). May be used as part of the <i>bootstrap</i> (page 1072) procedure.
<b>focus, desktop</b>	On a desktop, the window that is active. The window with the desktop focus receives the characters you type on the keyboard. Same as <i>active window</i> (page 1068).
<b>footer</b>	The part of a format that goes at the bottom (or foot) of a page. Contrast with <i>header</i> (page 1085).
<b>foreground process</b>	When you run a command in the foreground, the shell waits for the command to finish before giving you another prompt. You must wait for a foreground process to run to completion before you can give the shell another command. If you have job control, you can move background processes to the foreground, and vice versa. See <i>job control</i> on page 1089. Contrast with <i>background process</i> (page 1070).
<b>fork</b>	To create a process. When one process creates another process, it forks a process. Also <i>spawn</i> .
<b>FQDN</b>	Fully qualified domain name. The full name of a system, consisting of its hostname and its domain name, including the top-level domain. Technically the name that <code>gethostbyname(2)</code> returns for the host named by <code>gethostname(2)</code> . For example, <b>speedy</b> is a hostname and <b>speedy.example.com</b> is an FQDN. An FQDN is sufficient to determine a unique Internet address for a machine on the Internet. <sup>FOLDLOC</sup>
<b>frame</b>	A data link layer packet that contains, in addition to data, the header and trailer information required by the physical medium. Network layer packets are encapsulated to become frames. <sup>FOLDLOC</sup> See also <i>datagram</i> (page 1078) and <i>packet</i> (page 1098).
<b>free list</b>	In a filesystem, the list of blocks that are available for use. Information about the free list is kept in the superblock of the filesystem.
<b>free space</b>	The portion of a hard disk that is not within a partition. A new hard disk has no partitions and contains all free space.
<b>full duplex</b>	The ability to receive and transmit data simultaneously. A <i>network switch</i> (page 1096) is typically a full-duplex device. Contrast with <i>half-duplex</i> (page 1084).
<b>fully qualified domain name</b>	See <i>FQDN</i> .
<b>function</b>	See <i>shell function</i> on page 1106.
<b>gateway</b>	A generic term for a computer or a special device connected to more than one dissimilar type of network to pass data between them. Unlike a router, a gateway often must convert the information into a different format before passing it on. The historical usage of gateway to designate a router is deprecated.
<b>GCOS</b>	See <i>GECOS</i> .

<b>GECOS</b>	General Electric Comprehensive Operating System. For historical reasons, the user information field in the <code>/etc/passwd</code> file is called the GECOS field. Also GCOS.
<b>gibibyte</b>	Giga binary byte. A unit of storage equal to $2^{30}$ bytes = 1,073,741,824 bytes = 1024 <i>mebibytes</i> (page 1093). Abbreviated as GiB. Contrast with <i>gigabyte</i> .
<b>gigabyte</b>	A unit of storage equal to $10^9$ bytes. Sometimes used in place of <i>gibibyte</i> . Abbreviated as GB. See also <i>large number</i> on page 1090.
<b>glyph</b>	A symbol that communicates a specific piece of information nonverbally. A <i>smiley</i> (page 1106) is a glyph.
<b>GMT</b>	Greenwich Mean Time. See <i>UTC</i> on page 1114.
<b>graphical display</b>	A bitmapped monitor that can display graphical images. Contrast with <i>ASCII terminal</i> (page 1069).
<b>graphical user interface</b>	See <i>GUI</i> .
<b>group (of users)</b>	A collection of users. Groups are used as a basis for determining file access permissions. If you are not the owner of a file and you belong to the group the file is assigned to, you are subject to the group access permissions for the file. A user can simultaneously belong to several groups.
<b>group (of windows)</b>	A way to identify similar windows so they can be displayed and acted on similarly. Typically windows started by a given application belong to the same group.
<b>group ID</b>	A unique number that identifies a set of users. It is stored in the password and group databases ( <code>/etc/passwd</code> and <code>/etc/group</code> files or their NIS equivalents). The group database associates group IDs with group names. Also <i>GID</i> .
<b>GUI</b>	Graphical user interface. A GUI provides a way to interact with a computer system by choosing items from menus or manipulating pictures drawn on a display screen instead of by typing command lines. Under Linux, the X Window System provides a graphical display and mouse/keyboard input. GNOME and KDE are two popular desktop managers that run under X. Contrast with <i>character-based</i> (page 1074).
<b>hacker</b>	A person who enjoys exploring the details of programmable systems and learning how to stretch their capabilities, as opposed to users, who prefer to learn only the minimum necessary. One who programs enthusiastically (even obsessively) or who enjoys programming rather than just theorizing about programming. <sup>FOLDOC</sup> Contrast with <i>cracker</i> (page 1077).
<b>half-duplex</b>	A half-duplex device can only receive or transmit at a given moment; it cannot do both. A <i>hub</i> (page 1086) is typically a half-duplex device. Contrast with <i>full duplex</i> (page 1083).



<b>hard link</b>	A directory entry that contains the filename and inode number for a file. The inode number identifies the location of control information for the file on the disk, which in turn identifies the location of the file's contents on the disk. Every file has at least one hard link, which locates the file in a directory. When you remove the last hard link to a file, you can no longer access the file. See <i>link</i> (page 1091) and <i>symbolic link</i> (page 1110).
<b>hash</b>	A string that is generated from another string. See <i>one-way hash function</i> on page 1097. When used for security, a hash can prove, almost to a certainty, that a message has not been tampered with during transmission: The sender generates a hash of a message, encrypts the message and hash, and sends the encrypted message and hash to the recipient. The recipient decrypts the message and hash, generates a second hash from the message, and compares the hash that the sender generated to the new hash. When they are the same, the message has probably not been tampered with. Hashed versions of passwords can be used to authenticate users. A hash can also be used to create an index called a <i>hash table</i> . Also <i>hash value</i> .
<b>hash table</b>	An index created from hashes of the items to be indexed. The hash function makes it highly unlikely that two items will create the same hash. To look up an item in the index, create a hash of the item and search for the hash. Because the hash is typically shorter than the item, the search is more efficient.
<b>header</b>	When you are formatting a document, the header goes at the top, or head, of a page. In electronic mail the header identifies who sent the message, when it was sent, what the subject of the message is, and so forth.
<b>Here document</b>	A shell script that takes its input from the file that contains the script.
<b>hesiod</b>	The nameserver of project Athena. Hesiod is a name service library that is derived from <i>BIND</i> (page 1071) and leverages a DNS infrastructure.
<b>heterogeneous</b>	Consisting of different parts. A heterogeneous network includes systems produced by different manufacturers and/or running different operating systems.
<b>hexadecimal number</b>	A base 16 number. Hexadecimal (or <i>hex</i> ) numbers are composed of the hexadecimal digits 0–9 and A–F. See Table G-1, next page.
<b>hidden filename</b>	A filename that starts with a period. These filenames are called hidden because the <i>ls</i> utility does not normally list them. Use the <i>-a</i> option of <i>ls</i> to list all files, including those with hidden filenames. The shell does not expand a leading asterisk (*) in an ambiguous file reference to match files with hidden filenames. Also <i>hidden file</i> , <i>invisible file</i> .
<b>hierarchy</b>	An organization with a few things, or thing—one at the top—and with several things below each other thing. An inverted tree structure. Examples in computing include a file tree where each directory may contain files or other directories, a hierarchical network, and a class hierarchy in object-oriented programming. <sup>FOLDDOC</sup> Refer to “The Hierarchical Filesystem” on page 188.

**Table G-1**    Decimal, octal, and hexadecimal numbers

Decimal	Octal	Hex	Decimal	Octal	Hex
1	1	1	17	21	11
2	2	2	18	22	12
3	3	3	19	23	13
4	4	4	20	24	14
5	5	5	21	25	15
6	6	6	31	37	1F
7	7	7	32	40	20
8	10	8	33	41	21
9	11	9	64	100	40
10	12	A	96	140	60
11	13	B	100	144	64
12	14	C	128	200	80
13	15	D	254	376	FE
14	16	E	255	377	FF
15	17	F	256	400	100
16	20	10	257	401	101

- history

A shell mechanism that enables you to modify and reexecute recent commands.
- home directory

The directory that is the working directory when you first log in. The pathname of this directory is stored in the **HOME** shell variable.
- hover

To leave the mouse pointer stationary for a moment over an object. In many cases hovering displays a *tooltip* (page 1111).
- HTML

Hypertext Markup Language. A *hypertext* document format used on the World Wide Web. Tags, which are embedded in the text, consist of a less than sign (<), a directive, zero or more parameters, and a greater than sign (>). Matched pairs of directives, such as <TITLE> and </TITLE>, delimit text that is to appear in a special place or style.<sup>FOLDOUT</sup> For more information on HTML, go to [www.htmlhelp.com/faq/html/all.html](http://www.htmlhelp.com/faq/html/all.html).
- HTTP

Hypertext Transfer Protocol. The client/server TCP/IP protocol used on the World Wide Web for the exchange of *HTML* documents.
- hub

A multiport repeater. A hub rebroadcasts all packets it receives on all ports. This term is frequently used to refer to small hubs and switches, regardless of the device's intelligence. It is a generic term for a layer 2 shared-media networking device. Today the term *hub* is sometimes used to refer to small intelligent devices, although that was not its original meaning. Contrast with *network switch* (page 1096).

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<b>hypertext</b>	A collection of documents/nodes containing (usually highlighted or underlined) cross-references or links, which, with the aid of an interactive browser program, allow the reader to move easily from one document to another. <sup>FOLDOC</sup>
<b>Hypertext Markup Language</b>	See <i>HTML</i> .
<b>Hypertext Transfer Protocol</b>	See <i>HTTP</i> .
<b>i/o device</b>	Input/output device. See <i>device</i> on page 1079.
<b>IANA</b>	Internet Assigned Numbers Authority. A group that maintains a database of all permanent, registered system services ( <a href="http://www.iana.org">www.iana.org</a> ).
<b>ICMP</b>	Internet Control Message Protocol. A type of network packet that carries only messages, no data.
<b>icon</b>	In a GUI, a small picture representing a file, directory, action, program, and so on. When you click an icon, an action, such as opening a window and starting a program or displaying a directory or Web site, takes place. From miniature religious statues. <sup>FOLDOC</sup>
<b>iconify</b>	The process of changing a window into an <i>icon</i> . Contrast with <i>restore</i> (page 1103).
<b>ignored window</b>	A state in which a window has no decoration and therefore no buttons or titlebar to control it with.
<b>indentation</b>	See <i>indention</i> .
<b>indention</b>	The blank space between the margin and the beginning of a line that is set in from the margin.
<b>inode</b>	A <i>data structure</i> (page 1078) that contains information about a file. An inode for a file contains the file's length, the times the file was last accessed and modified, the time the inode was last modified, owner and group IDs, access privileges, number of links, and pointers to the data blocks that contain the file itself. Each directory entry associates a filename with an inode. Although a single file may have several filenames (one for each link), it has only one inode.
<b>input</b>	Information that is fed to a program from a terminal or other file. See <i>standard input</i> on page 1108.
<b>installation</b>	A computer at a specific location. Some aspects of the Linux system are installation dependent. Also <i>site</i> .
<b>interactive</b>	A program that allows ongoing dialog with the user. When you give commands in response to shell prompts, you are using the shell interactively. Also, when you give commands to utilities, such as <i>vim</i> and <i>mail</i> , you are using the utilities interactively.

interface	The meeting point of two subsystems. When two programs work together, their interface includes every aspect of either program that the other deals with. The <i>user interface</i> (page 1113) of a program includes every program aspect the user comes into contact with: the syntax and semantics involved in invoking the program, the input and output of the program, and its error and informational messages. The shell and each of the utilities and built-in commands have a user interface.
International Organization for Standardization	See <i>ISO</i> on page 1089.
internet	A large network that encompasses other, smaller networks.
Internet	The largest internet in the world. The Internet (uppercase “I”) is a multilevel hierarchy composed of backbone networks (ARPANET, NSFNET, MILNET, and others), midlevel networks, and stub networks. These include commercial (.com or .co), university (.ac or .edu), research (.org or .net), and military (.mil) networks and span many different physical networks around the world with various protocols, including the Internet Protocol (IP). Outside the United States, country code domains are popular (.us, .es, .mx, .de, and so forth), although you will see them used within the United States as well.
Internet Protocol	See <i>IP</i> .
Internet service provider	See <i>ISP</i> .
intranet	An inhouse network designed to serve a group of people such as a corporation or school. The general public on the Internet does not have access to the intranet. See page 358.
invisible file	See <i>hidden filename</i> on page 1085.
IP	Internet Protocol. The network layer for TCP/IP. IP is a best-effort, packet-switching, <i>connectionless protocol</i> (page 1076) that provides packet routing, fragmentation, and reassembly through the data link layer. <i>IPv4</i> is slowly giving way to <i>IPv6</i> . <sup>FOLDOUT</sup>
IP address	Internet Protocol address. A four-part address associated with a particular network connection for a system using the Internet Protocol (IP). A system that is attached to multiple networks that use the IP will have a different IP address for each network interface.
IP multicast	See <i>multicast</i> on page 1095.

<b>IP spoofing</b>	A technique used to gain unauthorized access to a computer. The would-be intruder sends messages to the target machine. These messages contain an IP address indicating that the messages are coming from a trusted host. The target machine responds to the messages, giving the intruder (privileged) access to the target.
<b>IPC</b>	Interprocess communication. A method to communicate specific information between programs.
<b>IPv4</b>	<i>IP</i> version 4. See <i>IP</i> and <i>IPv6</i> .
<b>IPv6</b>	<i>IP</i> version 6. The next generation of Internet Protocol, which provides a much larger address space ( $2^{128}$ bits versus $2^{32}$ bits for IPv4) that is designed to accommodate the rapidly growing number of Internet addressable devices. IPv6 also has built-in autoconfiguration, enhanced security, better multicast support, and many other features.
<b>ISDN</b>	Integrated Services Digital Network. A set of communications standards that allows a single pair of digital or standard telephone wires to carry voice, data, and video at a rate of 64 kilobits per second.
<b>ISO</b>	International Organization for Standardization. A voluntary, nontreaty organization founded in 1946. It is responsible for creating international standards in many areas, including computers and communications. Its members are the national standards organizations of 89 countries, including the American National Standards Institute. <sup>FOLDOC</sup>
<b>ISO9660</b>	The <i>ISO</i> standard defining a filesystem for CD-ROMs.
<b>ISP</b>	Internet service provider. Provides Internet access to its customers.
<b>job control</b>	A facility that enables you to move commands from the foreground to the background and vice versa. Job control enables you to stop commands temporarily.
<b>journaling filesystem</b>	<p>A filesystem that maintains a noncached log file, or journal, which records all transactions involving the filesystem. When a transaction is complete, it is marked as complete in the log file.</p> <p>The log file results in greatly reduced time spent recovering a filesystem after a crash, making it particularly valuable in systems where high availability is an issue.</p>
<b>JPEG</b>	Joint Photographic Experts Group. This committee designed the standard image-compression algorithm. JPEG is intended for compressing either full-color or gray-scale digital images of natural, real-world scenes and does not work as well on nonrealistic images, such as cartoons or line drawings. Filename extensions: <b>.jpg</b> , <b>.jpeg</b> . <sup>FOLDOC</sup>
<b>justify</b>	To expand a line of type in the process of formatting text. A justified line has even margins. A line is justified by increasing the space between words and sometimes between letters on the line.

<b>Kerberos</b>	An MIT-developed security system that authenticates users and machines. It does not provide authorization to services or databases; it establishes identity at logon, which is used throughout the session. Once you are authenticated, you can open as many terminals, windows, services, or other network accesses as you like until your session expires.
<b>kernel</b>	The part of the operating system that allocates machine resources, including memory, disk space, and <i>CPU</i> (page 1077) cycles, to all other programs that run on a computer. The kernel includes the low-level hardware interfaces (drivers) and manages <i>processes</i> (page 1100), the means by which Linux executes programs. The kernel is the part of the Linux system that Linus Torvalds originally wrote (see the beginning of Chapter 1).
<b>kernelspace</b>	The part of memory (RAM) where the kernel resides. Code running in kernelspace has full access to hardware and all other processes in memory. See the <i>KernelAnalysis-HOWTO</i> .
<b>key binding</b>	A <i>keyboard</i> key is said to be bound to the action that results from pressing it. Typically keys are bound to the letters that appear on the keycaps: When you press <b>A</b> , an <b>A</b> appears on the screen. Key binding usually refers to what happens when you press a combination of keys, one of which is <b>CONTROL</b> , <b>ALT</b> , <b>META</b> , or <b>SHIFT</b> , or when you press a series of keys, the first of which is typically <b>ESCAPE</b> .
<b>keyboard</b>	A hardware input device consisting of a number of mechanical buttons (keys) that the user presses to input characters to a computer. By default a keyboard is connected to standard input of a shell. <sup>FOLDOC</sup>
<b>kilo-</b>	In the binary system, the prefix <i>kilo-</i> multiplies by $2^{10}$ (i.e., 1,024). Kilobit and kilobyte are common uses of this prefix. Abbreviated as <i>k</i> .
<b>Korn Shell</b>	ksh. A command processor, developed by David Korn at AT&T Bell Laboratories, that is compatible with the Bourne Shell but includes many extensions. See also <i>shell</i> on page 1105.
<b>LAN</b>	Local area network. A network that connects computers within a localized area (such as a single site, building, or department).
<b>large number</b>	Visit <a href="http://mathworld.wolfram.com/LargeNumber.html">mathworld.wolfram.com/LargeNumber.html</a> for a comprehensive list.
<b>LDAP</b>	Lightweight Directory Access Protocol. A simple protocol for accessing online directory services. LDAP is a lightweight alternative to the X.500 Directory Access Protocol (DAP). It can be used to access information about people, system users, network devices, email directories, and systems. In some cases, it can be used as an alternative for services such as NIS. Given a name, many mail clients can use LDAP to discover the corresponding email address. See <i>directory service</i> on page 1079.
<b>leaf</b>	In a tree structure, the end of a branch that cannot support other branches. When the Linux filesystem hierarchy is conceptualized as a tree, files that are not directories are leaves. See <i>node</i> on page 1097.

least privilege, concept of	<p>Mistakes made by a user working with <b>root</b> privileges can be much more devastating than those made by an ordinary user. When you are working on the computer, especially when you are working as the system administrator, always perform any task using the least privilege possible. If you can perform a task logged in as an ordinary user, do so. If you must work with <b>root</b> privileges, do as much as you can as an ordinary user, log in as <b>root</b> or give an <b>su</b> or <b>sudo</b> command so you are working with <b>root</b> privileges, do as much of the task that has to be done with <b>root</b> privileges, and revert to being an ordinary user as soon as you can.</p> <p>Because you are more likely to make a mistake when you are rushing, this concept becomes more important when you have less time to apply it.</p>
Lightweight Directory Access Protocol	See <i>LDAP</i> .
link	A pointer to a file. Two kinds of links exist: <i>hard links</i> (page 1085) and <i>symbolic links</i> (page 1110) also called <i>soft links</i> . A hard link associates a filename with a place on the disk where the contents of the file is located. A symbolic link associates a filename with the pathname of a hard link to a file.
Linux-PAM	See <i>PAM</i> on page 1098.
Linux-Pluggable Authentication Modules	See <i>PAM</i> on page 1098.
list box	A <i>widget</i> (page 1115) that displays a static list for a user to choose from. The list appears as multiple lines with a <i>scrollbar</i> (page 1105) if needed. The user can scroll the list and select an entry. Different from a <i>drop-down list</i> (page 1080).
loadable kernel module	See <i>loadable module</i> .
loadable module	A portion of the operating system that controls a special device and that can be loaded automatically into a running kernel as needed to access that device.
local area network	See <i>LAN</i> on page 1090.
locale	The language; date, time, and currency formats; character sets; and so forth that pertain to a geopolitical place or area. For example, <i>en_US</i> specifies English as spoken in the United States and dollars; <i>en_UK</i> specifies English as spoken in the United Kingdom and pounds. See the <i>locale</i> man page in section 5 of the system manual for more information. Also the <i>locale</i> utility.

<b>log in</b>	To gain access to a computer system by responding correctly to the <b>login:</b> and <b>Password:</b> prompts. Also <i>log on</i> , <i>login</i> .
<b>log out</b>	To end your session by exiting from your login shell. Also <i>log off</i> .
<b>logical expression</b>	A collection of strings separated by logical operators (>, >=, =, !=, <=, and <) that can be evaluated as <i>true</i> or <i>false</i> . Also <i>Boolean</i> (page 1072) <i>expression</i> .
<b>.login file</b>	A file in a user's home directory that the TC Shell executes when you log in. You can use this file to set environment variables and to run commands that you want executed at the beginning of each session.
<b>login name</b>	See <i>username</i> on page 1113.
<b>login shell</b>	The shell that you are using when you log in. The login shell can fork other processes that can run other shells, utilities, and programs.
<b>.logout file</b>	A file in a user's home directory that the TC Shell executes when you log out, assuming that the TC Shell is your login shell. You can put in the <b>.logout</b> file commands that you want run each time you log out.
<b>MAC address</b>	<p>Media Access Control address. The unique hardware address of a device connected to a shared network medium. Each network adapter has a globally unique MAC address that it stores in ROM. MAC addresses are 6 bytes long, enabling <math>256^6</math> (about 300 trillion) possible addresses or 65,536 addresses for each possible IPv4 address.</p> <p>A MAC address performs the same role for Ethernet that an IP address performs for TCP/IP: It provides a unique way to identify a host.</p>
<b>machine collating sequence</b>	The sequence in which the computer orders characters. The machine collating sequence affects the outcome of sorts and other procedures that put lists in alphabetical order. Many computers use ASCII codes so their machine collating sequences correspond to the ordering of the ASCII codes for characters.
<b>macro</b>	A single instruction that a program replaces by several (usually more complex) instructions. The C compiler recognizes macros, which are defined using a <b>#define</b> instruction to the preprocessor.
<b>magic number</b>	A magic number, which occurs in the first 512 bytes of a binary file, is a 1-, 2-, or 4-byte numeric value or character string that uniquely identifies the type of file (much like a DOS 3-character filename extension). See <b>/usr/share/magic</b> and the <b>magic</b> man page for more information.
<b>main memory</b>	Random access memory (RAM), an integral part of the computer. Although disk storage is sometimes referred to as memory, it is never referred to as main memory.
<b>major device number</b>	A number assigned to a class of devices, such as terminals, printers, or disk drives. Using the <b>ls</b> utility with the <b>-l</b> option to list the contents of the <b>/dev</b> directory displays the major and minor device numbers of many devices (as major, minor).



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<b>MAN</b>	Metropolitan area network. A network that connects computers and LANs (page 1090) at multiple sites in a small regional area, such as a city.
<b>masquerade</b>	To appear to come from one domain or IP address when actually coming from another. Said of a packet ( <i>iptables</i> ) or message ( <i>sendmail</i> ). See also <i>NAT</i> on page 1095.
<b>MD5</b>	Message Digest 5. A <i>one-way hash function</i> (page 1097). The <i>SHA1</i> (page 1105) algorithm has supplanted MD5 in many applications.
<b>MDA</b>	Mail delivery agent. One of the three components of a mail system; the other two are the <i>MTA</i> (page 1094) and <i>MUA</i> (page 1094). An MDA accepts inbound mail from an MTA and delivers it to a local user.
<b>mebibyte</b>	Mega binary byte. A unit of storage equal to $2^{20}$ bytes = 1,048,576 bytes = 1,024 kibibytes. Abbreviated as MiB. Contrast with <i>megabyte</i> .
<b>megabyte</b>	A unit of storage equal to $10^6$ bytes. Sometimes used in place of <i>mebibyte</i> . Abbreviated as MB.
<b>memory</b>	See <i>RAM</i> on page 1102.
<b>menu</b>	A list from which the user may select an operation to be performed. This selection is often made with a mouse or other pointing device under a GUI but may also be controlled from the keyboard. Very convenient for beginners, menus show which commands are available and facilitate experimenting with a new program, often reducing the need for user documentation. Experienced users usually prefer keyboard commands, especially for frequently used operations, because they are faster to use. <sup>FOLDOUT</sup>
<b>merge</b>	To combine two ordered lists so that the resulting list is still in order. The <i>sort</i> utility can merge files.
<b>META key</b>	On the keyboard, a key that is labeled META or ALT. Use this key as you would the SHIFT key. While holding it down, press another key. The <i>emacs</i> editor makes extensive use of the META key.
<b>metacharacter</b>	A character that has a special meaning to the shell or another program in a particular context. Metacharacters are used in the ambiguous file references recognized by the shell and in the regular expressions recognized by several utilities. You must quote a metacharacter if you want to use it without invoking its special meaning. See <i>regular character</i> (page 1102) and <i>special character</i> (page 1107).
<b>metadata</b>	<p>Data about data. In data processing, metadata is definitional data that provides information about, or documentation of, other data managed within an application or environment.</p> <p>For example, metadata can document data about data elements or attributes (name, size, data type, and so on), records or <i>data structures</i> (page 1078) (length, fields, columns, and so on), and data itself (where it is located, how it is associated, who</p>

	owns it, and so on). Metadata can include descriptive information about the context, quality and condition, or characteristics of the data. <small>FOLDOC</small>
metropolitan area network	See <i>MAN</i> on page 1093.
MIME	Multipurpose Internet Mail Extension. Originally used to describe how specific types of files that were attached to email were to be handled. Today MIME types describe how a file is to be opened or worked with, based on its contents, determined by its <i>magic number</i> (page 1092), and filename extension. An example of a MIME <i>type</i> is <b>image/jpeg</b> : The MIME <i>group</i> is <b>image</b> and the MIME <i>subtype</i> is <b>jpeg</b> . Many MIME groups exist, including application, audio, image, inode, message, text, and video.
minimize	See <i>iconify</i> on page 1087.
minor device number	A number assigned to a specific device within a class of devices. See <i>major device number</i> on page 1092.
modem	Modulator/demodulator. A peripheral device that modulates digital data into analog data for transmission over a voice-grade telephone line. Another modem demodulates the data at the other end.
module	See <i>loadable module</i> on page 1091.
mount	To make a filesystem accessible to system users. When a filesystem is not mounted, you cannot read from or write to files it contains.
mount point	A directory that you mount a local or remote filesystem on. See
mouse	A device you use to point to a particular location on a display screen, typically so you can choose a menu item, draw a line, or highlight some text. You control a pointer on the screen by sliding a mouse around on a flat surface; the position of the pointer moves relative to the movement of the mouse. You select items by pressing one or more buttons on the mouse.
mouse pointer	In a GUI, a marker that moves in correspondence with the mouse. It is usually a small black x with a white border or an arrow. Differs from the <i>cursor</i> (page 1077).
mouseover	The action of passing the mouse pointer over an object on the screen.
MTA	Mail transfer agent. One of the three components of a mail system; the other two are the <i>MDA</i> and <i>MUA</i> . An MTA accepts mail from users and MTAs.
MUA	Mail user agent. One of the three components of a mail system; the other two are the <i>MDA</i> (page 1093) and <i>MTA</i> (page 1094). An MUA is an end-user mail program such as KMail, mutt, or Outlook.
multiboot specification	Specifies an interface between a boot loader and an operating system. With compliant boot loaders and operating systems, any boot loader should be able to load any operating system. The object of this specification is to ensure that different operat-

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	ing systems will work on a single machine. For more information, go to <a href="http://odin-os.sourceforge.net/guides/multiboot.html">odin-os.sourceforge.net/guides/multiboot.html</a> .
<b>multicast</b>	A multicast packet has one source and multiple destinations. In multicast, source hosts register at a special address to transmit data. Destination hosts register at the same address to receive data. In contrast to <i>broadcast</i> (page 1072), which is LAN-based, multicast traffic is designed to work across routed networks on a subscription basis. Multicast reduces network traffic by transmitting a packet one time, with the router at the end of the path breaking it apart as needed for multiple recipients.
<b>multitasking</b>	A computer system that allows a user to run more than one job at a time. A multitasking system, such as Linux, allows you to run a job in the background while running a job in the foreground.
<b>multiuser system</b>	A computer system that can be used by more than one person at a time. Linux is a multiuser operating system. Contrast with <i>single-user system</i> (page 1106).
<b>namespace</b>	A set of names (identifiers) in which all names are unique. <sup>FOLDOC</sup>
<b>NAT</b>	Network Address Translation. A scheme that enables a LAN to use one set of IP addresses internally and a different set externally. The internal set is for LAN (private) use. The external set is typically used on the Internet and is Internet unique. NAT provides some privacy by hiding internal IP addresses and allows multiple internal addresses to connect to the Internet through a single external IP address. See also <i>masquerade</i> on page 1093.
<b>NBT</b>	NetBIOS over TCP/IP. A protocol that supports NetBIOS services in a TCP/IP environment. Also <i>NetBT</i> .
<b>negative caching</b>	Storing the knowledge that something does not exist. A cache normally stores information about something that exists. A negative cache stores the information that something, such as a record, does not exist.
<b>NetBIOS</b>	Network Basic Input/Output System. An <i>API</i> (page 1069) for writing network-aware applications.
<b>netboot</b>	To boot a computer over the network (as opposed to booting from a local disk).
<b>netiquette</b>	<p>The conventions of etiquette—that is, polite behavior—recognized on Usenet and in mailing lists, such as not (cross-)posting to inappropriate groups and refraining from commercial advertising outside the business groups.</p> <p>The most important rule of netiquette is “Think before you post.” If what you intend to post will not make a positive contribution to the newsgroup and be of interest to several readers, do not post it. Personal messages to one or two individuals should not be posted to newsgroups; use private email instead.<sup>FOLDOC</sup></p>
<b>netmask</b>	A 32-bit mask (for IPv4), that shows how an Internet address is to be divided into network, subnet, and host parts. The netmask has ones in the bit positions in the 32-bit address that are to be used for the network and subnet parts and zeros for the

	host part. The mask should contain at least the standard network portion (as determined by the address class). The subnet field should be contiguous with the network portion. <sup>FOLDOC</sup>
<b>network address</b>	The network portion ( <b>netid</b> ) of an IP address. For a class A network, it is the first byte, or segment, of the IP address; for a class B network, it is the first two bytes; and for a class C network, it is the first three bytes. In each case the balance of the IP address is the host address ( <b>hostid</b> ). Assigned network addresses are globally unique within the Internet. Also <i>network number</i> .
<b>Network Filesystem</b>	See <i>NFS</i> .
<b>Network Information Service</b>	See <i>NIS</i> .
<b>network number</b>	See <i>network address</i> .
<b>network segment</b>	A part of an Ethernet or other network on which all message traffic is common to all nodes; that is, it is broadcast from one node on the segment and received by all others. This commonality normally occurs because the segment is a single continuous conductor. Communication between nodes on different segments is via one or more routers. <sup>FOLDOC</sup>
<b>network switch</b>	A connecting device in networks. Switches are increasingly replacing shared media hubs in an effort to increase bandwidth. For example, a 16-port 10BaseT hub shares the total 10 megabits per second bandwidth with all 16 attached nodes. By replacing the hub with a switch, both sender and receiver can take advantage of the full 10 megabits per second capacity. Each port on the switch can give full bandwidth to a single server or client station or to a hub with several stations. Network switch refers to a device with intelligence. Contrast with <i>hub</i> (page 1086).
<b>Network Time Protocol</b>	See <i>NTP</i> on page 1097.
<b>NFS</b>	Network Filesystem. A remote filesystem designed by Sun Microsystems, available on computers from most UNIX system vendors.
<b>NIC</b>	Network interface card (or controller). An adapter circuit board installed in a computer to provide a physical connection to a network. <sup>FOLDOC</sup>
<b>NIS</b>	Network Information Service. A distributed service built on a shared database to manage system-independent information (such as usernames and passwords).
<b>NIS domain name</b>	A name that describes a group of systems that share a set of NIS files. Different from <i>domain name</i> (page 1080).
<b>NNTP</b>	Network News Transfer Protocol.

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<b>node</b>	In a tree structure, the end of a branch that can support other branches. When the Linux filesystem hierarchy is conceptualized as a tree, directories are nodes. See <i>leaf</i> on page 1090.
<b>nonprinting character</b>	See <i>control character</i> on page 1076. Also <i>nonprintable character</i> .
<b>nonvolatile storage</b>	A storage device whose contents are preserved when its power is off. Also NVS and persistent storage. Some examples are CD-ROM, paper punch tape, hard disk, ROM (page 1103), PROM (page 1100), EPROM (page 1081), and EEPROM (page 1081). Contrast with RAM (page 1102).
<b>NTP</b>	Network Time Protocol. Built on top of TCP/IP, NTP maintains accurate local time by referring to known accurate clocks on the Internet.
<b>null string</b>	A string that could contain characters but does not. A string of zero length.
<b>octal number</b>	A base 8 number. Octal numbers are composed of the digits 0–7, inclusive. Refer to Table G-1 on page 1086.
<b>one-way hash function</b>	A one-way function that takes a variable-length message and produces a fixed-length hash. Given the hash, it is computationally infeasible to find a message with that hash; in fact, you cannot determine any usable information about a message with that hash. Also <i>message digest function</i> . See also <i>hash</i> (page 1085).
<b>OpenSSH</b>	A free version of the SSH (secure shell) protocol suite that replaces TELNET, rlogin, and more with secure programs that encrypt all communication—even passwords—over a network.
<b>operating system</b>	A control program for a computer that allocates computer resources, schedules tasks, and provides the user with a way to access resources.
<b>option</b>	A command-line argument that modifies the effects of a command. Options are usually preceded by hyphens on the command line and traditionally have single-character names (such as <b>-h</b> or <b>-n</b> ). Some commands allow you to group options following a single hyphen (for example, <b>-hn</b> ). GNU utilities frequently have two arguments that do the same thing: a single-character argument and a longer, more descriptive argument that is preceded by two hyphens (such as <b>--show-all</b> and <b>--invert-match</b> ).
<b>ordinary file</b>	A file that is used to store a program, text, or other user data. See <i>directory</i> (page 1079) and <i>device file</i> (page 1079).
<b>output</b>	Information that a program sends to the terminal or another file. See <i>standard output</i> on page 1108.
<b>P2P</b>	Peer-to-Peer. A network that does not divide nodes into clients and servers. Each computer on a P2P network can fulfill the roles of client and server. In the context of a file-sharing network, this ability means that once a node has downloaded (part of) a file, it can act as a server. BitTorrent implements a P2P network.

- packet** A unit of data sent across a network. *Packet* is a generic term used to describe a unit of data at any layer of the OSI protocol stack, but it is most correctly used to describe network or application layer data units (“application protocol data unit,” APDU).<sup>FOLDOC</sup> See also *frame* (page 1083) and *datagram* (page 1078).
- packet filtering** A technique used to block network traffic based on specified criteria, such as the origin, destination, or type of each packet. See also *firewall* (page 1082).
- packet sniffer** A program or device that monitors packets on a network. See *sniff* on page 1107.
- pager** A utility that allows you to view a file one screen at a time (for example, less and more).
- paging** The process by which virtual memory is maintained by the operating system. The contents of process memory is moved (paged out) to the *swap space* (page 1110) as needed to make room for other processes.
- PAM** Linux-PAM or Linux-Pluggable Authentication Modules. These modules allow a system administrator to determine how various applications authenticate users.
- parent process** A process that forks other processes. See *process* (page 1100) and *child process* (page 1074).
- partition** A section of a (hard) disk that has a name so you can address it separately from other sections. A disk partition can hold a filesystem or another structure, such as the swap area. Under DOS and Windows, partitions (and sometimes whole disks) are labeled C:, D:, and so on. Also *disk partition* and *slice*.
- passive FTP** Allows FTP to work through a firewall by allowing the flow of data to be initiated and controlled by the client FTP program instead of the server. Also called PASV FTP because it uses the FTP PASV command.
- passphrase** A string of words and characters that you type in to authenticate yourself. A passphrase differs from a *password* only in length. A password is usually short—6 to 10 characters. A passphrase is usually much longer—up to 100 characters or more. The greater length makes a passphrase harder to guess or reproduce than a password and therefore more secure.<sup>FOLDOC</sup>
- password** To prevent unauthorized access to a user’s account, an arbitrary string of characters chosen by the user or system administrator and used to authenticate the user when attempting to log in.<sup>FOLDOC</sup> See also *passphrase*.
- PASV FTP** See *passive FTP*.
- pathname** A list of directories separated by slashes (/) and ending with the name of a file, which can be a directory. A pathname is used to trace a path through the file structure to locate or identify a file.
- pathname, last element of a** The part of a pathname following the final /, or the whole filename if there is no /. A simple filename. Also *basename*.

<b>pathname element</b>	One of the filenames that forms a pathname.
<b>peripheral device</b>	See <i>device</i> on page 1079.
<b>persistent</b>	Data that is stored on nonvolatile media, such as a hard disk.
<b>phish</b>	An attempt to trick users into revealing or sharing private information, especially passwords or financial information. The most common form is email purporting to be from a bank or vendor that requests that a user fill out a form to “update” an account on a phoney Web site disguised to appear legitimate. Generally sent as <i>spam</i> (page 1107).
<b>physical device</b>	A tangible device, such as a disk drive, that is physically separate from other, similar devices.
<b>PID</b>	Process identification, usually followed by the word <i>number</i> . Linux assigns a unique PID number as each process is initiated.
<b>pipe</b>	A connection between programs such that standard output of one program is connected to standard input of the next. Also <i>pipeline</i> .
<b>pixel</b>	The smallest element of a picture, typically a single dot on a display screen.
<b>plaintext</b>	Text that is not encrypted. Also <i>cleartext</i> . Contrast with <i>ciphertext</i> (page 1075).
<b>Pluggable Authentication Modules</b>	See <i>PAM</i> on page 1098.
<b>point-to-point link</b>	A connection limited to two endpoints, such as the connection between a pair of modems.
<b>port</b>	<p>A logical channel or channel endpoint in a communications system. The <i>TCP</i> (page 1110) and <i>UDP</i> (page 1112) transport layer protocols used on Ethernet use port numbers to distinguish between different logical channels on the same network interface on the same computer.</p> <p>The <i>/etc/services</i> file (see the beginning of this file for more information) or the <i>NIS</i> (page 1096) <i>services</i> database specifies a unique port number for each application program. The number links incoming data to the correct service (program). Standard, well-known ports are used by everyone: Port 80 is used for HTTP (Web) traffic. Some protocols, such as TELNET and HTTP (which is a special form of TELNET), have default ports specified as mentioned earlier but can use other ports as well.<sup>FOLDOC</sup></p>
<b>port forwarding</b>	The process by which a network <i>port</i> on one computer is transparently connected to a port on another computer. If port X is forwarded from system A to system B, any data sent to port X on system A is sent to system B automatically. The connec-

	tion can be between different ports on the two systems. See also <i>tunneling</i> (page 1112).
<b>portmapper</b>	A server that converts TCP/IP port numbers into <i>RPC</i> (page 1104) program numbers.
<b>printable character</b>	One of the graphic characters: a letter, number, or punctuation mark. Contrast with a nonprintable, or <i>CONTROL</i> , character. Also <i>printing character</i> .
<b>private address space</b>	<p><i>IANA</i> (page 1087) has reserved three blocks of IP addresses for private internets or LANs:</p> <p>10.0.0.0 - 10.255.255.255 172.16.0.0 - 172.31.255.255 192.168.0.0 - 192.168.255.255</p> <p>You can use these addresses without coordinating with anyone outside of your LAN (you do not have to register the system name or address). Systems using these IP addresses cannot communicate directly with hosts using the global address space but must go through a gateway. Because private addresses have no global meaning, routing information is not stored by DNSs and most ISPs reject privately addressed packets. Make sure that your router is set up not to forward these packets onto the Internet.</p>
<b>privileged port</b>	A <i>port</i> (page 1099) with a number less than 1024. On Linux and other UNIX-like systems, only a process running with <b>root</b> privileges can bind to a privileged port. Any user on Windows 98 and earlier Windows systems can bind to any port. Also <i>reserved port</i> .
<b>procedure</b>	A sequence of instructions for performing a particular task. Most programming languages, including machine languages, enable a programmer to define procedures that allow the procedure code to be called from multiple places. Also <i>subroutine</i> . <sup>FOLDOUT</sup>
<b>process</b>	The execution of a command by Linux.
<b>.profile file</b>	A startup file in a user's home directory that the Bourne Again or Z Shell executes when you log in. The TC Shell executes <b>.login</b> instead. You can use the <b>.profile</b> file to run commands, set variables, and define functions.
<b>program</b>	A sequence of executable computer instructions contained in a file. Linux utilities, applications, and shell scripts are all programs. Whenever you run a command that is not built into a shell, you are executing a program.
<b>PROM</b>	Programmable readonly memory. A kind of nonvolatile storage. <i>ROM</i> (page 1103) that can be written to using a PROM programmer.
<b>prompt</b>	A cue from a program, usually displayed on the screen, indicating that it is waiting for input. The shell displays a prompt, as do some of the interactive utilities, such as <i>mail</i> . By default the Bourne Again and Z Shells use a dollar sign (\$) as a prompt, and the TC Shell uses a percent sign (%).
<b>protocol</b>	A set of formal rules describing how to transmit data, especially across a network. Low-level protocols define the electrical and physical standards, bit and byte



ordering, and transmission, error detection, and correction of the bit stream. High-level protocols deal with data formatting, including message syntax, terminal-to-computer dialog, character sets, and sequencing of messages.<sup>FOLDOC</sup>

- proxy** A service that is authorized to act for a system while not being part of that system. See also *proxy gateway* and *proxy server*.
- proxy gateway** A computer that separates clients (such as browsers) from the Internet, working as a trusted agent that accesses the Internet on their behalf. A proxy gateway passes a request for data from an Internet service, such as HTTP from a browser/client, to a remote server. The data that the server returns goes back through the proxy gateway to the requesting service. A proxy gateway should be transparent to the user.
- A proxy gateway often runs on a *firewall* (page 1082) system and acts as a barrier to malicious users. It hides the IP addresses of the local computers inside the firewall from Internet users outside the firewall.
- You can configure browsers, such as Mozilla/Firefox and Netscape, to use a different proxy gateway or to use no proxy for each URL access method including FTP, netnews, SNMP, HTTPS, and HTTP. See also *proxy*.
- proxy server** A *proxy gateway* that usually includes a *cache* (page 1073) that holds frequently used Web pages so that the next request for that page is available locally (and therefore more quickly). The terms proxy server and proxy gateway are frequently interchanged so that the use of cache does not rest exclusively with the proxy server. See also *proxy*.
- Python** A simple, high-level, interpreted, object-oriented, interactive language that bridges the gap between C and shell programming. Suitable for rapid prototyping or as an extension language for C applications, Python supports packages, modules, classes, user-defined exceptions, a good C interface, and dynamic loading of C modules. It has no arbitrary restrictions. For more information, see [www.python.org](http://www.python.org).<sup>FOLDOC</sup>
- quote** When you quote a character, you take away any special meaning that it has in the current context. You can quote a character by preceding it with a backslash. When you are interacting with the shell, you can also quote a character by surrounding it with single quotation marks. For example, the command `echo \*` or `echo ' '` displays `*`. The command `echo *` displays a list of the files in the working directory. See *ambiguous file reference* (page 1068), *metacharacter* (page 1093), *regular character* (page 1102), *regular expression* (page 1103), and *special character* (page 1107). See also *escape* on page 1081.
- radio button** In a GUI, one of a group of buttons similar to those used to select the station on a car radio. Radio buttons within a group are mutually exclusive; only one button can be selected at a time.
- RAID** Redundant array of inexpensive/independent disks. Two or more (hard) disk drives used in combination to improve fault tolerance and performance. RAID can be implemented in hardware or software.

- RAM** Random access memory. A kind of volatile storage. A data storage device for which the order of access to different locations does not affect the speed of access. Contrast with a hard disk or tape drive, which provides quicker access to sequential data because accessing a nonsequential location requires physical movement of the storage medium and/or read/write head rather than just electronic switching. Contrast with *nonvolatile storage* (page 1097). Also *memory*.<sup>FOLDOC</sup>
- RAM disk** RAM that is made to look like a floppy diskette or hard disk. A RAM disk is frequently used as part of the *boot* (page 1072) process.
- RAS** Remote access server. In a network, a computer that provides access to remote users via analog modem or ISDN connections. RAS includes the dial-up protocols and access control (authentication). It may be a regular fileserver with remote access software or a proprietary system, such as Shiva's LANRover. The modems may be internal or external to the device.
- RDF** Resource Description Framework. Being developed by W3C (the main standards body for the World Wide Web), a standard that specifies a mechanism for encoding and transferring *metadata* (page 1093). RDF does not specify what the metadata should or can be. It can integrate many kinds of applications and data, using XML as an interchange syntax. Examples of the data that can be integrated include library catalogs and worldwide directories; syndication and aggregation of news, software, and content; and collections of music and photographs. Go to [www.w3.org/RDF](http://www.w3.org/RDF) for more information.
- redirection** The process of directing standard input for a program to come from a file rather than from the keyboard. Also, directing standard output or standard error to go to a file rather than to the screen.
- reentrant** Code that can have multiple simultaneous, interleaved, or nested invocations that do not interfere with one another. Noninterference is important for parallel processing, recursive programming, and interrupt handling.
- It is usually easy to arrange for multiple invocations (that is, calls to a subroutine) to share one copy of the code and any readonly data. For the code to be reentrant, however, each invocation must use its own copy of any modifiable data (or synchronized access to shared data). This goal is most often achieved by using a stack and allocating local variables in a new stack frame for each invocation. Alternatively, the caller may pass in a pointer to a block of memory that that invocation can use (usually for output), or the code may allocate some memory on a heap, especially if the data must survive after the routine returns.
- Reentrant code is often found in system software, such as operating systems and teleprocessing monitors. It is also a crucial component of multithreaded programs, where the term *thread-safe* is often used instead of reentrant.<sup>FOLDOC</sup>
- regular character** A character that always represents itself in an ambiguous file reference or another type of regular expression. Contrast with *special character*.

<b>regular expression</b>	A string—composed of letters, numbers, and special symbols—that defines one or more strings. See Appendix A.
<b>relative pathname</b>	A pathname that starts from the working directory. Contrast with <i>absolute pathname</i> (page 1068).
<b>remote access server</b>	See <i>RAS</i> on page 1102.
<b>remote filesystem</b>	A filesystem on a remote computer that has been set up so that you can access (usually over a network) its files as though they were stored on your local computer's disks. An example of a remote filesystem is NFS.
<b>remote procedure call</b>	See <i>RPC</i> on page 1104.
<b>resolver</b>	The TCP/IP library software that formats requests to be sent to the <i>DNS</i> (page 1079) for hostname-to-Internet address conversion. <sup>FOLDOC</sup>
<b>Resource Description Framework</b>	See <i>RDF</i> on page 1102.
<b>restore</b>	The process of turning an icon into a window. Contrast with <i>iconify</i> (page 1087)
<b>return code</b>	See <i>exit status</i> on page 1081.
<b>RFC</b>	<p>Request for comments. Begun in 1969, one of a series of numbered Internet informational documents and standards widely followed by commercial software and freeware in the Internet and UNIX/Linux communities. Few RFCs are standards but all Internet standards are recorded in RFCs. Perhaps the single most influential RFC has been RFC 822, the Internet electronic mail format standard.</p> <p>The RFCs are unusual in that they are floated by technical experts acting on their own initiative and reviewed by the Internet at large rather than being formally promulgated through an institution such as ANSI. For this reason they remain known as RFCs, even after they are adopted as standards. The RFC tradition of pragmatic, experience-driven, after-the-fact standard writing done by individuals or small working groups has important advantages over the more formal, committee-driven process typical of ANSI or ISO. For a complete list of RFCs, go to <a href="http://www.rfc-editor.org">www.rfc-editor.org</a>.<sup>FOLDOC</sup></p>
<b>roam</b>	To move a computer between <i>wireless access points</i> (page 1115) on a wireless network without the user or applications being aware of the transition. Moving between access points typically results in some packet loss, although this loss is transparent to programs that use TCP.
<b>ROM</b>	Readonly memory. A kind of nonvolatile storage. A data storage device that is manufactured with fixed contents. In general, ROM describes any storage system whose contents cannot be altered, such as a phonograph record or printed book. When

used in reference to electronics and computers, ROM describes semiconductor integrated circuit memories, of which several types exist, and CD-ROM.

ROM is nonvolatile storage—it retains its contents even after power has been removed. ROM is often used to hold programs for embedded systems, as these usually have a fixed purpose. ROM is also used for storage of the *BIOS* (page 1071) in a computer. Contrast with *RAM* (page 1102).<sup>FOLDOC</sup>

<b>root directory</b>	The ancestor of all directories and the start of all absolute pathnames. The root directory has no name and is represented by <i>/</i> standing alone or at the left end of a pathname.
<b>root filesystem</b>	The filesystem that is available when the system is brought up in single-user mode. This filesystem is always represented by <i>/</i> . You cannot unmount or mount the root filesystem. You can remount root to change its mount options.
<b>root login</b>	Usually the username of <i>Superuser</i> (page 1109).
<b>root (user)</b>	Another name for <i>Superuser</i> (page 1109).
<b>root window</b>	Any place on the desktop not covered by a window, object, or panel.
<b>rotate</b>	When a file, such as a log file, gets indefinitely larger, you must keep it from taking up too much space on the disk. Because you may need to refer to the information in the log files in the near future, it is generally not a good idea to delete the contents of the file until it has aged. Instead you can periodically save the current log file under a new name and create a new, empty file as the current log file. You can keep a series of these files, renaming each as a new one is saved. You will then <i>rotate</i> the files. For example, you might remove <i>xyzlog.4</i> , <i>xyzlog.3</i> → <i>xyzlog.4</i> , <i>xyzlog.2</i> → <i>xyzlog.3</i> , <i>xyzlog.1</i> → <i>xyzlog.2</i> , <i>xyzlog</i> → <i>xyzlog.1</i> , and create a new <i>xyzlog</i> file. By the time you remove <i>xyzlog.4</i> , it will not contain any information more recent than you want to remove.
<b>router</b>	A device (often a computer) that is connected to more than one similar type of network to pass data between them. See <i>gateway</i> on page 1083.
<b>RPC</b>	Remote procedure call. A call to a <i>procedure</i> (page 1100) that acts transparently across a network. The procedure itself is responsible for accessing and using the network. The RPC libraries make sure that network access is transparent to the application. RPC runs on top of TCP/IP or UDP/IP.
<b>RSA</b>	A public key encryption (page 1045) technology that is based on the lack of an efficient way to factor very large numbers. Because of this lack, it takes an extraordinary amount of computer processing time and power to deduce an RSA key. The RSA algorithm is the de facto standard for data sent over the Internet.
<b>run</b>	To execute a program.
<b>runlevel</b>	The mode that Linux is running in. Runlevels include single-user and multiuser. See Table 11-1 on page 424 for a complete list of runlevels.

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<b>Samba</b>	A free suite of programs that implement the Server Message Block (SMB) protocol. See <i>SMB</i> (page 1106).
<b>schema</b>	Within a GUI, a pattern that helps you see and interpret the information that is presented in a window, making it easier to understand new information that is presented using the same schema.
<b>scroll</b>	To move lines on a terminal or window up and down or left and right.
<b>scrollbar</b>	A <i>widget</i> (page 1115) found in graphical user interfaces that controls (scrolls) which part of a document is visible in the window. A window can have a horizontal scrollbar, a vertical scrollbar (more common), or both. <sup>FOLDLOC</sup>
<b>server</b>	A powerful centralized computer (or program) designed to provide information to clients (smaller computers or programs) on request.
<b>session</b>	The lifetime of a process. For a desktop, it is the desktop session manager. For a character-based terminal, it is the user's login shell process. A session may also be the sequence of events between when you start using a program, such as an editor, and when you finish.
<b>setgid</b>	When you execute a file that has <code>setgid</code> (set group ID) permission, the process executing the file takes on the privileges of the group the file belongs to. The <code>ls</code> utility shows <code>setgid</code> permission as an <code>s</code> in the group's executable position. See also <i>setuid</i> .
<b>setuid</b>	When you execute a file that has <code>setuid</code> (set user ID) permission, the process executing the file takes on the privileges of the owner of the file. As an example, if you run a <code>setuid</code> program that removes all the files in a directory, you can remove files in any of the file owner's directories, even if you do not normally have permission to do so. When the program is owned by <b>root</b> , you can remove files in any directory that a user working with <b>root</b> privileges can remove files from. The <code>ls</code> utility shows <code>setuid</code> permission as an <code>s</code> in the owner's executable position. See also <i>setgid</i> .
<b>sexillion</b>	In the British system, $10^{36}$ . In the American system, this number is named <i>undecillion</i> . See also <i>large number</i> (page 1090).
<b>SHA1</b>	Secure Hash Algorithm 1. The SHA family is a set of cryptographic <i>hash</i> (page 1085) algorithms that were designed by the National Security Agency (NSA). The second member of this family is SHA1, a successor to <i>MD5</i> (page 1093). See also <i>cryptography</i> on page 1077.
<b>share</b>	A filesystem hierarchy that is shared with another system using <i>SMB</i> (page 1106). Also <i>Windows share</i> (page 1115).
<b>shared network topology</b>	A network, such as Ethernet, in which each packet may be seen by systems other than its destination system. <i>Shared</i> means that the network bandwidth is shared by all users.
<b>shell</b>	A Linux system command processor. The three major shells are the <i>Bourne Again Shell</i> (page 1072), the <i>TC Shell</i> (page 1110), and the <i>Z Shell</i> (page 1116).

- shell function** A series of commands that the shell stores for execution at a later time. Shell functions are like shell scripts but run more quickly because they are stored in the computer's main memory rather than in files. Also, a shell function is run in the environment of the shell that calls it (unlike a shell script, which is typically run in a subshell).
- shell script** An ASCII file containing shell commands. Also *shell program*.
- signal** A very brief message that the UNIX system can send to a process, apart from the process's standard input. Refer to “trap: Catches a Signal” on page 943.
- simple filename** A single filename containing no slashes (/). A simple filename is the simplest form of pathname. Also the last element of a pathname. Also *basename* (page 1071).
- single-user system** A computer system that only one person can use at a time. Contrast with *multiuser system* (page 1095).
- slider** A *widget* (page 1115) that allows a user to set a value by dragging an indicator along a line. Many sliders allow the user also to click on the line to move the indicator. Differs from a *scrollbar* (page 1105) in that moving the indicator does not change other parts of the display.
- SMB** Server Message Block. Developed in the early 1980s by Intel, Microsoft, and IBM, SMB is a client/server protocol that is the native method of file and printer sharing for Windows. In addition, SMB can share serial ports and communications abstractions, such as named pipes and mail slots. SMB is similar to a remote procedure call (RPC, page 1104) that has been customized for filesystem access. Also *Microsoft Networking*.<sup>FOLDOC</sup>
- SMP** Symmetric multiprocessing. Two or more similar processors connected via a high-bandwidth link and managed by one operating system, where each processor has equal access to I/O devices. The processors are treated more or less equally, with application programs able to run on any or all processors interchangeably, at the discretion of the operating system.<sup>FOLDOC</sup>
- smiley** A character-based *glyph* (page 1084), typically used in email, that conveys an emotion. The characters :- ) in a message portray a smiley face (look at it sideways). Because it can be difficult to tell when the writer of an electronic message is saying something in jest or in seriousness, email users often use :- ) to indicate humor. The two original smileys, designed by Scott Fahlman, were :- ) and :- (. Also *emoticon*, *smileys*, and *smilies*. For more information search on **smiley** on the Internet.
- smilies** *See smiley.*
- SMTP** Simple Mail Transfer Protocol. A protocol used to transfer electronic mail between computers. It is a server-to-server protocol, so other protocols are used to access the messages. The SMTP dialog usually happens in the background under the control of a message transport system such as **sendmail**.<sup>FOLDOC</sup>

<b>snap (windows)</b>	As you drag a window toward another window or edge of the workspace, it can move suddenly so that it is adjacent to the other window/edge. Thus the window <i>snaps</i> into position.
<b>sneakernet</b>	Using hand-carried magnetic media to transfer files between machines.
<b>sniff</b>	To monitor packets on a network. A system administrator can legitimately sniff packets and a malicious user can sniff packets to obtain information such as user-names and passwords. See also <i>packet sniffer</i> (page 1098).
<b>SOCKS</b>	<p>A networking proxy protocol embodied in a SOCKS server, which performs the same functions as a <i>proxy gateway</i> (page 1101) or <i>proxy server</i> (page 1101). SOCKS works at the application level, requiring that an application be modified to work with the SOCKS protocol, whereas a <i>proxy</i> (page 1101) makes no demands on the application.</p> <p>SOCKSv4 does not support authentication or UDP proxy. SOCKSv5 supports a variety of authentication methods and UDP proxy.</p>
<b>sort</b>	To put in a specified order, usually alphabetic or numeric.
<b>SPACE character</b>	A character that appears as the absence of a visible character. Even though you cannot see it, a SPACE is a printable character. It is represented by the ASCII code 32 (decimal). A SPACE character is considered a <i>blank</i> or <i>whitespace</i> (page 1115).
<b>spam</b>	Posting irrelevant or inappropriate messages to one or more Usenet newsgroups or mailing lists in deliberate or accidental violation of <i>netiquette</i> (page 1095). Also, sending large amounts of unsolicited email indiscriminately. This email usually promotes a product or service. Another common purpose of spam is to <i>phish</i> (page 1099). Spam is the electronic equivalent of junk mail. From the Monty Python “Spam” song. <sup>FOLDOC</sup>
<b>sparse file</b>	A file that is large but takes up little disk space. The data in a sparse file is not dense (thus its name). Examples of sparse files are core files and dbm files.
<b>spawn</b>	See <i>fork</i> on page 1083.
<b>special character</b>	A character that has a special meaning when it occurs in an ambiguous file reference or another type of regular expression, unless it is quoted. The special characters most commonly used with the shell are * and ?. Also <i>metacharacter</i> (page 1093) and <i>wildcard</i> .
<b>special file</b>	See <i>device file</i> on page 1079.
<b>spin box</b>	In a GUI, a type of <i>text box</i> (page 1110) that holds a number you can change by typing over it or using the up and down arrows at the end of the box. Also <i>spinner</i> .
<b>spinner</b>	See <i>spin box</i> .
<b>spoofing</b>	See <i>IP spoofing</i> on page 1089.

spool	To place items in a queue, each waiting its turn for some action. Often used when speaking about printers. Also used to describe the queue.
SQL	Structured Query Language. A language that provides a user interface to relational database management systems (RDBMS). SQL, the de facto standard, is also an ISO and ANSI standard and is often embedded in other programming languages. <sup>FOLDOC</sup>
square bracket	A left square bracket ([) or a right square bracket (]). These special characters define character classes in ambiguous file references and other regular expressions.
SSH Communications Security	The company that created the original SSH (secure shell) protocol suite (www.ssh.com). Linux uses <i>OpenSSH</i> (page 1097).
standard error	A file to which a program can send output. Usually only error messages are sent to this file. Unless you instruct the shell otherwise, it directs this output to the screen (that is, to the device file that represents the screen).
standard input	A file from which a program can receive input. Unless you instruct the shell otherwise, it directs this input so that it comes from the keyboard (that is, from the device file that represents the keyboard).
standard output	A file to which a program can send output. Unless you instruct the shell otherwise, it directs this output to the screen (that is, to the device file that represents the screen).
startup file	A file that the login shell runs when you log in. The Bourne Again and Z Shells run <b>.profile</b> , and the TC Shell runs <b>.login</b> . The TC Shell also runs <b>.cshrc</b> whenever a new TC Shell or a subshell is invoked. The Z Shell runs an analogous file whose name is identified by the <b>ENV</b> variable.
status line	The bottom (usually the twenty-fourth) line of the terminal. The vim editor uses the status line to display information about what is happening during an editing session.
sticky bit	An access permission bit that causes an executable program to remain on the swap area of the disk. It takes less time to load a program that has its sticky bit set than one that does not. Only a user with <b>root</b> privileges can set the sticky bit. If the sticky bit is set on a directory that is publicly writable, only the owner of a file in that directory can remove the file.
streaming tape	A tape that moves at a constant speed past the read/write heads rather than speeding up and slowing down, which can slow the process of writing to or reading from the tape. A proper blocking factor helps ensure that the tape device will be kept streaming.
streams	See <i>connection-oriented protocol</i> on page 1076.
string	A sequence of characters.



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<b>stylesheet</b>	See <i>CSS</i> on page 1077.
<b>subdirectory</b>	A directory that is located within another directory. Every directory except the root directory is a subdirectory.
<b>subnet</b>	Subnetwork. A portion of a network, which may be a physically independent network segment, that shares a network address with other portions of the network and is distinguished by a subnet number. A subnet is to a network as a network is to an internet. <sup>FOLDOC</sup>
<b>subnet address</b>	The subnet portion of an IP address. In a subnetted network, the host portion of an IP address is split into a subnet portion and a host portion using a subnet mask (also address mask). See also <i>subnet number</i> .
<b>subnet mask</b>	A bit mask used to identify which bits in an IP address correspond to the network address and subnet portions of the address. Called a subnet mask because the network portion of the address is determined by the number of bits that are set in the mask. The subnet mask has ones in positions corresponding to the network and subnet numbers and zeros in the host number positions. Also <i>address mask</i> .
<b>subnet number</b>	The subnet portion of an IP address. In a subnetted network, the host portion of an IP address is split into a subnet portion and a host portion using a <i>subnet mask</i> . Also <i>address mask</i> . See also <i>subnet address</i> .
<b>subpixel hinting</b>	Similar to <i>anti-aliasing</i> (page 1069) but takes advantage of colors to do the anti-aliasing. Particularly useful on LCD screens.
<b>subroutine</b>	See <i>procedure</i> on page 1100.
<b>subshell</b>	A shell that is forked as a duplicate of its parent shell. When you run an executable file that contains a shell script by using its filename on the command line, the shell forks a subshell to run the script. Also, commands surrounded with parentheses are run in a subshell.
<b>superblock</b>	A block that contains control information for a filesystem. The superblock contains housekeeping information, such as the number of inodes in the filesystem and free list information.
<b>superserver</b>	The extended Internet services daemon.
<b>Superuser</b>	A user working with <b>root</b> privileges. This user has access to anything any other system user has access to and more. The system administrator must be able to become Superuser (work with <b>root</b> privileges) to establish new accounts, change passwords, and perform other administrative tasks. The username of Superuser is usually <b>root</b> . Also <i>root</i> or <i>root user</i> .
<b>swap</b>	The operating system moving a process from main memory to a disk, or vice versa. Swapping a process to the disk allows another process to begin or continue execution.

swap space	An area of a disk (that is, a swap file) used to store the portion of a process's memory that has been paged out. Under a virtual memory system, the amount of swap space—rather than the amount of physical memory—determines the maximum size of a single process and the maximum total size of all active processes. Also <i>swap area</i> or <i>swapping area</i> . <sup>FOLDOC</sup>
switch	See <i>network switch</i> on page 1096.
symbolic link	A directory entry that points to the pathname of another file. In most cases a symbolic link to a file can be used in the same ways a hard link can be used. Unlike a hard link, a symbolic link can span filesystems and can connect to a directory.
system administrator	The person responsible for the upkeep of the system. The system administrator has the ability to log in as <b>root</b> or use <b>sudo</b> to work with <b>root</b> privileges. See also <i>Superuser</i> .
system console	See <i>console</i> on page 1076.
system mode	The designation for the state of the system while it is doing system work. Some examples are making system calls, running NFS and autofs, processing network traffic, and performing kernel operations on behalf of the system. Contrast with <i>user mode</i> (page 1113).
System V	One of the two major versions of the UNIX system.
TC Shell	<b>tcsh</b> . An enhanced but completely compatible version of the BSD UNIX C shell, <b>csh</b> .
TCP	Transmission Control Protocol. The most common transport layer protocol used on the Internet. This connection-oriented protocol is built on top of <i>IP</i> (page 1088) and is nearly always seen in the combination TCP/IP (TCP over <i>IP</i> ). TCP adds reliable communication, sequencing, and flow control and provides full-duplex, process-to-process connections. <i>UDP</i> (page 1112), although connectionless, is the other protocol that runs on top of <i>IP</i> . <sup>FOLDOC</sup>
tera-	In the binary system, the prefix <i>tera-</i> multiplies by $2^{40}$ (1,099,511,627,776). Tera-byte is a common use of this prefix. Abbreviated as <i>T</i> . See also <i>large number</i> on page 1090.
termcap	Terminal capability. On older systems, the <b>/etc/termcap</b> file contained a list of various types of terminals and their characteristics. <i>System V</i> replaced the function of this file with the <i>terminfo</i> system.
terminal	Differentiated from a <i>workstation</i> (page 1116) by its lack of intelligence, a terminal connects to a computer that runs Linux. A workstation runs Linux on itself.
terminfo	Terminal information. The <b>/usr/lib/terminfo</b> directory contains many subdirectories, each containing several files. Each of those files is named for and holds a summary of the functional characteristics of a particular terminal. Visually oriented textual programs, such as <b>vim</b> , use these files. An alternative to the <b>termcap</b> file.
text box	A GUI <i>widget</i> (page 1115) that allows a user to enter text.

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<b>theme</b>	Defined as an implicit or recurrent idea, <i>theme</i> is used in a GUI to describe a look that is consistent for all elements of a desktop. Go to <a href="http://themes.freshmeat.net">themes.freshmeat.net</a> for examples.
<b>thicknet</b>	A type of coaxial cable (thick) used for an Ethernet network. Devices are attached to thicknet by tapping the cable at fixed points.
<b>thinnet</b>	A type of coaxial cable (thin) used for an Ethernet network. Thinnet cable is smaller in diameter and more flexible than <i>thicknet</i> cable. Each device is typically attached to two separate cable segments by using a T-shaped connector; one segment leads to the device ahead of it on the network and one to the device that follows it.
<b>thread-safe</b>	See <i>reentrant</i> on page 1102.
<b>thumb</b>	The movable button in the <i>scrollbar</i> (page 1105) that positions the image in the window. The size of the thumb reflects the amount of information in the buffer. Also <i>bubble</i> .
<b>tick</b>	A mark, usually in a <i>check box</i> (page 1074), that indicates a positive response. The mark can be a check mark (✓) or an x. Also <i>check mark</i> or <i>check</i> .
<b>TIFF</b>	Tagged Image File Format. A file format used for still-image bitmaps, stored in tagged fields. Application programs can use the tags to accept or ignore fields, depending on their capabilities. <sup>FOLDOC</sup>
<b>tiled windows</b>	An arrangement of windows such that no window overlaps another. The opposite of <i>cascading windows</i> (page 1073).
<b>time to live</b>	See <i>TTL</i> .
<b>toggle</b>	To switch between one of two positions. For example, the <b>ftp glob</b> command toggles the <b>glob</b> feature: Give the command once, and it turns the feature on or off; give the command again, and it sets the feature back to its original state.
<b>token</b>	A basic, grammatically indivisible unit of a language, such as a keyword, operator, or identifier. <sup>FOLDOC</sup>
<b>token ring</b>	A type of <i>LAN</i> (page 1090) in which computers are attached to a ring of cable. A token packet circulates continuously around the ring. A computer can transmit information only when it holds the token.
<b>tooltip</b>	A minicontext help system that a user activates by allowing the mouse pointer to <i>hover</i> (page 1086) over an object (such as those on a panel).
<b>transient window</b>	A dialog or other window that is displayed for only a short time.
<b>Transmission Control Protocol</b>	See <i>TCP</i> on page 1110.

**Trojan horse** A program that does something destructive or disruptive to your system. Its action is not documented, and the system administrator would not approve of it if she were aware of it.

The term *Trojan horse* was coined by MIT-hacker-turned-NSA-spook Dan Edwards. It refers to a malicious security-breaking program that is disguised as something benign, such as a directory lister, archive utility, game, or (in one notorious 1990 case on the Mac) a program to find and destroy viruses. Similar to *back door* (page 1070).<sup>FOLDOC</sup>

**TTL** Time to live.

1. All DNS records specify how long they are good for—usually up to a week at most. This time is called the record's *time to live*. When a DNS server or an application stores this record in *cache* (page 1073), it decrements the TTL value and removes the record from cache when the value reaches zero. A DNS server passes a cached record to another server with the current (decremented) TTL guaranteeing the proper TTL, no matter how many servers the record passes through.
2. In the IP header, a field that indicates how many more hops the packet should be allowed to make before being discarded or returned.

**TTY** Teletypewriter. The terminal device that UNIX was first run from. Today TTY refers to the screen (or window, in the case of a terminal emulator), keyboard, and mouse that are connected to a computer. This term appears in UNIX, and Linux has kept the term for the sake of consistency and tradition.

**tunneling** Encapsulation of protocol A within packets carried by protocol B, such that A treats B as though it were a data link layer. Tunneling is used to transfer data between administrative domains that use a protocol not supported by the internet connecting those domains. It can also be used to encrypt data sent over a public internet, as when you use *ssh* to tunnel a protocol over the Internet.<sup>FOLDOC</sup> See also *VPN* (page 1114) and *port forwarding* (page 1099).

**UDP** User Datagram Protocol. The Internet standard transport layer protocol that provides simple but unreliable datagram services. UDP is a *connectionless protocol* (page 1076) that, like *TCP* (page 1110), is layered on top of *IP* (page 1088).

Unlike *TCP*, UDP neither guarantees delivery nor requires a connection. As a result it is lightweight and efficient, but the application program must handle all error processing and retransmission. UDP is often used for sending time-sensitive data that is not particularly sensitive to minor loss, such as audio and video data.<sup>FOLDOC</sup>

**UID** User ID. A number that the *passwd* database associates with a username.

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<b>undecillion</b>	In the American system, $10^{36}$ . In the British system, this number is named <i>sexillion</i> . See also <i>large number</i> (page 1090).
<b>unicast</b>	A packet sent from one host to another host. Unicast means one source and one destination.
<b>Unicode</b>	A character encoding standard that was designed to cover all major modern written languages with each character having exactly one encoding and being represented by a fixed number of bits.
<b>unmanaged window</b>	See <i>ignored window</i> on page 1087.
<b>URI</b>	Universal Resource Identifier. The generic set of all names and addresses that are short strings referring to objects (typically on the Internet). The most common kinds of URIs are <i>URLs</i> . <sup>FOLDOC</sup>
<b>URL</b>	Uniform (was Universal) Resource Locator. A standard way of specifying the location of an object, typically a Web page, on the Internet. URLs are a subset of <i>URIs</i> .
<b>usage message</b>	A message displayed by a command when you call the command using incorrect command-line arguments.
<b>User Datagram Protocol</b>	See <i>UDP</i> .
<b>User ID</b>	See <i>UID</i> .
<b>user interface</b>	See <i>interface</i> on page 1088.
<b>user mode</b>	The designation for the state of the system while it is doing user work, such as running a user program (but not the system calls made by the program). Contrast with <i>system mode</i> (page 1110).
<b>username</b>	The name you enter in response to the <b>login:</b> prompt. Other users use your username when they send you mail or write to you. Each username has a corresponding user ID, which is the numeric identifier for the user. Both the username and the user ID are stored in the <b>passwd</b> database ( <i>/etc/passwd</i> or the NIS equivalent). Also <i>login name</i> .
<b>userspace</b>	The part of memory (RAM) where applications reside. Code running in userspace cannot access hardware directly and cannot access memory allocated to other applications. Also <i>userland</i> . See the <i>KernelAnalysis-HOWTO</i> .

UTC	Coordinated Universal Time. UTC is the equivalent to the mean solar time at the prime meridian (0 degrees longitude). Also called Zulu time (Z stands for longitude zero) and GMT (Greenwich Mean Time).
UTF-8	An encoding that allows <i>Unicode</i> (page 1113) characters to be represented using sequences of 8-bit bytes.
utility	A program included as a standard part of Linux. You typically invoke a utility either by giving a command in response to a shell prompt or by calling it from within a shell script. Utilities are often referred to as commands. Contrast with <i>builtin (command)</i> (page 1073).
UUID	Universally Unique Identifier. A 128-bit number that uniquely identifies an object on the Internet. Frequently used on Linux systems to identify an <b>ext2</b> or <b>ext3</b> disk partition.
variable	A name and an associated value. The shell allows you to create variables and use them in shell scripts. Also, the shell inherits several variables when it is invoked, and it maintains those and other variables while it is running. Some shell variables establish characteristics of the shell environment; others have values that reflect different aspects of your ongoing interaction with the shell.
viewport	Same as <i>workspace</i> (page 1116).
virtual console	Additional consoles, or displays, that you can view on the system, or physical, console.
virus	A <i>cracker</i> (page 1077) program that searches out other programs and “infects” them by embedding a copy of itself in them, so that they become <i>Trojan horses</i> (page 1112). When these programs are executed, the embedded virus is executed as well, propagating the “infection,” usually without the user’s knowledge. By analogy with biological viruses. <sup>FOLDOC</sup>
VLAN	Virtual LAN. A logical grouping of two or more nodes that are not necessarily on the same physical network segment but that share the same network number. A VLAN is often associated with switched Ethernet. <sup>FOLDOC</sup>
VPN	Virtual private network. A private network that exists on a public network, such as the Internet. A VPN is a less expensive substitute for company-owned/leased lines and uses encryption to ensure privacy. A nice side effect is that you can send non-Internet protocols, such as AppleTalk, IPX, or <i>NetBIOS</i> (page 1095), over the VPN connection by <i>tunneling</i> (page 1112) them through the VPN IP stream.
W2K	Windows 2000 Professional or Server.
W3C	World Wide Web Consortium ( <a href="http://www.w3.org">www.w3.org</a> ).
WAN	Wide area network. A network that interconnects <i>LANs</i> (page 1090) and <i>MANs</i> (page 1093), spanning a large geographic area (typically states or countries).

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<b>WAP</b>	Wireless access point. A bridge or router between wired and wireless networks. WAPs typically support some form of access control to prevent unauthorized clients from connecting to the network.
<b>Web ring</b>	A collection of Web sites that provide information on a single topic or group of related topics. Each home page that is part of the Web ring has a series of links that let you go from site to site.
<b>whitespace</b>	A collective name for SPACES and/or TABS and occasionally NEWLINES. Also <i>white space</i> .
<b>wide area network</b>	See WAN.
<b>widget</b>	The basic objects of a graphical user interface. A button, <i>combo box</i> (page 1075), and <i>scrollbar</i> (page 1105) are examples of widgets.
<b>wildcard</b>	See <i>metacharacter</i> on page 1093.
<b>Wi-Fi</b>	Wireless Fidelity. A generic term that refers to any type of 802.11 (page 1068) wireless network.
<b>window</b>	On a display screen, a region that runs or is controlled by a particular program.
<b>window manager</b>	A program that controls how windows appear on a display screen and how you manipulate them.
<b>Windows share</b>	See <i>share</i> on page 1105.
<b>WINS</b>	Windows Internet Naming Service. The service responsible for mapping NetBIOS names to IP addresses. WINS has the same relationship to NetBIOS names that DNS has to Internet domain names.
<b>WINS server</b>	The program responsible for handling WINS requests. This program caches name information about hosts on a local network and resolves them to IP addresses.
<b>wireless access point</b>	See WAP.
<b>word</b>	A sequence of one or more nonblank characters separated from other words by TABS, SPACES, or NEWLINES. Used to refer to individual command-line arguments. In vim, a word is similar to a word in the English language—a string of one or more characters bounded by a punctuation mark, a numeral, a TAB, a SPACE, or a NEWLINE.
<b>Work buffer</b>	A location where vim stores text while it is being edited. The information in the Work buffer is not written to the file on the disk until you give the editor a command to write it.
<b>working directory</b>	The directory that you are associated with at any given time. The relative pathnames you use are <i>relative to</i> the working directory. Also <i>current directory</i> .

<b>workspace</b>	A subdivision of a <i>desktop</i> (page 1078) that occupies the entire display. See page 110.
<b>workstation</b>	A small computer, typically designed to fit in an office and be used by one person and usually equipped with a bit-mapped graphical display, keyboard, and mouse. Differentiated from a <i>terminal</i> (page 1110) by its intelligence. A workstation runs Linux on itself while a terminal connects to a computer that runs Linux.
<b>worm</b>	A program that propagates itself over a network, reproducing itself as it goes. Today the term has negative connotations, as it is assumed that only <i>crackers</i> (page 1077) write worms. Compare to <i>virus</i> (page 1114) and <i>Trojan horse</i> (page 1112). From <b>Tapeworm</b> in John Brunner's novel, <i>The Shockwave Rider</i> , Ballantine Books, 1990 (via XEROX PARC). <small>FOLDOC</small>
<b>WYSIWYG</b>	What You See Is What You Get. A graphical application, such as a word processor, whose display is similar to its printed output.
<b>X server</b>	The X server is the part of the <i>X Window System</i> that runs the mouse, keyboard, and display. (The application program is the client.)
<b>X terminal</b>	A graphics terminal designed to run the X Window System.
<b>X Window System</b>	A design and set of tools for writing flexible, portable windowing applications, created jointly by researchers at MIT and several leading computer manufacturers.
<b>XDMCP</b>	X Display Manager Control Protocol. XDMCP allows the login server to accept requests from network displays. XDMCP is built into many X terminals.
<b>xDSL</b>	Different types of <i>DSL</i> (page 1081) are identified by a prefix, for example, ADSL, HDSL, SDSL, and VDSL.
<b>Xinerama</b>	An extension to X.org. Xinerama allows window managers and applications to use the two or more physical displays as one large virtual display. Refer to the Xinerama-HOWTO.
<b>XML</b>	Extensible Markup Language. A universal format for structured documents and data on the Web. Developed by W3C (page 1114), XML is a pared-down version of SGML. See <a href="http://www.w3.org/XML">www.w3.org/XML</a> and <a href="http://www.w3.org/XML/1999/XML-in-10-points">www.w3.org/XML/1999/XML-in-10-points</a> .
<b>XSM</b>	X Session Manager. This program allows you to create a session that includes certain applications. While the session is running, you can perform a <i>checkpoint</i> (saves the application state) or a <i>shutdown</i> (saves the state and exits from the session). When you log back in, you can load your session so that everything in your session is running just as it was when you logged off.
<b>Z Shell</b>	<i>zsh</i> . A <i>shell</i> (page 1105) that incorporates many of the features of the <i>Bourne Again Shell</i> (page 1072), <i>Korn Shell</i> (page 1090), and <i>TC Shell</i> (page 1110), as well as many original features.
<b>Zulu time</b>	See <i>UTC</i> on page 1114.



# INDEX

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Note: Only variables that must always appear with a leading dollar sign are indexed with a leading dollar sign. Other variables are indexed without a leading dollar sign.

## SYMBOLS

- ! Boolean operator, 313, 954, 958
- ! variable, 321
- !! to reexecute the previous event, 321
- !\$ last word of the previous event, 323
- # comment, 289
- # prompt, 405
- # variable, 931
- #! to choose a script shell, 288
- \$ in regular expressions, 1026
- \$ in variable name, 301
- !\$ variable, 930
- \$# variable, 915
- \$\$ variable, 917, 929
- \$(...). *See Command, substitution*
- \$\* variable, 932
- \$? variable, 930
- \$@ variable, 903, 932
- \${}, expand variable, 935
- \$0 variable, 931
- % job number, 242, 295
- & background, 241, 292–294, 316, 930
- & background process, 1070
- & bitwise operator, 954, 957
- & in replacement strings (regular expressions), 1029
- && Boolean operator, 313, 515, 951, 955, 956, 958
- ((...)). *See Arithmetic evaluation*
- () command grouping, 293
- () in shell functions, 336
- \* in regular expressions, 1026
- \* special character, 244
- + in extended regular expressions, 1030
- . (dot) builtin, 283, 337, 941, 949
- . directory, 197, 244, 481
- . in regular expressions, 1025
- ./ to execute a file in the working directory, 287, 307
- .. directory, 197, 244, 481
- .autofsck file, 492
- .bash\_history file, 316
- .bash\_login file, 281
- .bash\_logout file, 281
- .bash\_profile file, 281, 317, 468
- .bashrc file, 194, 281, 468
- .bmp filename extension, 191
- .bz2 filename extension, 162, 191
- .c filename extension, 191
- .conf filename extension, 441
- .config file, 547
- .db filename extension, 789, 791
- .forward file, 676, 682
- .gif filename extension, 191
- .gz filename extension, 163, 191
- .htaccess file, 850, 880
- .htm filename extension, 854
- .html filename extension, 191, 854
- .htpasswd file, 880
- .inputrc file, 329
- .jpeg filename extension, 191
- .jpg filename extension, 191, 1089
- .ldif filename extension, 711
- .netrc file, 649
- .o filename extension, 191
- .pdf filename extension, 191
- .pgpkey file, 171

- .php filename extension, 854
- .plan file, 170
- .profile file, 281, 468
- .project file, 171
- .ps filename extension, 191
- .repo filename extension, 499
- .rhosts file, 377, 1053
- .rpmnew filename extension, 30
- .shtml filename extension, 854
- .ssh directory, 623
- .tar.bz2 filename extension, 164
- .tar.gz filename extension, 164
- .tar.Z filename extension, 164, 191
- .tbz filename extension, 164
- .tgz filename extension, 191
- .tif filename extension, 191
- .tiff filename extension, 191
- .toprc file, 568
- .txt filename extension, 191, 245
- .tz filename extension, 164
- .var filename extension, 854
- .Z filename extension, 163, 191
- / (root) directory, 32, 34
- / directory (root), 190, 198
- / within pathnames, 32
- /bin, 198
  - false file, 476
- /boot, 198
  - grub/grub.conf file, 543, 551
  - location, 571
  - partition, 550
- /dev, 199, 230
  - nst0 file, 564
  - null file, 237, 469, 471, 579, 907, 946
  - pts file, 469
  - random file, 470
  - special files, 482
  - st0 file, 563, 564
  - tty file, 942
  - urandom file, 470
  - zero file, 470
- /etc, 199
  - aliases file, 471, 576, 675
  - anacrontab file, 565
  - at.allow file, 471
  - at.deny file, 471
  - auto\_master file, 745
  - bashrc file, 281, 432
  - cron.\* directories, 565
  - cron.allow file, 471
  - cron.d directory, 389
  - cron.deny file, 471
  - crontab file, 389
  - defaultrouter file, 390
  - dhclient.conf file, 452
  - dhcpd.conf file, 453
  - dovecot.conf file, 689
  - dumpdates file, 471, 563
  - exports file, 737, 738, 739
  - fstab file, 388, 472, 731, 735
  - group file, 432, 472, 558
  - grub.conf file, 543, 551
  - hosts file, 372, 387, 472, 601, 695
  - hosts.allow file, 444, 445, 447
  - hosts.deny file, 444, 445, 447
  - hosts.equiv file, 376, 1053
  - httpd directory, 849
  - inittab file, 425, 473, 574
  - issue file, 432
  - login.defs file, 475, 557
  - logrotate.conf file, 580
  - logrotate.d directory, 580
  - mail directory, 677, 680
  - motd file, 432, 474, 476, 572
  - mtab file, 474
  - named.conf file, 786, 793, 794, 807, 812
  - netgroup file, 474
  - nologin.txt file, 462, 476
  - nsswitch.conf file, 387, 432, 455, 475, 696, 785
  - ntp.conf file, 389
  - opt directory, 199
  - pam.conf file, 463
  - pam.d directory, 458, 459, 461, 463, 475
  - passwd file, 305, 431, 475, 574, 695, 903, 904
  - printcap file, 476
  - profile file, 281, 412, 432, 476
  - protocols file, 476, 829
  - rc.d
    - directory hierarchy, 429, 476
  - init.d
    - about, 426
    - independent services, 428
    - init scripts, 426
  - rc file, 426
  - rc.local file, 427
  - rc.sysinit file, 426, 492
  - rcn.d directory, 426
  - resolv.conf file, 476, 602, 787
  - rpc file, 392, 477
  - rsyslog.conf file, 390, 583
  - securetty file, 407
  - security/access.conf file, 407
  - selinux/config file, 415
  - services file, 388, 392, 477
  - shadow file, 431, 477
  - share/magic file, 480
  - shells file, 439
  - skel directory, 557
  - ssh directory, 623
  - sudoers file, 406
  - sysconfig, 478
    - httpd file, 844, 871
    - iptables file, 823, 833, 838
    - iptables-config file, 823
    - named file, 786, 805
    - network file, 699, 704
    - rsyslog file, 584
    - selinux file, 415
    - yppasswdd file, 710
  - sysctl.conf file, 543, 544
  - vsftpd
    - chroot\_list file, 666
    - ftputers file, 666
    - user\_list file, 666
  - X11, 84
  - xinetd.conf file, 428, 445
  - xinetd.d directory, 428, 446
  - yp.conf file, 700
  - ypserv.conf file, 704
  - yum.conf file, 498
  - yum.repos.d directory, 498, 499
  - /home directory, 199
  - /lib, 199
    - modules directory, 199, 550
    - security directory, 458, 461
  - /lost+found directory, 436
  - /mnt directory, 199
  - /opt directory, 199, 513
  - /proc
    - contents, 199
    - filesystem, 478, 487
    - fs/nfs file, 738
    - mounts file, 474
    - sys file, 544
  - /root, 199
    - anaconda-ks.cfg file, 65
    - install.log file, 65
  - /sbin, 199
  - /sys directory, 199

/tmp directory, 199, 579, 917  
 /usr, 199  
   bin directory, 199  
   doc directory, 200  
   games directory, 199  
   include, 199  
   info directory, 200  
   lib, 199  
   local, 199, 513  
   man directory, 200  
   sbin, 200  
     daemons, 388  
   share, 200  
   src directory, 200, 544  
 /var, 200  
   ftp directory, 655  
   lib/nfs/xtab file, 738, 743  
   log, 200, 480, 1034  
     disk usage, 579  
     lastlog file, 200  
     maillog file, 578  
     messages file, 200, 459, 480,  
       574, 578, 579, 805,  
       1034  
     secure file, 459, 480, 1034  
     vsftpd.log file, 666  
     wtmp file, 200, 581  
   log directory, 1054  
   mail directory, 579  
   named directory, 794, 800  
   spool, 1034  
     disk usage, 579  
     mail directory, 307  
     mqueue file, 674  
   tmp directory, 579  
   www  
     Apache files, 849  
     html directory, 844, 846,  
       849  
 : (null) builtin, 936, 945, 949  
 := assign default value, 935  
 := substitute default value, 935  
 :? display error message, 936  
 ; command separator, 290  
 < redirect standard input, 234,  
   284, 1068  
 <& duplicate input file  
   descriptor, 922  
 << Here document, 919, 1068  
 > redirect standard output, 232,  
   235, 284, 285, 1068  
 >& duplicate output file  
   descriptor, 285, 922

>> append standard output, 236,  
   1068  
 ? in extended regular  
   expressions, 1030  
 ? special character, 243  
 @ in a network address, 374–376  
 @ variable, 903  
 @ with email, 376  
 [] character class, 245  
 [] character class (regular  
   expressions), 1025,  
   1074  
 [[...]] builtin, 952. *See also*  
   Conditional expression  
 \ escape character, 148, 291, 301  
 \ ( in regular expressions, 1028  
 \) in regular expressions, 1028  
 ^ bitwise operator, 954  
 ^ in regular expressions, 1026  
 ^ quick substitution character,  
   324  
 { expansion, 344  
 { in a shell function, 336  
 | bitwise operator, 954  
 | (OR) Boolean operator, 1030  
 | in extended regular expressions,  
   1030  
 | pipe, 238, 285, 292  
 || Boolean operator, 313, 951,  
   955–957  
 } expansion, 344  
 } in a shell function, 336  
 ~ (tilde) expansion, 193, 305,  
   345  
 ~ home directory, 305. *See also*  
   Home directory  
 ~ in pathnames, 193  
 ` ... `. *See Command,*  
   substitution

## NUMERICS

0< redirect standard input, 284  
 1> redirect standard output, 284  
 10.0.0.0 (IP address), 1068  
 10Base2 cable, 361  
 10BaseT cable, 361  
 100BaseT cable, 361  
 172.16.0.0 (IP address), 1068  
 192.168.0.0 (IP address), 1068  
 2> redirect standard error, 284  
 3-DES encryption, 1047

64-bit PC processor architecture,  
   27  
 802.11 wireless specification,  
   1068

## A

A, 1092  
 -a Boolean operator, 895, 951  
 Aborting execution, 140  
 Absolute pathname, 193, 228,  
   311, 1068  
 Access, 1068  
 Access Control Lists. *See ACL*  
 access file, 680  
 Access permission, 204, 288,  
   1068  
   change using chmod, 204  
   defined, 203  
   directory, 206  
   display using ls, 203  
   execute, 203, 287  
   group, 203  
   Nautilus, 121  
   other, 203  
   owner, 203  
   read, 203  
   write, 203  
 access.conf file, 407  
 Account, FTP, 476  
 accton utility, 1054  
 ACL, 207, 1049, 1068  
   access rules, 208  
   default rules, 211  
   effective rights mask, 210  
 acpi boot parameter, 69  
 acpid daemon, 388  
 Active window, 141, 1068  
 Add  
   software package, 497, 512  
   user, 556, 557  
 Add/Remove Applications  
   window, 123  
 addbanner shell script, 945  
 Address  
   *See also the type of address you*  
   *are looking for (e.g.,*  
   *MAC address, IP*  
   *address) or see the*  
   *specific address (e.g.,*  
   *127.0.0.1)*  
 IP  
   class, 368  
   representation, 367

Address, *continued*

- MAC, 454
- mask, 371. *See also Subnet, mask*
- network, 374
- space, private, 598
- adduser utility, 557
- adfs filesystem, 485
- Administration submenu, 114
- Administrator, system. *See System, administrator*
- Advanced Encryption Standard. *See AES encryption*
- AES encryption, 1047
- affs filesystem, 485
- AIDE utility, 413, 1053, 1058
- AIM, 358
- Algorithm, 959
- Alias, 1068
  - bash, 332
  - double versus single quotation marks, 333
  - email, 675
  - quotation marks, 333
  - recursion, 332
  - recursive plunge, 335
  - single versus double quotation marks, 333
- alias builtin, 332
- aliases file, 471, 576, 675, 682
- Alphanumeric character, 1068
- amanda utility, 560
- Ambiguous file reference, 243, 1068
- AMD64 processor architecture, 27
- American National Standards Institute, 9
- Anaconda, 57
- anaconda.cfg file, 82
- anaconda-ks.cfg file, 65
- anacron utility, 565
- anacrontab file, 565
- AND bitwise operator, 370, 371
- AND Boolean operator, 895, 951
- Andreessen, Marc, 395
- Angle bracket, 1068
- ANI, 1056
- Animate, 1068
- Anonymous FTP, 394, 649
- ANSI, 9
- ANSI C, 9

- ansi terminal name, 1041
- Answers to questions, finding, 394
- Antialiasing, 1069
- Apache, 841
  - .htaccess context, 854
  - .htaccess file, 850, 880
  - .htpasswd file, 880
  - <Directory> container, 855, 872
  - <Files> container, 855
  - <IfModule> container, 856, 871
  - <Limit> container, 856
  - <LimitExcept> container, 857
  - <Location> container, 857
  - <LocationMatch> container, 858
  - <VirtualHost> container, 858, 874
- AddHandler directive, 862
- Alias directive, 862
- Allow directive, 868
- AllowOverride directive, 869
- authentication modules, 880
- CGI, 877, 881
- Common Gateway Interface. *See Apache, CGI*
- configuration directives. *See Apache, directives*
- containers, 855
- content, 842, 844, 846
- contexts, 854
- Deny directive, 869
- directives, 850
  - control content, 862
  - control processes, 858
  - security, 868
- directory context, 854
- directory listings, 874
- DirectoryIndex directive, 853, 873
- document root, 844
- DocumentRoot directive, 852, 872
- DSO, 842, 876
- dynamic shared objects, 842, 876
- error codes, 882
- ErrorDocument directive, 863
- ErrorLog directive, 861
- Fedora test page, 872
- files, where to find, 848

- filesystem layout, 848
- group **apache**, 844
- Group directive, 866
- HostnameLookups directive, 860
- httpd daemon and, 844
- httpd directory, 849
- httpd.conf file, 845, 850, 870
- HTTPS protocol, 877
- Include directive, 866, 872
- index.htm file, 854
- index.html file, 854
- index.php file, 854
- index.shtml file, 854
- indexing, 874
- IndexOptions directive, 863
- JumpStart
  - Apache, getting up and running, 844
  - Apache, setting up with system-config-httpd, 846
- Listen directive, 851, 871
- LoadModule directive, 867, 872
- log, 849
- LogLevel directive, 861
- logresolve utility, 860
- MaxClients directive, 858
- MaxRequestsPerChild directive, 859
- MaxSpareServers directive, 859
- MinSpareServers directive, 859
- mod\_perl module, 881
- mod\_python module, 881
- mod\_ssl module, 877
- modules, 842, 876
- more information, 843
- MRTG, 882
- multiviews, 874
- Options directive, 867
- Order directive, 870
- pathname, 850
- Perl, 881
- PHP, 881
- prerequisites, 843
- privileged port, 844
- process, defined, 844
- public\_html directory, 853
- Python, 881
- redirect, 873
- RHEL test page, 872
- root permission, 844

ScriptAlias directive, 868  
 scripting modules, 881  
 self-signed certificate, 878  
 server config context, 854  
 server, defined, 844  
 ServerAdmin directive, 845, 851, 872  
 ServerName directive, 845, 852, 872  
 ServerRoot directive, 865, 871  
 ServerSignature directive, 866  
 ServerTokens directive, 865, 871  
 Software Foundation, 841  
 special directives. *See Apache, containers*  
 SSL, 877  
 StartServers directive, 860  
 system-config-httpd utility, 846  
 terminology, 844  
 test page, 872  
 Testing, 845  
 Timeout directive, 860  
 troubleshooting, 875  
 UseCanonicalName directive, 861, 873  
 User directive, 868  
 UserDir directive, 853  
 Users publishing content, 853  
 virtual host context, 854  
 virtual hosts, 874  
 webalizer utility, 881  
 www directory, 849  
 API, 1069  
 apic boot parameter, 69  
 apm boot parameter, 69  
 apm utility, 435  
 apmd daemon, 388  
 Appearance Preferences window, 106  
 Append, 1069  
 Append standard output, 236  
 Applet, 113, 1069  
   clock, 96  
   Window List, 113  
   Workspace Switcher, 95  
 AppleTalk, 371  
 Application, Run window, 274  
 Application, terminating, 98  
 Applications menu, 114  
 apropos utility, 67, 127, 167, 1035  
 Archive, 1069  
   pack using tar, 163

  shell, 920  
   unpack using tar, 163  
 Argument, 195, 224, 1069  
   command-line, 932  
   display, 932  
   testing, 890  
 Arithmetic  
   bash, 950  
   expansion, 346  
   expression, 1069  
 Arithmetic evaluation, 950  
   example, 905, 928, 951  
 Array, 979, 1069  
 ASCII, 1069  
 ascii file, 1069  
 ASCII terminal, 1069  
 ASP, 1069  
 aspell utility, 905, 907  
 Assembly language, 9  
 Asterisk special character, 1026  
 Asymmetric encryption. *See Public key encryption*  
 Asynchronous communication, 483  
 Asynchronous event, 1070  
 at utility, 388, 471, 565  
 at.allow file, 471  
 at.deny file, 471  
 atd daemon, 388  
 Athena, Project, 256  
 ATM link, 360  
 AT&T Bell Laboratories, 5, 280  
 Attachments, 1070  
 Attribute, LDAP, 711  
 authconfig utility, 437  
 Authenticated relaying, email, 689  
 Authentication, 1070  
   Apache, 880  
   database, 1055  
   OpenSSH, 622, 624, 626  
   user, 432  
 authorized\_keys file, 623  
 auto\_master file, 745  
 autofs filesystem, 485, 744  
 Automake, 513  
 Automatic  
   mounting, 388, 1070  
   number identification, 1056  
 automount daemon, 388, 745, 746  
 automount utility, 744  
 Avoided, 1070

## B

B language, 9  
 Back door, 1070  
 Back tick, 349, 1075. *See also Command, substitution*  
 Background  
   command grouping, 293  
   defined, 241  
   foreground, versus, 241  
   job control, 13, 294  
   PID stored in \$!, 930  
   process, 316, 1070  
   running a command in, 241  
   symbol (&), 292  
 BACKSLASH escape character, 148, 291, 301  
 BACKSLASH in replacement strings, 1029  
 BACKSPACE key (erase character), 139  
 Backup  
   active filesystem, 559  
   amanda, 560  
   cpio utility, 561  
   dump level, 563  
   failing to perform, 573  
   file, 558, 563  
   full, 559  
   incremental, 559  
   media, 559  
   offsite, 559  
   partition planning and, 36  
   policy, 559  
   simple, 562  
   tar utility, 560  
   utilities, 560  
 Basename, 193, 1071  
 basename utility, 915, 916, 945  
 bash, 1072  
   <& duplicate input file  
     descriptor, 922  
   >& duplicate output file  
     descriptor, 922  
   alias, 332  
   arguments, 932  
   arithmetic evaluation, 950  
     example, 905, 928, 951  
     operators, 953  
   arithmetic expansion, 346  
     operators, 953  
   array variables, 924

- bash, *continued*
  - attribute
    - array, 304
    - export, 304
    - function, 304
    - integer, 304, 305
    - readonly, 303, 304
  - background, 280
  - builtin
    - exec, 921
    - getopts, 946
    - typeset, 928
  - close file, 922
  - command
    - process, 342
    - substitution, 348
  - command line, order of
    - expansion, 301
  - conditional expression, 951
    - example, 923, 947
  - control structure. *See Control, structure*
  - directory stack manipulation, 296
  - editing previous commands, 318, 319
  - emacs command-line editor, 327
  - event number, 317
  - expand null variable, 935
  - expand unset variable, 935
  - expression, 953
  - features, 338
  - file descriptor, 921
  - globbing, 349
  - history mechanism, 316, 320
  - makepath** shell script, 959
  - menu, 917
  - open file, 921
  - operator, 953
    - bitwise, 957
    - remainder, 956
    - short-circuiting, 956
    - ternary, 957
  - options. *See bash, features*
  - overlay, 290
  - pathname completion, 328
  - process substitution, 351
  - program structures, 958
  - programming, 958
  - prompt, 307
  - PS3** prompt, 918
  - quick substitution, 325
  - quiz shell script, 962
  - quotation mark removal, 343
  - recursion, 959
  - redirection operators, 286
  - reexecuting events, 318, 319
  - REPLY** keyword variable, 918
  - signal names, 943, 946
  - special characters, 148
  - standard error. *See Standard, error*
  - standard input. *See Standard, input*
  - standard output. *See Standard, output*
  - startup files, 281
  - string pattern matching, 952
  - substitution, quick, 325
  - symbolic link, 217
  - ternary operator, 955
  - tilde substitution, 345
  - variable
    - See also Variable*
    - array, 924
    - assign default value, 935
    - BASH\_ENV**, 282
    - COLUMNS**, 918
    - DISPLAY**, 260
    - display error message, 936
    - expansion, 935
    - LINES**, 918
    - modifier, 935
    - OPTARG**, 947
    - OPTIND**, 947
    - PS3**, 918
    - REPLY**, 918, 938
    - substitute default value, 935
    - TERM**, 135
    - vim command-line editor, 326
    - x** option, 900
- BASH\_ENV** variable, 282
- bashrc** file, 432
- Baud, 1071
- BCPL language, 9
- Bell Laboratories. *See AT&T Bell Laboratories*
- Berkeley
  - DB, 710
  - Internet Name Domain. *See DNS*
  - UNIX, 6, 14, 1071
- Berners-Lee, Tim, 395
- bg** builtin, 241, 295, 949
- bin** directory, 306
- Binary file, 287
- BIND. *See DNS*
- bind builtin, 330
- Binding, key, 1090
- BIOS, 1071
  - boot from CD, 26
  - security, 577
  - setup, 26
- birthday** shell script, 919
- bison utility, 16
- Bit, 1071
  - bucket, 237, 469
  - depth. *See Color depth*
  - bit-mapped display, 1071
- BitTorrent, 507
  - bittorrent-curses utility, 508
  - downloading from the
    - command line, 508
  - manners, 508
  - obtaining Fedora using, 44
  - peer, 507
  - prerequisites, 508
  - seed, 507
  - swarm, 508
  - torrent, 508
  - torrent information,
    - displaying, 509
  - torrentinfo-console utility, 509
  - tracker, 507
- bittorrent-curses utility, 508
- Bitwise operator
  - &**, 954, 957
  - ^**, 954
  - l**, 954
  - AND**, 370, 371
- Blank character, 148, 301, 1071, 1107
- Block
  - device, 484, 1071
  - disk, 1071
  - number, 1071
  - Perl, 979
  - special file, 1071
- Blocking factor, 1072
- Blowfish encryption, 1047
- bmp** filename extension, 191
- Boolean operator, 956, 1072
  - !**, 313, 954, 958
  - &&**, 313, 515, 951, 955, 956, 958
  - l**, 1030
  - ll**, 313, 951, 955–957
  - a**, 895, 951
  - NOT**, 958
  - o**, 951

- Boot, 1072
    - Linux, 551
    - loader, 1072
      - grub, 551
    - netboot, 1095
    - options, 68
    - options, kernel, 543
    - parameter
      - modifying, 68
      - quiet, 54
      - splash, 54
    - the system, 52, 425
  - /boot directory, 35
  - boot partition, 550
  - Bootstrap, 1072
  - Bottleneck, network, 381
  - Bourne, Steve, 280, 1072
  - Bourne Shell (original), 280, 1072
  - Brace, 1072
    - around a variable, 302
    - expansion, 344
    - shell functions, 336
  - Bracket, 1072
    - character class, 1025
    - filename expansion, 245
  - Branch, 1072
  - break control structure, 910, 949
  - Bridge, network, 1072
  - Bringing the system down, 433
  - Broadcast, 1072
    - about, 370
    - address, 1072
    - network, 360, 1072
    - packet, 367
    - unicast versus, 367
  - Browse/Save window, 103
  - Browser, 395
    - file. *See* *Nautilus*
    - Firefox, 109
    - Lynx (text only), 396
    - Mosaic, 395
    - Mozilla, 393, 395, 396, 516
  - BSD. *See* *Berkeley, UNIX*
  - Buffer, 1073
    - copy, 116
    - disk, 434
    - primary, 116
    - selection, 116
  - Bug, 515, 1073
    - BugSplat, 516
    - Bugtraq, 1054
    - Bugzilla, 516
  - defect-tracking system, 516
  - system, 515
  - Builtin, 247, 890, 936, 1073
    - . (dot), 283, 941, 949
    - : (null), 936, 945, 949
    - [[...]], 952
    - alias, 332
    - bash, list of, 949
    - bg, 241, 295, 949
    - bind, 330
    - cd, 196, 217, 293, 305, 311, 949
    - command, editing using *fc*, 320
    - declare, 303, 304
    - dirs, 296
    - echo, 159, 244, 301, 914, 929, 937, 945, 949
    - eval, 337, 949
    - exec, 286, 921, 940, 949
    - execution of, 316
    - exit, 109, 930, 945, 949
    - export, 304, 305, 476, 926, 949
    - fc*, 318
    - fg*, 242, 295, 949
    - getopts*, 946, 949
    - history, 316, 317
    - jobs, 140, 242, 294, 296, 949
    - kill, 140, 242, 408–410, 575, 917, 944, 946, 949
    - let, 347, 950
    - locale, 312
    - null, 945, 949
    - popd*, 298
    - pushd*, 297
    - pwd*, 192, 196, 949
    - read, 907, 908, 913, 937, 938, 950
    - readonly, 303, 304, 305, 950
    - set, 304, 897, 899, 900, 934, 935, 950
    - shift, 933, 948, 950
    - source, 283
    - test, 889–891, 895, 899, 902, 904, 950
    - times, 950
    - tput*, 909
    - trap, 909, 943, 950
    - type, 937, 950
    - typeset*, 928
    - umask, 440, 476
    - unalias, 332, 335
    - unset, 303, 336, 950
    - utility versus, 890
    - wait, 950
  - bundle shell script, 920
  - bunzip2 utility, 162, 166
  - Burning installation CD/DVD, 45
  - Buttons, 113
  - by-id file, 469
  - Byte, 1073
  - by-uuid file, 469
  - bz2 filename extension, 162, 191
  - bzcat utility, 163
  - bzip2 utility, 162, 166, 562
  - bzip2recover utility, 163
- ## C
- C. *See* *C programming language*
  - c filename extension, 191
  - C programming language, 1073
    - about, 8, 9
    - library
      - getpwnam()* function, 697
      - getpwuid()* function, 697
      - libwrap.a*, 445, 447
    - portability, 9
  - C++ programming language, 9
  - C89 programming language, 9
  - Cable
    - 10Base2, 361
    - 10BaseT, 361
    - Category 5, 361
    - Category 5e, 361
    - Category 6, 359, 361
    - Category 7, 359
    - coaxial, 361
    - fiberoptic, 361
    - glass, 361
    - modems, 1073
    - thicknet, 361
    - thinnet, 361
    - twisted pair, 361
    - unshielded twisted pair, 361
    - UTP, 361
  - Cache, 1073
  - Cache, DNS. *See* *DNS, cache*
  - Cacti, 607
  - Call by value, 926
  - Caller ID, 1056
  - Calling environment, 1073
  - Calling program, name of, 931
  - cancel utility, 531
  - Caret in regular expressions, 1026
  - Cascading stylesheet. *See* *CSS*

- Cascading windows, 1073
- case control structure, 911
- Case-sensitive, 1073
  - domain name, not, 386
  - filename, 191
- cat utility, 149, 231, 233, 234, 284, 894
- Category 5 cable, 361
- Category 5e cable, 361
- Category 6 cable, 359, 361
- Category 7 cable, 359
- Catenate, 149, 234, 1073
- CD
  - download, burn, and install
    - Fedora, 41
  - live, 24
- cd builtin, 196, 217, 293, 305, 311, 949
- CDPATH variable, 311
- CentOS, 29
- CERN, 395
- CERT, 1054, 1058
- CGI, 877
- Chain loading, 1074
- Change
  - access permission using `chmod`, 204
  - directories using `cd`, 196
  - filename using `mv`, 152
- Character
  - alphanumeric, 1068
  - blank, 1071, 1107
  - class, 245, 1074
  - control, 1076
  - device, 484, 1074
  - escaping, 291
  - list. *See Character, class*
  - meta, 1093
  - nonprinting, 1097
  - printable, 1100
  - quoting, 291
  - typeface, 17
  - regular, 1102
  - special, 1074. *See also Special, character; Special, file*
- Character based, 1074
- Character-based terminal, 1074
- Check box, 1074
- Check mark. *See Tick*
- Check. *See Tick*
- Checksum, 1074
- CHECKSUM file, 45
- Child
  - directory, 189, 190
  - process, 314, 316, 1074
- chkargs shell script, 890, 892
- chkconfig utility, 429
- chkrootkit utility, 1058
- chmod utility, 204, 288
- chroot jail
  - BIND, 804
  - DNS, 804
  - FTP, 658
  - named daemon, 804
  - running a service in, 450
  - security considerations, 451
  - setting up, 448
  - using, 449
  - vsftpd, 658
- chroot\_list file (vsftpd), 666
- chsh utility, 439
- CIDR, 371, 1074
- CIFS, 1075
- CIPE, 1075
- Cipher, 1075
- Ciphertext, 1044, 1075
- Clark, Jim, 395
- Class
  - character, 1074
  - IP address, 368
- Classless Inter-Domain Routing.  
*See CIDR*
- Clear screen, 173
- clear utility, 439
- Cleartext, 1075
- CLI, 1075. *See also Command line; Textual, interface*
- Click and right-click, 93
- Click object, 93
- Click-to-focus, 141
- CLID, 1056
- Client, 1075
  - specifying, 442
- Client/server model, 384, 386, 395, 447, 643, 695, 727
- Clipboard, 117
- Clock applet, 96
- Close files, bash, 922
- CMOS setup, 26
- CN, LDAP, 711
- Coaxial cable, 361
- coda filesystem, 485
- Code, reentrant, 1102
- CODEC, 1075
- Collating sequence, machine, 1092
- Colon (:) builtin, 936
- Color
  - depth, 261, 1075
  - Pick a Color window, 273
  - quality. *See Color depth*
- Column, 585
- COLUMNS variable, 918
- Combo box, 1075
- Comer, Doug, 4
- Command, 224, 1075
  - ; separator, 290
  - argument, 224
  - builtin, 247, 316
  - completion, 328
  - control flow. *See Control, structure*
  - control structure. *See Control, structure*
  - editing previous, 319
  - editing/repeating, 140
  - execution of, 316
  - export, 468
  - grouping, 290, 293
  - interpreter, shell, 118
  - line. *See Command line*
  - mode, vim, 176
  - name, 224
  - NEWLINE separator, 290
  - option, 225
  - process, 342
  - reexecuting previous, 319
  - run remotely, ssh, 628
  - separation, 290
  - separator, 291, 892
  - substitution, 348, 899, 916, 1075
  - summary, 949
  - syntax, 224
  - terminator, 291
  - usage message, 224, 892, 898
- Command line, 138, 224, 1075
  - argument, 224, 931
  - editing, 140, 326
  - execution, 229
  - expansion, 301, 343
  - interface, 1075
  - option, 225
  - parse, 227, 342
  - printing from, 530
  - processing, 227, 301
  - syntax, 224



- token, 224, 342
- whitespace, 291
- word, 224, 342
- command\_menu** shell script, 913
- Comments, shell scripts, 289
- Common Name, LDAP, 711
- Common UNIX Printing System.
  - See CUPS*
- Communication
  - interprocess, 158, 483
  - network, 374
  - write, 172
- comp.lang.c** newsgroup, 393
- comp.os.linux.announce**
  - newsgroup, 394
- comp.os.linux.answers**
  - newsgroup, 413, 1037
- comp.os.linux.misc** newsgroup, 393, 394, 413, 1037
- comp.os.linux.networking**
  - newsgroup, 394
- comp.os.linux.security**
  - newsgroup, 394
- comp.os.linux.setup** newsgroup, 394
- comp.security.firewalls**
  - newsgroup, 1053
- Compare files using diff, 157
- Compiz window manager, 108, 143
- Completion
  - command, 328
  - filename, 1082
  - pathname, 328
  - Readline Library, 328
  - variable, 329
- Component architecture, 1076
- Compress
  - bunzip2, 166
  - bzip2, 162, 166, 562
  - bzip2recover, 163
  - compress, 163, 191
  - gzip, 163
  - OpenSSH, 641
  - uncompress, 191
  - unzip, 163
  - zip, 163
- compress utility, 163, 191
- Computer Systems Research Group, 6
- Computer, diskless, 1079
- Computing, distributed, 383, 1079
- Concatenate. *See Catenate*
- Condition code. *See Exit, status*
- Conditional expression, 951
  - example, 923, 947
- conf** filename extension, 441
- config** file, 415, 631
- configs** directory, 547
- Configure
  - and Build System, 513
  - daemon, 429
- configure** shell script, 514
- Connectionless protocol, 1076
- Connection-oriented protocol, 366, 1076
- Console, 1076
  - single-user mode, 430
  - virtual, 137, 1114
- consolehelper utility, 409, 434
- Content, Apache, 842
- Context menu, Object, 96, 119
- continue** control structure, 910, 949
- Control
  - characters, printer, 914
  - flow. *See Control, structure*
  - job, 241
  - structure, 888
    - break**, 910, 949
    - case**, 911
    - continue**, 910, 949
    - do**, 901, 902, 904, 908
    - done**, 901, 902, 904, 908
    - elif**, 895
    - elif** versus **fi**, 895
    - else**, 892
    - esac**, 911
    - fi**, 888, 892, 895
    - fi** versus **elif**, 895
    - for**, 901, 902, 945
    - for...in**, 901, 902
    - if**, 888, 892, 895
    - if...then**, 888
    - if...then...elif**, 895
    - if...then...else**, 892
    - in**, 901
    - select**, 917
    - shell scripts, 287
    - then**, 888, 892, 895
    - two-way branch, 892
    - until**, 908
    - while**, 904, 940, 945
- Control bars, Nautilus, 266
- Control character, 1076
- CONTROL key, 17
- Control structures, 1076
- control-alt-delete event, 434
- control-alt-delete** file, 434
- CONTROL-C key (copy), 116
- CONTROL-C key (interrupt), 140
- CONTROL-D key (exit), 109, 232, 296
- CONTROL-H key (erase character), 139, 148, 179, 227
- CONTROL-L key, 173, 181
- CONTROL-M key, 148
- CONTROL-Q key (Xoff), 135
- CONTROL-R key, 173
- CONTROL-U key (line kill), 139, 148, 179, 227
- CONTROL-V key (paste), 116, 148
- CONTROL-W key (delete word), 139, 179, 227
- CONTROL-X key (cut), 116
- CONTROL-X key (line kill), 139
- CONTROL-Z key (suspend), 139, 241, 295
- Conventions
  - end line key, 17
  - file naming, 245
  - in this book, 16
- Convert file to/from Windows format, 161
- Cookie, 1076
- Coordinated Universal Time. *See UTC*
- Copy
  - buffer, 116
  - directory recursively using mv, 481
  - directory, shell script, 293
  - file using cp, 151, 202
- Copyleft, 5
- core** file, 579
- Correcting typing mistakes, 138
- count** shell script, 905
- cp utility, 151, 202, 293
- cp versus ln, 214
- CPAN, 1013
- cpdir** shell script, 293
- cpio utility, 561, 562
- CPU, 1077
- CPU-intensive processes, report on, 567
- crack utility, 577
- Cracker, 1077
- Crash, 436, 1077
- Crash flag, 492

## Create

- directory using mkdir, 195
- file using vim, 174
- file, null, 469

Creation date, file, display using  
ls, 203

**cron** directory, 389

**cron.\*** directories, 565

**cron.allow** file, 471

**cron.d** directory, 389

**cron.deny** file, 471

**crond** daemon, 389, 565

**crontab** file, 389

crontab utility, 471, 565

Cryptography, 1077. *See also*  
*Encryption*

csh Shell, 1073

.cshrc file, 1077

CSRG, 6

CSS, 1077

CUPS, 520

- command-line interface,  
533–537

- configuring a printer, 532–533
- drivers, display using lpinfo,  
533

firewall setup, 521

IPP protocol, 520

JumpStart

- configuring a local printer,  
521
- setting up a local or remote  
printer using the CUPS  
Web interface, 527

more information, 521

**ppd** directory, 535

PPD files, 533

prerequisites, 520

print queue, managing, 523,  
536

printer

- configure using lpadmin,  
534–536
- disable using cupsreject, 536
- enable using cupsaccept, 536
- sharing, 537

printing from Windows, 538

printing quotas, 536

printing to Windows, 540

URIs, 525, 534

Web interface, 527–530,  
532–533

cupsaccept utility, 536, 537

cupsdisable utility, 537

cupsenable utility, 537

cupsreject utility, 536, 537

Current, 1077

Current directory. *See Working  
directory*

Cursor, 1077

Cut and paste, 116

cut utility, 347

Cycling, window, 116

Cypher, 1075

## D

Daemon, 1078

acpid, 388

apmd, 388

atd, 388

automount, 388, 745, 746

configure, 429

crond, 389, 565

dhcpcd, 389

dhcpcd, 389, 452, 453

ftpd, 389

gated, 390

gateway, 390

gpm, 389

httpd, 389

imapd. *See Daemon, imap-  
login*

imap-login, 689

in.fingerd, 375, 389

inetd, 389

ipop3d. *See Daemon, pop3-  
login*

lockd, 389

lpd, 389

messages, 480, 574, 579, 1054

mountd, 389, 733

name, 388

named, 389, 788, 794

network, 358, 388

NetworkManager, 599

nfsd, 389, 743

nmbd, 390, 750, 768, 769

ntpd, 389

pop3-login, 689

portmap, 389, 392, 730

postfix, 1050

pppd, 389

prefix

in., 388

rpc., 388

printer, 389, 427

procmail, 670

protocol, 388

rexecd, 390

rhnsd, 517

rlogind, 1054

routed, 390

routing, 390

rpcbind, 392, 443, 730

rquotad, 389

rshd, 1054

rsyslogd, 200, 390, 579, 582,  
1054

sendmail, 390, 471, 669, 670,  
674, 676, 1050

services, providing, 388

smbd, 390, 750, 768

spamd, 682

sshd, 388, 390, 633

statd, 389

Superserver. *See Daemon,  
xinetd*

talkd, 390

telnetd, 390, 1054

tftpd, 390

timed, 390

xinetd, 390, 428, 429, 445,  
756

ybind, 701

ybind-mt, 701

yppasswdd, 709

ypxfrd, 708

yum-updatesd, 504

Data

Encryption Standard. *See DES  
encryption*

sink, 237

structure, 1078

Database, 585

authentication, 1055

Berkeley, 710

dbm, 1078

DNS, 385

gdbm, 1078

hosts, 387

initializing, 67

Linux Software Map, 1039

locate, 67, 168

magic number, 480

MySQL, 584

ndbm, 1078

NIS, 373, 387, 695, 1096

passwd, 556

- printcap**, 476
- RHN, 516
- rpm**, 512
- search engine, 396
- Sleepycat, 710
- SQL, 1108
- terminfo**, 175
- whatis**, 67, 127, 168
- Datagram, network, 359, 1078
- Dataless system, 729, 1078
- Date, display, 159
- date utility, 159, 237
- db** filename extension, 789, 791
- dbm** database, 1078
- DC, LDAP, 711
- DDoS attack, 1078
- Debug, 1078
- Debugger
  - option, 900
  - shell script, 900
- declare builtin, 303, 304
- Decorations, window, 142
- Decrement operator, 955
- Default, 1078
- defaultrouter** file, 390
- Defect-tracking system, 516
- Delete
  - character using BACKSPACE, 139
  - directory using rmdir, 200
  - file using rm, 150
  - line using CONTROL-U, 139
  - link using rm, 218
  - word using CONTROL-W, 139
- DELETE key (erase character), 139
- Delimiter, regular expression, 1024
- Delta, SCCS, 1078
- Demand mounting, filesystem, 744
- Denial of service. *See* DoS attack; DDoS attack
- depmod utility, 550
- Dereference, 1078
- DES encryption, 1047
- Descriptor, file, 284, 922
- Design, top-down, 964
- Desktop, 90–109, 110, 1078
  - appearance, 105
  - CD, 24
  - effects, 108
  - focus, 1083
  - font preferences, 272
  - manager, 1078
  - panel. *See* Panel
  - resolution, changing the, 142
  - terminology, 110
  - theme, 105
  - visual effects, 108
  - window. *See* Window
  - workspace, 93
- Desktop** directory, 101–104
- Detached process. *See* Background, process
- dev** directory, 468, 482
- devfs** filesystem, 482
- Device, 1079
  - block, 484, 1071
  - character, 484, 1074
  - driver, 482, 484, 1079
  - file, 230, 1079
    - export, 738
  - filename, 1079
  - floppy diskette, 468
  - IDE disk, 468
  - independence, 13
  - independent input and output, 13
  - name, 564
  - names, dynamic (udev), 482
  - non-IDE disk, 468
  - nonrewinding, 564
  - null, 237
  - number
    - major, 484, 1092
    - minor, 484, 1094
    - raw, 485
  - physical, 1099
  - tape, 563
  - tape, nonrewinding, 564
  - UUID numbers, 469
- devpts** filesystem, 485
- df utility, 729
- dhclient utility, 452
- dhclient.conf** file, 452
- dhclient.leases** file, 452
- DHCP, 451, 1079
  - client, 452
  - how it works, 452
  - MAC addresses, 454
  - more information, 452
  - prerequisites, client, 452
  - prerequisites, server, 453
  - protocol, 451
  - resolv.conf** file, and, 477
  - server, 453
    - static IP addresses, 454
- dhcpcd** daemon, 389
- dhcpcd** daemon, 389, 452, 453
- dhcpcd.conf** file, 453
- Dialog box, 1079
- Dial-up connection, 135
- Die, process, 316
- diff utility, 157, 628
- Diffie-Hellman encryption, 1046
- dig utility, 382, 784, 788, 806
- Digital
  - signature, 1046
  - Signature Algorithm. *See* DSA
- Directory, 11, 12, 149, 189, 482
  - ., 197, 481, 1079
  - .., 197, 481
  - .ssh, 623
  - / (root), 190, 198
  - /bin, 198
  - /boot, 198
  - /dev, 199, 230, 482
  - /etc, 199
    - cron.\*, 565
    - cron.d, 389
    - httpd, 849
    - logrotate.d, 580
    - mail, 677, 680
    - opt, 199
    - pam.d, 459, 461, 463, 475
    - rc.d, 476
      - about, 429
      - init.d, 426, 428
      - rcn.d, 426
    - skel, 557
    - ssh, 623
    - sysconfig, 478
    - X11, 84, 199
    - xinetd.d, 428, 446
    - yum.repos.d, 498, 499
  - /home, 199
  - /lib, 199
    - modules, 199, 550
    - security, 458, 461
  - /lost+found, 436
  - /mnt, 199
  - /opt, 199, 513
  - /proc, 199
  - /root, 199
  - /sbin, 199
  - /sys, 199
  - /tmp, 199, 579, 917

Directory, *continued*

/usr, 199

bin, 199

doc, 200

games, 199

include, 199

info, 200

lib, 199

man, 200

sbin, 388

share, 200

src, 200, 544

/var, 200

ftp, 655

log, 200, 480, 579, 1034,  
1054

mail, 579

named, 794, 800

spool

disk usage, 579

problem solving, 1034

tmp, 579

www

Apache files, 849

html, 844, 846, 849

~ (home). *See Home directory*

access permission, 206

bin, 199, 306

boot, 550

change using cd, 196

child, 189, 190

compact, 581

configs, 547

copy recursively using mv, 481

copy, shell script, 293

create using mkdir, 195

cron, 389

cron.\*, 565

cron.d, 389

current. *See Working directory*

delete using rmdir, 200

dev, 230, 482

doc, 200

empty, 189

erase using rmdir, 200

file, 189, 1079

folder and, 98

ftp, 655

games, 199

hierarchy, 32, 1079

home, 149, 192, 305, 744

home, 475

home versus working  
directory, 197

httpd, 849

important, 468

include, 199

info, 200

init.d, 426

LDAP, 710

lib, 199

link, 212

list using ls, 149

listing, 149

local, 199

log, 200, 480, 579, 1034, 1054

logrotate.d, 580

mail, 579, 674, 677, 680

make using mkdir, 195

man, 200

modules, 199, 550

move using mv, 202

named, 794, 800

opt, 199, 513

pam.d, 459, 461, 463, 475

parent, 189, 190

pathname, 189, 201

proc, 199

public\_html, 853

rc.d, 476

init.d, 426, 428

maintain, 429

rcn.d, 426

remove unused space, 581

remove using rmdir, 200

rename using mv, 202

root (/), 32, 34, 188, 190, 198,  
1104

sbin, 199, 200, 388

security, 458, 461

service, 1079

share, 200

skel, 557

spool

disk usage, 579

problem solving, 1034

src, 200, 544

ssh, 623

stack manipulation, 296

standard, 198

sysconfig, 478

tmp, 579, 917

working

change using cd, 196

defined, 192

home versus, 197

relative pathnames, 194

significance of, 194

with, 200

www, 849

X11, 84, 199

xinetd.d, 428, 446

yum.repos.d, 498, 499

dirs builtin, 296

Disk

block, 1071

buffer, 434

Druid, 71

filesystem, 31

formatting, low-level, 30

fragmentation, 578

free space, 30, 578, 1083

IDE, device name, 468

monitor using SMART, 81

non-IDE, device name, 468

partition. *See Partition*

partition table, 569

quota system, 582

RAM, 39

usage, 578

utility, palimpsest, 78

Volume label, 439

Diskette, floppy. *See Floppy  
diskette*

Diskless system, 728, 1079

Display

bit-mapped, 1071

color depth, 261, 1075

date using date, 159

end of a file using tail, 154

file using cat, 149

graphical, 1084

hidden filename, 244

machine name, 151

number, X Window System,  
260

ordered file using sort, 155

resolution, changing, 142

sorted file using sort, 155

system load using w, 172

text using echo, 159

top of a file using head, 154

uptime using w, 172

user list

using finger, 169

using w, 171

using who, 169

- display option, X Window System, 261
- DISPLAY variable, 260
- Distributed computing, 383, 744, 1079
- Distribution, Linux, 4
- Distribution, Perl, 979
- dmesg utility, 426, 439, 553
- DMZ, 1079
- DN, LDAP, 711
- DNS, 1079
  - \$INCLUDE, 797
  - \$ORIGIN, 797
  - \$TTL, 797
  - A (address) record, 780
  - AAAA (address) record, IPv6, 780
  - about, 373, 385
  - authority, 776
  - cache, 779, 782, 797
  - caching-only server. *See* DNS, *cache*
  - chroot jail, 804
  - CNAME record, 780
  - database, 385, 779
  - delegation, 777
  - dig utility, 382, 784, 788, 806
  - domain
    - defined, 774
    - qualification, 797
    - root, 776
  - domain name. *See* Domain, *name*
  - FQDN, 775
  - full-functioned nameserver, 807
  - glue, 802
  - hints zone, 800
  - host utility, 382, 785
  - how it works, 785
  - in-addr.arpa domain, 783
  - inverse mapping. *See* DNS, *reverse name resolution*
  - ip6.arpa domain, 783
  - iterative query, 777
  - JumpStart
    - setting up a DNS cache, 787
    - setting up a domain with system-config-bind, 789
  - log, 805, 808, 810
  - master server, 778
  - more information, 786
  - MX record, 681, 780
  - named daemon, 389, 788, 794
  - named directory, 794
  - named.ca file, 800
  - named.conf file, 794, 807, 812
  - nameserver, full-functioned, 807
  - node. *See* DNS, *domain*
  - NS record, 780
  - nsswitch.conf file, 785
  - origin. *See* DNS, *zone, name*
  - overview, 773
  - prerequisites, 785
  - primary master server, 778
  - PTR record, 781
  - query, 777, 782
  - recursive query, 777
  - resolver, 776
  - resource record, 779
  - response, 782
  - reverse mapping. *See* DNS, *reverse name resolution*
  - reverse name resolution, 783
  - root domain, 775, 776
  - root zone, 800
  - secondary server, 778
  - security, 774
  - server
    - caching, 797
    - master, 778
    - primary master, 778
    - secondary, 778
    - slave, 778, 810
    - split horizon, 811
    - types of, 778
  - setting up, 793
  - slave server, 778, 810
  - SOA record, 781
  - split horizon server, 811
  - subdomain, 776
  - system-config-bind utility, 789
  - time format, 796
  - transactions signatures. *See* DNS, *TSIG*
  - troubleshooting, 805
  - TSIG, 803, 806
  - TTL value, 781
  - TXT record, 782
  - zone, 776
    - file, 796, 800
    - hint, 800
    - name, 796, 797
    - root, 800
    - section, **named.conf**, 795
- do control structure, 901, 902, 904, 908
- doc directory, 131, 200
- Document Object Model. *See* DOM
- Document root, Apache, 844
- Documentation
  - See also* Help
  - finding, 1035
  - online, 383
- Documentation file (kernel), 131
- Dollar sign
  - variables, use with, 301
  - in regular expressions, 1026
- DOM, 1080
- Domain
  - See also* DNS
  - DNS, defined, 774
  - in-addr.arpa, 783
  - ip6.arpa, 783
  - name, 385, 1080
  - Name Service. *See* DNS
  - name, not case-sensitive, 386
  - NIS, 696
  - root, 776
- done control structure, 901, 902, 904, 908
- Door, 1080
- DOS
  - convert files, 161
  - filename, 190
  - filename extension, 190
  - filesystem, mounting, 487
  - mounting filesystems, 488
- DoS attack, 1080
- dos2unix utility, 161, 650
- Double versus single quotation marks, 333
- Double-click timeout, mouse, 97
- dovecot self-signed certificate, 689
- dovecot.conf file, 689
- Downloading Fedora, 41
- DPMS, 1080
- Drag, 1080
- Drag-and-drop, 1080
- Dragging an object, 98
- DragonSquire utility, 1053
- Drawers, 113
- Driver, device, 482, 1079
- Drop-down list, 1080
- Druid, 1080

DSA (Digital Signature Algorithm), 1047, 1080  
 DSA, LDAP, 711  
 DSE, LDAP, 711  
 DSL, 360, 1081  
 dsniff utility, 1058  
 DSO, Apache, 842  
 Dual-boot system, 82  
 Dump level, 563  
 dump utility, 491, 563  
**dumpdates** file, 471, 563  
 Duplicate lines, getting rid of  
   using **uniq**, 156  
 DVD, install, 24  
   *See also Installation*  
   ISO image, 41  
 Dynamic  
   device names (**udev**), 482  
   Host Configuration Protocol.  
     *See DHCP*  
   IP address, 368  
   shared objects, Apache, 842

## E

e2label utility, 439  
 echo builtin, 159, 244, 301, 914,  
   929, 937, 945, 949  
 ed editor, 153  
 Editor 1081  
   command-line, 326  
   ed, 153  
   ex, 310  
   Readline Library, 326  
   vim, 174  
 edquota utility, 582  
 Edwards, Dan, 1112  
 EEPROM, 1081  
 Effective user ID, 1081  
 egrep utility, 1030  
 Electronic message, write, 172  
 Element, 1081  
 El-Gamal encryption, 1046  
**elif** control structure, 895  
**else** control structure, 892  
 emacs mail, 174  
 Emblems, Nautilus, 120, 266  
 Emoticon, 1081  
 Empathy utility, 109  
 Empty regular expressions, 1028  
 Emulator, operating system, 7  
 Emulator, terminal, 118, 135,  
   275

Encapsulation. *See Tunneling*  
 Encryption, 1044  
   3-DES, 1047  
   AES, 1047  
   algorithm, 1044  
   asymmetric. *See Encryption,*  
     *public key*  
   Blowfish, 1047  
   DES, 1047  
   Diffie-Hellman, 1046  
   digital signature, 1046  
   DSA, 1047  
   El-Gamal, 1046  
   GnuPG, 1048  
   host key, 624  
   IDEA, 1047  
   implementation, 1047  
   key, 1044  
   man-in-the-middle, 803, 1048,  
     1051  
   MD5, 477  
   OpenSSH, 624  
   PEM, 1049  
   PGP, 1048  
   private key, 1045  
   public key, 1045  
   RC5, 1047  
   ring of trust, 1048  
   RSA, 1046, 1104  
   scheme, weaknesses of, 1045  
   secret key, 1045  
   session key, 624  
   symmetric key, 1046  
 End line key, 17  
 End of file. *See EOF*  
 Enquire program, 395  
 Enter text using vim, 177  
 Enter-exit focus, 141  
 Enter-only input focus, 141  
 Entry, LDAP, 711  
 ENV variable, 282  
 Environment  
   *See also Calling environment*  
   establish, 476  
   exec, 941  
   export, 305, 316, 926  
   variable, 299  
 EOF, 173, 232, 1081  
 EPROM, 1081  
 Erase key (CONTROL-H), 139, 227,  
   327, 468  
 Errata, 516

Error  
   *See also Usage message*  
   codes, Apache, 882  
   correcting typing mistakes, 138  
   message  
     cannot execute, 229  
     conditional, 936  
     name of calling script, 916  
     **NFS server xxx not**  
       **responding**, 729  
     not found, 229  
     redirecting to standard error,  
       286  
     standard error. *See Standard,*  
       *error*  
     system, 480  
     usage, 224, 892, 898  
   shell script, 899  
   standard. *See Standard, error*  
   usage message, 224, 892, 898  
**esac** control structure, 911  
 Escape a character, 148, 291  
 Escape an end of line, 291  
 etherreal utility, 1058  
 Ethernet network, 357, 360, 361,  
   362, 1081  
 eval builtin, 337, 949  
 Event, 1081  
   asynchronous, 1070  
   control-alt-delete, 434  
   history, 316  
   modifying previous, 324  
   number, 317, 321  
   reexecuting, 318  
   text, 321  
   Upstart, 418  
   words within, 322  
   X Window System, 257  
**event.d** directory, 419, 422–424  
 Evolution utility, 174  
 ex editor, 310  
 Exabyte, 1081  
 Exclamation point, 321  
 exec builtin, 286, 921, 940, 949  
 exec() system call, 289  
 Execute  
   access, 203, 287, 288  
   command, 229, 316  
   permission, 288  
   shell script, 289  
 Exit  
   from a shell, 296  
   status, 930, 1081

exit builtin, 109, 930, 945, 949  
 Expansion  
   arithmetic, 346  
   brace, 302, 344  
   command-line, 343  
   filename, 350  
   null variable, 935  
   order of, 301, 343  
   parameter, 346  
   pathname, 243, 302, 349, 350  
   quotation marks, double, 350  
   tilde, 193, 345  
   unset variable, 935  
   variable, 346  
 Explicit focus, 141  
 Exploit, 1081  
 Export  
   device file, 738  
   link, 738  
   variable, 941  
 export builtin, 304, 305, 476, 926, 949  
 exportfs utility, 435, 742  
 exports file, 737, 738, 739  
 Expression, 1081  
   arithmetic, 1069  
   logical, 1092  
   regular. *See Regular expression*  
 ext2 filesystem, 485, 492  
 ext3 filesystem, 485, 492  
 ext4 filesystem, 486, 492  
 Extended multiuser mode, 431  
 Extended regular expression. *See Regular expression, extended*  
 Extensible Markup Language. *See XML*  
 Extension, filename. *See Filename, extension*  
 Extranet, 359, 1081  
 EXTRAVERSION number, kernel, 548

## F

Fahlman, Scott, 1106  
 Failsafe session, 1082  
 false file, 476  
 Family tree, 188  
 fc builtin, 318  
 FCEDIT variable, 320  
 FDDI network, 1082  
 fdformat utility, 489  
 fdn file, 468  
 Features, bash. *See bash, features*  
 Fedora  
   Anaconda, 57  
   booting, 52  
   Desktop Live Media. *See Live CD*  
   Directory Server, 711  
   documentation, 124–132  
   errata, 516  
   Firstboot, 66  
   GNOME Live Media. *See Live CD*  
   installing, 55  
     Anaconda, 57  
     BIOS setup, 26  
     boot commands, 69  
     burning CD/DVD, 41  
     CHECKSUM file, 45  
     CMOS setup, 26  
     Disk Druid, 71  
     disk setup, 71  
     disk space, 26  
     display, configuring, 84  
     download, burn, and install CD/DVD, 41  
     DVD, testing, 57  
     explained, 23  
     firewall, 66  
     Firstboot, 66  
     how it works, 39  
     installation type, 63  
     installer interface, 28  
     Kickstart, 82  
     MD5SUM file, 45  
     network configuration, 62  
     network installation, 41  
     planning, 24  
     requirements, 25  
     start, 55  
     upgrade, 60  
     upgrading versus installing, 29  
     virtual consoles, 58  
     X Window System, configuring, 84  
   Kickstart, 82  
   mirror sites, 42  
   Project, 28  
   rescue mode, 56  
   RHEL versus, 28  
   SELinux, 414  
   software, adding, 505

updates, 516, 1053  
 upgrade. *See Fedora, installing*  
 X.org, 84  
 fg builtin, 242, 295, 949  
 FHS, 12, 198  
 fi control structure, 888, 892, 895  
 Fiber Distributed Data Interface. *See FDDI network*  
 Fiberoptic cable, 361  
 FIFO special file, 351, 482, 483  
 File, 1082  
   .autofsck, 492  
   .bash\_history, 316  
   .bash\_login, 281  
   .bash\_logout, 281  
   .bash\_profile, 281, 317, 468  
   .bashrc, 194, 281, 468  
   .config, 547  
   .forward, 676, 682  
   .htaccess, 850, 880  
   .htpasswd, 880  
   .inputrc, 329  
   .netrc, 649  
   .pgpkkey, 171  
   .plan, 170  
   .profile, 281, 468  
   .project, 171  
   .rhosts, 377, 1053  
   .toprc, 568  
   /bin/false, 476  
   /boot/grub/grub.conf, 543, 551  
   /dev  
     nst0, 564  
     null, 237, 469, 471, 579, 907, 946  
     pts, 469  
     random, 470  
     st0, 563, 564  
     tty, 942  
     urandom, 470  
     zero, 470  
   /etc  
     aliases, 471, 576, 675  
     anacrontab, 565  
     at.allow, 471  
     at.deny, 471  
     auto\_master, 745  
     bashrc, 432  
     cron.allow, 471  
     cron.deny, 471

File, /etc, *continued*

crontab, 389  
 defaultrouter, 390  
 dhclient.conf, 452  
 dhcpd.conf, 453  
 dovecot.conf, 689  
 dumpdates, 471, 563  
 exports, 737, 738, 739  
 fstab, 388, 472, 731, 735  
 group, 432, 472, 558  
 grub.conf, 543, 551  
 hosts, 372, 387, 472, 601, 695  
 hosts.allow, 444, 445, 447  
 hosts.deny, 444, 445, 447  
 hosts.equiv, 376, 1053  
 inittab, 425, 473, 574  
 issue, 432  
 login.defs, 475, 557  
 logrotate.conf, 580  
 motd, 432, 474, 476, 572  
 mtab, 474  
 named.conf, 786, 793, 794, 807, 812  
 netgroup, 474  
 nologin.txt, 462, 476  
 nsswitch.conf, 387, 432, 455, 475, 696, 785  
 ntp.conf, 389  
 pam.conf, 463  
 pam.d, 458  
 passwd, 305, 431, 475, 574, 695, 903, 904  
 printcap, 476  
 profile, 281, 412, 432, 476  
 protocols, 476, 829  
 rc.d  
   init.d, 426  
   rc, 426  
   rc.local, 427  
   rc.sysinit, 426, 492  
 resolv.conf, 476, 602, 787  
 rpc, 392, 477  
 rsyslog.conf, 390, 583  
 securetty, 407  
 security/access.conf, 407  
 selinux/config, 415  
 services, 388, 392, 477  
 shadow, 431, 477  
 share/magic, 480  
 shells, 439  
 sudoers, 406  
 sysconfig

httpd, 844, 871  
 iptables, 823, 833, 838  
 iptables-config, 823  
 named, 786, 805  
 network, 699, 704  
 rsyslog, 584  
 selinux, 415  
 yppasswdd, 710  
 sysctl.conf, 543, 544  
 vsftpd  
   chroot\_list, 666  
   ftpuers, 666  
   user\_list, 666  
 xinetd.conf, 428, 445  
 yp.conf, 700  
 ypserv.conf, 704  
 yum.conf, 498  
 /proc  
   fs/nfs, 738  
   mounts, 474  
   sys, 544  
 /root  
   anaconda-ks.cfg, 65  
   install.log, 65  
 /usr  
   local, 199  
   sbin, 200  
 /var  
   lib/nfs/xtab, 738, 743  
   log  
     lastlog, 200  
     maillog, 578  
     messages, 200, 459, 480, 574, 578, 579, 805, 1034  
     secure, 459, 480, 1034  
     vsftpd.log, 666  
     wtmpt, 200, 581  
   spool/mqueue, 674  
 access, 680  
 access permission, 203, 204  
 access.conf, 407  
 aliases, 471, 576, 675, 682  
 ambiguous reference, 243  
 anaconda.cfg, 82  
 anaconda-ks.cfg, 65  
 anacrontab, 565  
 archive using tar, 163  
 at.allow, 471  
 at.deny, 471  
 authorized\_keys, 623  
 auto\_master, 745  
 backup, 558, 563

bashrc, 281, 432  
 block special, 1071  
 browser. *See Nautilus*  
 Browser versus Spatial  
   windows, Nautilus, 99  
 Browser window, 99  
 character special, 1074  
 CHECKSUM, 45  
 close (bash), 922  
 config, 415, 631  
 configuration, rules, 441  
 copy using cp, 202  
 core, 579  
 create using cat, 233  
 creation date, display using ls, 203  
 cron.allow, 471  
 cron.deny, 471  
 crontab, 389  
 defaultrouter, 390  
 defined, 11  
 descriptor, 284, 921  
 descriptor, duplicating, 922  
 device, 230, 482  
 dhclient.conf, 452  
 dhclient.leases, 452  
 dhcpd.conf, 453  
 directory, 189  
 directory versus ordinary, 481  
 display  
   beginning of, using head, 154  
   end of, using tail, 154  
   using cat, 149  
 dovecot.conf, 689  
 dumpdates, 471, 563  
 empty, creating an, 201  
 execute permission, 288  
 exports, 737, 738, 739  
 false, 476  
 FIFO special, 351, 482, 483  
 forcefsck, 492  
 fstab, 388, 472, 731, 735  
 ftpusers (vsftpd), 666  
 group, 432, 472, 558  
 group assignment, 472  
 group, display using ls, 203  
 growing, 578  
 grub.conf, 543, 551  
 hidden, 1085  
 hierarchical structure, 188  
 hosts, 372, 387, 472, 601, 695  
 hosts.allow, 444, 445, 447  
 hosts.deny, 444, 445, 447



- hosts.equiv, 376, 1053
- html, 844, 846, 849
- httpd, 844, 871
- httpd.conf, 845, 850, 870
- identifying using file, 157
- important, 468
- index.htm, 854
- index.html, 854
- index.php, 854
- index.shtml, 854
- inittab, 425, 473, 574
- install.log, 65
- iptables, 823, 833, 838
- iptables-config, 823
- issue, 432
- job definition (Upstart), 419
- known\_hosts, 624, 626, 627
- ks.cfg, 82
- large, rotate, 579
- lastlog, 200
- link, 212
- linux-gate.so.1, 449
- list, 149
- log, 200, 577, 579
- login.defs, 475, 557
- logrotate.conf, 580
- magic, 480
- mailertable, 680
- maillog, 578, 674
- manager, Nautilus, 270
- MD5SUM, 45
- message of the day. *See motd*
- messages, 200, 459, 480, 574, 578, 579, 805, 1034
- motd, 432, 474, 476, 572
- mounts, 474
- move using mv, 201
- mqueue, 674
- mtab, 474
- name. *See Filename*
- named, 786, 805
- named pipe, 351, 482, 483
- named.conf, 786, 793, 794, 807, 812
- netgroup, 474
- network, 699, 704
- nfs, 738
- nicknames, 698
- nologin.txt, 462, 476
- nsswitch.conf, 387, 432, 455, 475, 696, 785
- nst0, 564
- ntp.conf, 389
- null, 237, 469, 471, 579, 907, 946
- open, bash, 921
- open, finding, 576
- open using Nautilus, 110
- order using sort, 155
- ordinary, 189, 1097
- ordinary versus directory, 481
- owner, 288
- owner, display using ls, 203
- pack archive using tar, 163
- pam.conf, 463
- pam.d, 458
- passwd, 305, 431, 475, 574, 695, 903, 904
- pathname, 189, 201
- permission, 204, 288, 472
- pointer to, 212
- PPD, 533
- printcap, 476
- profile, 281, 412, 432, 476
- protocols, 476, 829
- pts, 469
- random, 470
- rc, 426
- rc.local, 427
- rc.sysinit, 426, 492
- reference, ambiguous, 243, 1068
- remove using rm, 150
- rename using mv, 201
- resolv.conf, 476, 602, 787
- rotate, 579, 1104
- rpc, 392, 477
- rsyslog, 584
- rsyslog.conf, 390, 583
- search for, using Search for Files window, 274
- secure, 459, 480, 1034
- securenets, 706
- securetty, 407
- security, 1049
- selinux, 415
- sendmail.cf, 677
- sendmail.mc, 672, 678
- services, 388, 392, 477
- shadow, 431, 477
- shells, 439
- size, display using ls, 203
- smb.conf, 759
- smbpasswd, 752
- smbusers, 752
- sort using sort, 155
- sparse, 1107
- special, 482
- ssh\_config, 631
- ssh\_known\_hosts, 623, 626, 627
- sshd\_config, 636
- st0, 563, 564
- standard, 198
- startup, 192, 281, 468, 574, 1108
- structure, 188
- sudoers, 406
- symbolic link, 482
- sys, 544
- sysctl.conf, 543, 544
- tar, 163
- temporary, name of, 917
- terminal, 230
- text, 174
- trash, moving to, 104
- truncate, 469, 579
- tty, 942
- type of, discover using ls, 203
- typescript, 160
- UNIX domain socket, 482
- urandom, 470
- user\_list (vsftpd), 666
- virtustable, 681, 682
- vsftpd
  - chroot\_list, 666
  - ftpusers, 666
  - user\_list, 666
- vsftpd.conf, 656
- vsftpd.log, 666
- window, 230
- wtmp, 200, 581
- xinetd.conf, 428, 445
- xtab, 738, 743
- yp.conf, 700
- yppasswdd, 710
- ypserv.conf, 704
- yum.conf, 498
- yum-updatesd.conf, 504
- zero, 470
- file utility, 157, 480, 579
- Filename, 174, 189, 1082
- /, 190
  - absolute, 311
  - ambiguous reference. *See File, ambiguous reference*
  - basename, 193, 1071
  - case, 17

Filename, *continued*

- case-sensitive, 191
  - change using mv, 152
  - characters in, 190
  - choice of, 190
  - completion, 1082
  - conventions, 245
  - defined, 193
  - device, 1079
  - DOS, 190
  - extension, 191, 1082
    - bmp, 191
    - bz2, 162, 191
    - c, 191
    - conf, 441
    - db, 789, 791
    - DOS, 190
    - gif, 191
    - gz, 163, 191
    - htm, 854
    - html, 191, 854
    - jpeg, 191
    - jpg, 191
    - ldif, 711
    - o, 191
    - pdf, 191
    - php, 854
    - ps, 191
    - remove an, 325
    - repo, 499
    - rpmnew, 30
    - shtml, 854
    - tar.bz2, 164
    - tar.gz, 164
    - tar.Z, 164, 191
    - tbz, 164
    - tgz, 191
    - tif, 191
    - tiff, 191
    - torrent, 508
    - txt, 191, 245
    - tz, 164
    - var, 854
    - Z, 163, 191
  - generation, 13, 243, 1082
  - hidden, 192, 244, 1085
  - length, 189, 190, 440, 917
  - period, leading, 244
  - quoting, 350
  - reference, ambiguous. *See File, ambiguous reference*
  - root directory, 190
  - simple, 193, 195, 228, 1106
  - temporary file, 917
  - typeface, 17
  - unique, 917, 929
  - Windows, 190
- Fileserver, 384, 727
- Filesystem, 31, 1082
- /proc, 478, 487
  - active, 559
  - adfs, 485
  - affs, 485
  - autofs, 485, 744
  - check integrity of, 492
  - coda, 485
  - copy directory recursively
    - using mv, 481
  - defined, 187
  - demand mounting, 744
  - devfs, 482
  - devpts, 485
  - ext2, 485, 492
  - ext3, 485, 492
  - ext4, 486, 492
  - filename length, 189, 440
  - free list, 481, 1083
  - GFS, 486
  - hfs, 486
  - Hierarchy Standard, Linux, 12
  - hpf, 486
  - independence, 33
  - iso9660, 486
  - journaling, 485, 486, 492, 1089
  - minix, 486
  - mount
    - automatically, 744
    - demand, 744
    - point, 32, 745, 1094
    - remote, 730
    - table, 490
  - msdos, 486
  - naming, 33
  - nepfs, 486
  - NFS, 427, 486, 732
  - ntfs, 486
  - organize, 188
  - proc, 478, 486, 487, 562
  - qnx4, 486
  - RAID, 37, 486
  - reiserfs, 486
  - remote, 358, 1103
  - repair, 436
  - romfs, 486
  - smbfs, 486
  - Standard, Linux, 12, 198
  - structure, 11, 187
  - superblock, 1109
  - swap, 34, 479
  - sysv, 486
  - types, list of, 485
  - ufs, 486
  - umsdos, 486
  - use, 188
  - vfat, 486
  - virtual, 487
  - xfs, 486
- Filling, 1082
- Filter, 14, 240, 1082
- Find
  - command name using apropos, 167
  - inode using find utility, 897, 900
  - string using grep, 153
- find utility, 413, 579
- finger utility, 169, 374, 375, 389, 903
- fingerd daemon. *See in.fingerd daemon*
- Firefox, 109
- Firewall, 363, 1082
  - See also iptables*
  - building a, 824
  - OpenSSH, 640
  - toolkit, 1059
- Firmware, 1083
- Firstboot, 66
- Flag, crash, 492
- flex utility, 16
- Floppy diskette, device name, 468
- Floppy diskette, mount, 488, 489
- Focus, desktop, 1083
- Focus, input, 116, 141
- Focus-strictly-under-mouse, 141
- Focus-under-mouse, 141
- Folder. *See Directory*
- Font
  - antialiasing, 1069
  - Pick a Font window, 272
  - preferences, GNOME, 272
- Footer, 1083
- for control structure, 901, 902, 945
- for...in control structure, 901, 902
- forcefsck file, 492
- Foreground, 13, 241, 1083
  - background versus, 241

- Fork, 1083
  - process, 314
- fork()** system call, 289, 314, 316
- FQDN, 373, 386, 775, 1083
- Fragmentation, disk, 578
- Frame, network, 359, 1083
- Free
  - list, filesystem, 481, 1083
  - software, definition, 1063
  - space, disk, 30, 578, 1083
  - Standards Group, 198
- freedesktop.org group, 264
- Freefire, security solutions, 1058
- fsck utility, 436, 485, 492, 578
- FSG, 198
- FSSTND, 12, 198
- fstab** file, 388, 472, 490, 731, 735
- FTP
  - about, 644
  - account, 476
  - active, 644
  - anonymous, 649
  - ASCII transfer mode, 650
  - automatic login, 649
  - basic commands, 646
  - binary transfer mode, 650
  - chroot jail, 658
  - ftp utility, 644, 650
  - JumpStart
    - downloading files using ftp, 646
    - starting a **vsftpd** server, 655
  - more information, 645
  - passive, 644
  - PASV (passive) connection, 644, 1098
  - PORT connection, 644
  - prerequisites, 645
  - pub** directory, 649
  - security, 644, 650, 655
  - server, 654
  - tutorial, 646
  - vsftpd** server, 654
  - vsftpd.conf** file, 656
- ftp** directory, 655
- ftp utility, 358, 644, 650
- ftpd** daemon, 389
- ftpusers** file, 666
- Full
  - backup, 559
  - duplex, 1083
  - functioned nameserver, DNS, 807
  - regular expressions. *See Regular expressions, extended*
- Fully qualified domain name. *See FQDN*
- Function, 1083
  - shell, 335, 1106
- fuser utility, 490
- gtk utility, 1059
- G**
- Gaim. *See Empathy IM client*
- games** directory, 199
- gated** daemon, 390
- Gateway, 1083
  - daemon, 390
  - network, 362
  - proxy, 391
  - router, and, 597
- gawk, 903, 904
- gcc
  - See also C programming language*
  - history, 9
- GCOS. *See GECOS*
- gdbm** database, 1078
- gdm utility, 433
- GECOS, 1084
  - and NIS, 710
- Generate filenames, 243
- Generic operating system, 8
- getenforce utility, 416
- gethostbyname()** system call, 785
- getopts builtin, 946, 949
- getty utility, 314
- GFS filesystem, 486
- GIAC, security certification and training, 1059
- Gibibyte, 33, 1084
- GID, 1084
- gif** filename extension, 191
- Gigabyte, 33, 1084
- Global Filesystem, 486
- Global variable, 299, 941
- Globbering, 243, 349
- Glue, DNS, 802
- Glyph, 1084
- GMT. *See UTC*
- GNOME, 90, 263
  - desktop. *See Desktop*
  - desktop, about, 15
  - font preferences, 272
  - gdm utility, 433
  - GTK, 263
  - Help Browser window, 125
  - Nautilus
    - See also Nautilus*
    - file manager, 270
    - spatial view, 270
  - object. *See Object*
  - panel. *See Panel*
  - terminal emulator, 275
  - terminology, 110
  - window. *See Window*
  - workspace. *See Workspace*
- gnome-search-tool utility, 274
- gnome-terminal utility, 275
- GNU
  - Configure and Build System, 513
  - General Public License, 4
  - GnuPG encryption, 1048
  - GNUSstep window manager, 264
  - grub utility, 551
  - manuals, 1035
  - usage message, 225
- GnuPG encryption, 1048
- gopher utility, 395
- GPG. *See GnuPG encryption*
- GPL. *See GNU, General Public License*
- gpm** daemon, 389
- gprof utility, 16
- gq utility, 722
- Grand Unified Boot Loader. *See grub utility*
- Graphical display, 1084
- Grave accent, 1075. *See also Command, substitution*
- grep utility, 153, 239, 903, 904, 907, 919, 976
- Group
  - about, 472
  - access, 203
  - add, 558
  - apache**, 844
  - commands, 290, 293
  - file assigned to, 472
  - ID, 472, 475
  - name of, display using **ls**, 203
  - password, 472
  - user private, 472
  - users, 1084
  - wheel**, 463
  - windows, 1084
- group** file, 432, 472, 558, 1016
- groupadd utility, 558

groupdel utility, 558  
 groupmod utility, 558  
 groups utility, 472  
 grub utility, 551  
**grub.conf** file, 543, 551  
 GTK, 263  
 GUI, 28, 1084  
   check box, 1074  
   check mark. *See* GUI, *tick*  
   check. *See* GUI, *tick*  
   combo box, 1075  
   dialog box, 1079  
   drag, 1080  
   drag-and-drop, 1080  
   drop-down list, 1080  
   list box. *See* GUI, *drop-down list*  
   radio button, 1101  
   scrollbar, 1105  
   slider, 1106  
   spin box, 1107  
   spinner. *See* GUI, *spin box*  
   text box, 1110  
   thumb, 1111  
   tick, 1111  
   tick box. *See* GUI, *check box*  
   tooltip, 1111  
   WYSIWYG, 1116  
   X Window System, 15, 84  
 Guided partitioning, 34  
 gunzip utility, 163  
 gz filename extension, 163, 191  
 gzip utility, 163

## H

**-h** option, 130  
 Hacker, 1084  
 Half duplex, 1084  
 halt utility, 433, 435  
 Hard disk. *See* Disk  
 Hard link  
   create using ln, 481  
   remove using rm, 218  
   symbolic link versus, 481  
 Hardcoded filename in shell  
   scripts, 916  
 Hardware, help, 132  
 Hash, 1085  
   one-way, 1097  
   SHA1 algorithm, 1105  
   table, 1085  
**hdn** file, 468  
 head utility, 154  
 Header, document, 1085  
 Help  
   answers, finding, 394  
   Browser window, GNOME,  
     125  
   documentation, 124–132  
   error messages, 131  
   getting, 1035  
   GNOME Help Browser, 125  
   GNU manuals, 132  
   **-h** option, 130  
   hardware, 132  
   **-help** option, 130  
   **--help** option, 130  
   HOWTOs, 130  
   info utility, 127–129  
   Internet, 131  
   Linux Documentation Project,  
     132  
   local, 131  
   man pages, 125, 126  
   netnews, 394  
   obtaining, 124–132  
   Red Hat Web site, 131  
   support forums, 132  
   system manuals, 125–129  
   **-help** option, 130  
   **--help** option, 130  
 Here document control structure,  
   919, 920, 1085  
 Hesiod, 1085  
 Heterogeneous, 1085  
 Heterogeneous network, 695  
 Hexadecimal number, 1085  
**hfs** filesystem, 486  
 Hidden filename, 1085  
   defined, 192  
   display, 244  
   not displayed with ?, 244  
 Hierarchical file structure, 188  
 Hierarchy, 1085  
 Hinting, subpixel, 1109  
**HISTFILESIZE** variable, 316  
 History, 1086  
   C Shell mechanism, classic,  
     320  
   event  
     editing, 319  
     number, 321  
     previous  
       !**\$** last word of, 323  
     modifying, 324

reexecuting, 319  
   text, 321  
   words within, 322  
   mechanism, 316  
   viewing, 318  
   word designator, 322  
 history builtin, 316, 317  
**HISTSIZE** variable, 316  
 Home directory, 149, 192, 305,  
   1086  
   **.bash\_history** file, 316  
   **.bash\_login** file, 281  
   **.bash\_logout** file, 281  
   **.bash\_profile** file, 281, 317  
   **.bashrc** file, 194, 281  
   **.forward** file, 676, 682  
   **.inputrc** file, 329  
   **.netrc**, 649  
   **.profile** file, 281  
   **.rhosts**, 1053  
   **.ssh**, 623  
   ~, shorthand for, 193, 305  
   automount, 744  
   hidden file, 192  
   **passwd** and, 475  
   startup file, 192  
   working directory versus, 197  
**/home** directory, 36  
**HOME** variable, 300, 305, 432,  
   945  
 Host  
   address, 367  
   key, OpenSSH, 624  
   security, 1053  
   specifying, 442  
   trusted, 376  
 host utility, 382, 785  
 Hostname  
   about, 776  
   resolution, 473  
   symbolic, 387  
 hostname utility, 151, 374  
**hosts** database, 387  
**hosts** file, 372, 387, 472, 601,  
   695  
**hosts.allow** file, 444, 445, 447  
**hosts.deny** file, 444, 445, 447  
**hosts.equiv** file, 376, 1053  
 Hover, 93, 1086  
 HOWTOs, 130  
**hpfs** filesystem, 486  
 hping utility, 1059  
**htm** filename extension, 854

HTML, 1086  
   history, 395  
   suffix, 396  
**html** file, 844, 846, 849  
**html** filename extension, 191, 854  
 HTTP protocol, 396, 1086  
**httpd** daemon, 389. *See also Apache*  
**httpd** directory, 849  
**httpd** file, 844, 871  
**httpd.conf** file, 845, 850, 870  
 HTTPS protocol, 396, 877  
 Hub, 361, 596, 1086  
 Humor, 5, 1052, 1106  
 Hunk (diff), 157  
 HUP signal, 575  
 Hypermedia, 396  
 Hypertext, 395, 1087  
   link, 395  
   Markup Language. *See HTML*  
   Transfer Protocol. *See HTTP protocol*  
   World Wide Web, 395

## I

I/O device. *See Device*  
 IANA (Internet Assigned Numbers Authority), 388, 1087  
 ICMP packet, 380, 1087  
**icmp\_seq**, 380  
 Icon, 1087  
 Iconify, 1087  
 ICQ, 358  
 ID string, X Window System, 260  
 id utility, 408  
 IDEA encryption, 1047  
 IDS  
   about, 1053  
   AIDE, 1053  
   DragonSquire, 1053  
   samhain, 1053  
   tripwire, 1053  
 if control structure, 888, 892, 895  
**if...then** control structure, 888  
**if...then...elif** control structure, 895  
**if...then...else** control structure, 892  
 IFS variable, 309

Ignored window, 1087  
 IM client (Empathy), 109  
 IMAP, email, 689  
**imapsd** daemon. *See imap-login daemon*  
**imap-login** daemon, 689  
**in** control structure, 901  
**in.fingerd** daemon, 375, 389  
 in-addr.arpa domain, 783  
**include** directory, 199  
 Increment operator, 955  
 Incremental backup, 559  
 Indentation. *See Indention*  
 Indention, 1087  
**index.htm** file, 854  
**index.html** file, 854  
**index.php** file, 854  
**index.shtml** file, 854  
 Indirect pointer, 216  
**inetd** daemon, 389  
 Infinite recursion, alias, 332  
**info** directory, 200  
 info utility, 127–129, 247  
   manual, 1035  
 Information. *See More information*  
 Init script, 426, 476  
 init utility, 314, 425, 431, 473  
**init.d** directory, 426  
 initctl utility, 419  
**initng** daemon, 417  
**inittab** file, 423, 425, 473, 574  
 Inode, 215, 481, 1087  
   altering using mv, 481  
   create another reference using ln, 481  
   file, 481  
   filesystem, 216  
   links shell script, 896  
   number, 481  
 Input, 1087  
   focus, 116, 141  
   mode, vim, 176  
   standard. *See Standard, input*  
 Input/output device. *See Device*  
**INPUTRC** variable, 329  
 insmod utility, 550  
 Install DVD  
   about, 24  
   rescue mode, 56  
**install.log** file, 65  
 Installation  
   *See also Live CD; Install DVD*  
   boot parameters, 68

  computer, 1087  
   dual-boot system, 82  
   processor architecture, 26  
 Installation disk  
   formatting, 30  
   free space, 30  
   guided partitioning, 34  
   partition  
     set up, 30  
     setup, guided, 34  
 Installing Fedora or RHEL. *See Fedora, installing*  
 Installing software, 497  
 Integrated Services Digital Network. *See ISDN*  
 Integrity, filesystem, 492  
 Interactive, 1087  
 Interface, 1088  
   pseudographical, 28, 138  
   user, 1113  
 Internal Field Separator. *See IFS variable*  
 International Organization for Standardization. *See ISO*  
 Internet, 16, 1088  
   Assigned Numbers Authority. *See IANA*  
   browser, 395  
   connection sharing, 835  
   Control Message Protocol. *See ICMP packet*  
   look up a user, 382  
   mirror site, 1036  
   multiple clients on a single connection, 836  
   multiple servers on a single connection, 838  
   netiquette, 1095  
   netnews. *See Netnews*  
   network, 358  
   Printing Protocol. *See IPP protocol*  
   Protocol Security. *See IPsec*  
   Protocol. *See IP; TCP/IP*  
   Relay Chat, 358  
   search engine, 396  
   service provider. *See ISP*  
   services, 392  
   sharing a connection, 835  
   speed, 359  
   URI, 1113  
   URL, 396, 1113  
   Usenet, 396

- internet (*lowercase “i”*), 1088
  - Internetwork, 358
  - InterNIC, 382
  - Interprocess communication, 14, 158, 483
  - Interrupt key, 140, 943
  - Intranet, 358, 1088
  - Intrusion detection system. *See IDS*
  - Invisible file. *See Hidden filename*
  - IP, 1088
    - address, 367, 386, 1088
    - class, address, 368
    - IPng, 373
    - IPv6, 373, 1051
    - masquerading, 821, 832, 836
    - multicast. *See Multicast*
    - Next Generation, 373
    - spoofing, 377, 1089
    - version 6. *See IP, IPv6*
  - ip6.arp domain, 783
  - IPC, 1089
  - ipchains utility, 820
  - ipop3d daemon. *q pop3-login daemon*
  - IPP protocol, 520
  - IPSec, 1051
  - iptables, 819
    - ACCEPT target, 831
    - building a set of rules, 826
    - chain policy, 827
    - chain, about, 820
    - classifiers. *See iptables, match*
    - command line, 825
    - commands, 827
    - connection tracking, 822, 830
    - conntrack module, 822
    - display criteria, 828
    - DNAT, 821
    - DNAT target, 831
    - DROP target, 831
    - Filter table, 820
    - how it works, 820
    - Internet connection sharing, 835
    - IP masquerading, 836
    - iptables-restore utility, 832
    - iptables-save utility, 832
    - jump, 826
    - JumpStart, building a firewall with system-config-securitylevel, 824
    - LOG target, 831
    - Mangle table, 821
    - MASQUERADE, 821, 832, 1093
    - match, 820
      - criteria, 825
      - extension, 829
      - explicit, 830
      - implicit, 829
    - more information, 822
    - NAT table, 820
    - netfilter, 820
    - network packet, 821
    - nonterminating target, 826
    - packet match criteria, 826, 828
    - patch-o-matic, 819
    - policy, 827
    - prerequisites, 823
    - protocols file, 829
    - REJECT target, 832
    - resetting rules, 823
    - RETURN target, 832
    - router, 835
    - rule, 820
      - match criteria, 826
      - number, 826
      - saving, 832
      - specification, 826
    - sharing an Internet connection, 835
    - SNAT, 821, 832, 836
    - state machine, 822, 830
    - system-config-firewall utility, 824
    - system-config-securitylevel utility, 824, 833
    - target, 820, 826, 831
    - iptables file, 823, 833, 838
    - iptables-config file, 823
    - iptables-restore utility, 832
    - iptables-save utility, 832
    - IPv6, 373, 1089
      - address record, DNS, 780
      - ping6, 380
      - traceroute6, 381
  - IRC, 358
  - is\_regfile shell script, 891
  - ISC2 security certification, 1059
  - ISDN, 360, 1089
  - ISO, 1089
    - image, 41
    - ISO9660 filesystem, 486
    - protocol model, 365
  - ISO9660 filesystem, 486, 1089
  - ISP, 1089
  - issue file, 135, 432
  - iwconfig utility, 605
- ## J
- Job, 241, 1089
    - control, 13, 294
      - bg builtin, 295
      - fg builtin, 295
      - how to use, 241
      - jobs builtin, 294
      - number, 241, 242
      - stop foreground, 241
      - Upstart, 418–424
    - jobs builtin, 140, 242, 294, 296, 949
  - John the Ripper utility, 1059
  - Journaling filesystem, 485, 486, 492, 1089
  - Joy, Bill, 1073
  - JPEG, 1089
  - jpeg filename extension, 191, 1089
  - jpg filename extension, 191
  - JumpStart
    - Apache, getting up and running, 844
    - Apache, setting up with system-config-httpd, 846
    - building a firewall with system-config-securitylevel, 824
    - configuring a Samba server with system-config-samba, 753
    - configuring sendmail on a client, 672
    - configuring sendmail on a server, 673
    - DNS, setting up a cache, 787
    - DNS, setting up a domain with system-config-bind, 789
    - downloading files using ftp, 646
    - NFS, mounting a remote directory, 730
    - NFS server, configuring with system-config-nfs, 737
    - OpenSSH, starting the sshd daemon, 633
    - OpenSSH, using ssh and scp, 625
    - starting a vsftpd server, 655

Justify, 1089  
jwhois utility, 382

## K

K&R, 9  
KDE, 90, 263  
    desktop, 15  
    portability, 263  
    Qt toolkit, 263  
Kerberos, 1055, 1059, 1090  
Kernel, 6, 1090  
    /*proc* filesystem, 478  
    booting, 425  
    boot options, 543  
    cleaning the source tree, 547  
    compiling, 549  
    configuring, 547  
    display messages using *dmesg*, 439  
    *dmesg* utility, 553  
    export table, 738  
    EXTRAVERSION number, 548  
    install binary, 512  
    install compiled, 550  
    loadable module, 1091  
    messages, 553  
        display using *dmesg*, 426  
        saving, 426  
    module, 549, 1091  
    network packet filtering. *See iptables*  
    packet filtering. *See iptables*  
    parameter, 544  
    programming interface, 10  
    raw device, 485  
    rebuild, 543  
    source code  
        installing, 545  
        locating, 544  
    space, 1090  
    special files, 482  
Kerneldspace, 1090  
Kernighan & Ritchie. *See K&R*  
Key  
    BACKSPACE (erase character), 139  
    binding, 1090  
    CONTROL, 17  
    CONTROL-C (copy), 116  
    CONTROL-C (interrupt), 140  
    CONTROL-D (exit), 109, 232, 296

    CONTROL-H (erase character), 139, 148, 179, 227  
    CONTROL-L, 173, 181  
    CONTROL-M, 148  
    CONTROL-Q (Xoff), 135  
    CONTROL-R, 173  
    CONTROL-U (line kill), 139, 148, 179, 227  
    CONTROL-V (paste), 116, 148  
    CONTROL-W (delete word), 139, 179, 227  
    CONTROL-X (cut), 116  
    CONTROL-X (line kill), 139, 241, 295  
    CONTROL-Z (suspend), 139, 140  
    DELETE (erase character), 139  
    encryption, 1044  
    end line, 17  
    ENTER, 17  
    erase, 139, 227, 327, 468  
    interrupt, 140  
    kill (line), 139, 227  
    line kill, 139, 227  
    META, 1093  
    NEWLINE, 17, 290, 291  
    RETURN, 17, 227, 290  
    SPACE bar, 148  
    suspend, 181, 241, 295, 943  
    TAB, 148  
    typeface, 17  
    word erase, 227  
Keyboard, 1090  
    move cursor to next line, 17  
    system-config-keyboard, configuring with, 437  
Keyword  
    searching for using *apropos*, 127, 167  
    variable, 300, 305  
Kickstart utility, 82  
kill builtin, 140, 242, 408–410, 575, 917, 944, 946, 949  
Kill key, 227  
Kill line key (CONTROL-U), 139, 227  
KILL signal, 575  
killall utility, 411  
Kilo-, 1090  
Knowledgebase, Red Hat, 1036  
known\_hosts file, 624, 626, 627  
Konqueror as an LDAP client, 722  
Korn, David, 280, 1090  
Korn Shell, 1090

ks.cfg file, 82  
ksh, 280  
ksh shell, 1090  
kudzu utility, 598

## L

LAMP, 608  
LAN, 16, 361, 1090  
    compared to intranet, 358  
    configuring, 595  
    example, 363  
    more information, setting up a LAN, 617  
    setting up, 596  
Language, procedural, 958  
Large number, 1090  
Last in first out stack, 296  
Last Line mode, vim, 177  
lastlog file, 200  
launchd daemon, 417  
Launchers, 113, 114  
LBX, 367  
LCD monitor, subpixel smoothing, 272  
LDAP, 710, 1090  
    administrator, 714, 715  
    gq client, 722  
    Konqueror client, 722  
    setting up a server, 713  
ldapadd utility, 717  
ldapmodify utility, 716  
ldapsearch utility, 716  
ldif filename extension, 711  
LDIF, LDAP, 711  
Leaf, 1090  
Least privilege, 406, 1091  
Left-click, 93  
Left-handed mouse, 97, 262  
Length of filename, 190, 440  
less utility, 125, 150, 240, 292, 894  
let builtin, 347, 950  
Lexical variable, 979  
lib directory, 199  
libwrap.a library, 445, 447  
lids utility, 1059  
LIFO stack, 296  
Lightweight Directory Access Protocol. *See LDAP*  
Line kill key (CONTROL-U), 139, 227  
Line Printer Daemon. *See lpd daemon*

- LINES** variable, 918
  - Link**, 12, 212, 1091
    - create using **ln**, 214
    - delete using **rm**, 218
    - export, 738
    - hard, 481, 482, 1085, 1091
    - hard versus symbolic, 213
    - hypertext, 395
    - inode, 481
    - number of, display using **ls**, 203
    - point-to-point, 1099
    - remove using **rm**, 218, 481
    - soft. *See Link, symbolic*
    - symbolic, 1091, 1110
      - bash and, 217
      - create using **ln**, 216
      - defined, 481
      - dereference, 1078
      - versus hard, 213, 216
    - symlink. *See Link, symbolic*
  - lnks** shell script, 896
  - links** utility, 396
  - Linux**
    - boot, 551
    - distribution, 4
    - documentation, 124–132
    - Documentation Project, 132
    - file namespace, 32
    - Filesystem Hierarchy
      - Standard, 12, 198
    - Filesystem Standard, 12, 198
    - manual sections, 126
    - newsgroup, 413, 1037
    - PAM. *See PAM*
    - Pluggable Authentication Modules. *See PAM*
    - Standard Base, 198
    - Terminal Server Project, 728
  - Linux Software Map** database, 1039
  - linux** terminal name, 1041
  - linux.redhat.install** newsgroup, 393, 394
  - linux.redhat.misc** newsgroup, 394
  - linux.redhat.rpm** newsgroup, 394
  - linux-gate.so.1** file, 449
  - LinuxSecurity.com security news, 1059
  - List**
    - box. *See Drop-down list*
    - operator. *See Character, class*
    - server, 376, 1037
    - Perl, 979
  - Listserv**, 376, 1037
  - Live CD**, 24, 24
    - See also Installation*
    - ISO image, 41
  - Live session**, 53
  - liveuser**, 54
  - ln** utility, 214, 216, 481
    - versus **cp**, 214
  - Load**, system, display using **w**, 172
  - Load average**, 172
  - Loadable modules**, 1091
  - Local**
    - area network. *See LAN*
    - variable, 316, 926, 941
  - /local** directory, 36
  - local** directory, 513
  - local** file, 199
  - Locale**, 1091
  - locale** builtin, 312
  - localhost**, 373, 473
  - locate** database, 67, 168
  - locate** utility, 67, 168
  - Location bar, Nautilus, 267
  - lock** utility, 909
  - lockd** daemon, 389
  - locktty** shell script, 909
  - Log**
    - Apache, 849
    - DNS, 805, 808, 810
    - email, 674
    - file, 200
      - check, 577
      - rotate, 579
    - in. *See Login*
    - machine, 576
    - OpenSSH, 637
    - out, 433, 1092
    - rsyslogd daemon, 390
    - sendmail, 674
    - system, 390
    - vsftpd, 663
  - log** directory, 200, 480, 579, 1034, 1054
  - Logical**
    - expressions, 1092
    - Volume Manager. *See LVM*
    - volume. *See LVM, LV*
  - Login**, 1092
    - description of, 431
    - GUI, 133
    - name. *See Username*
    - options, 91
    - problems, 134, 574
    - prompt, 431
    - remote, 135
    - root**, 405, 577, 1104
    - screen, 91, 133
    - security, 1054
    - shell, 314, 432, 476, 1092
  - .login** file, 1092
  - login** utility, 314, 431
  - login.defs** file, 475, 557
  - LOGNAME** variable, 432
  - .logout** file, 1092
  - logresolve** utility, 860
  - logrotate** utility, 579
  - logrotate.conf** file, 580
  - logrotate.d** directory, 580
  - logwatch** utility, 578
  - Loopback service, 473
  - lost+found** directory, 436
  - lp** utility, 531
  - lpadmin** utility, 534–536
  - lpd** daemon, 389, 520
  - lpinfo** utility, 533
  - lpq** utility, 153, 531
  - LPR** line printer system, 520
  - lpr** utility, 153, 239, 241, 531
  - lprm** utility, 153, 531
  - lpstat** utility, 153, 531
  - ls** utility, 149, 195, 203, 206, 215, 244, 288
  - LSB**, 198
  - lsmod** utility, 550
  - lsuf** utility, 576
  - LV**. *See LVM, LV*
  - LVM**, 31, 38, 73
    - LV**, 31, 38, 73
    - PV**, 38
    - VG**, 73
  - LWN.net security alerts, 1059
  - lynx** text browser, 396
- ## M
- m4** macro processor, 678
  - MAC** address, 454, 1092
  - Machine**
    - collating sequence, 1092



- independence, 9
- log, 576
- name, display, 151
- Macro, 1092
  - m4, processor, 678
  - processor, m4, 678
- magic** file, 480, 1092
- Magic number, 480, 1092
- magic number** database, 480
- Mail
  - .forward** file, 676, 682
  - accepting mail from unknown hosts, 679
  - access** file, 680
  - aliases, 471, 675
  - aliases** file, 682
  - authenticated relaying, 689
  - backup server, 679
  - check **root**, 577
  - communicate with users, 572
  - delivery agent, 390
  - forwarding email, 680
  - how **sendmail** works, 674
  - IMAP, 689
  - JumpStart
    - configuring **sendmail** on a client, 672
    - configuring **sendmail** on a server, 673
  - list server, 376, 1037
  - log, 674
  - mail** directory, 674, 677, 680
  - mailbox, 307
  - maildir** format, 674
  - mailertable** file, 680
  - mailing list, 688
  - maillog** file, 674
  - Mailman, 688
  - mailq utility, 676
  - mailstats utility, 677
  - makemap utility, 677
  - masquerading, 678
  - mbox** format, 674
  - MDA, 669, 1093
  - more information, 672
  - mqueue** file, 674
  - MTA, 669, 1049, 1094
  - MUA, 669, 1050, 1094
  - network addresses, 174
  - newaliases utility, 676
  - POP, 689
  - Postfix, 691
  - postmaster, 577
  - praliases utility, 676
  - prerequisites, 671
  - procmail** daemon, 670
  - Qmail, 691
  - relay host, 680
  - security
    - about, 1049
    - GnuPG, 1049
    - MTA, 1049
    - MUA, 1050
    - PEM encryption, 1049
  - self-signed certificate, 690
  - sending to remote user, 375
  - sendmail** daemon, 669, 670, 674, 676
  - sendmail.cf** file, 677
  - sendmail.mc** file, 672, 678
  - serving multiple domains, 681
  - SMTP, 669
  - spam, 382
  - SpamAssassin, 682
  - spamd** daemon, 682
  - SquirrelMail, 686
  - SSL, 690
  - user agent, 390
  - virtusertable** file, 681, 682
  - Webmail, 686
- mail** directory, 579, 674, 677, 680
- mail utility, 174, 577
- MAIL** variable, 307, 432
- Mailbox, 307
- MAILCHECK** variable, 307
- maildir** format, 674
- mailertable** file, 680
- Mailing list, 688
- maillog** file, 578, 674
- Mailman, 688
- MAILPATH** variable, 307
- mailq utility, 676
- mailstats utility, 677
- Main memory, 1092
- Main menu, 93, 114
- Main toolbar, Nautilus, 267
- Mainframe computer, 7
- Maintenance. *See* **System**, *administration*
- Major device number, 484, 1092
- make utility, 164, 1014
- makedbm utility, 706
- makemap utility, 677
- makewhatis utility, 67, 127, 168
- MAN, 362, 1093
- man** directory, 200
- man utility, 14, 125–126
- Manager
  - file. *See* **Nautilus**
  - session, 108
  - window, 142
- Man-in-the-middle, 803, 1048, 1051
- Manuals
  - See also* **Help**
  - GNU, 1035
  - reference, finding, 1035
- Map file, 745
- Masquerading
  - IP, 821, 832, 836, 1093
  - mail, 678
- Massachusetts Institute of Technology. *See* **MIT**
- Master Boot Record. *See* **MBR**
- Master server, DNS, 778
- mawk utility, 1030
- mbox** format, 674
- MBR**, 551
- MD5 encryption, 477, 1093
- MD5SUM** file, 45
- md5sum utility, 45
- MDA, 669, 1093
- Mebibyte, 33, 1093
- Megabyte, 1093
- Memory
  - See also* **RAM**
  - main, 1092
  - paging, 479
  - testing, 53
  - virtual, 479
- memtest86+ utility, 53
- Menu, 1093
  - Administration, 114
  - context, 96, 119
  - Main, 114
  - Object context, 96, 119
  - objects, 113
  - Panel (context), 111
  - Panel Object context, 113
  - panel. *See* **Panel**
  - Preferences, 114
  - shell script, 913
  - System, 114
  - Window Operations, 116
- Menubar, Nautilus, 267

- Merge, 1093
  - mesg utility, 173
  - Message
    - See also Error, message; Usage message*
    - daemon, from, 480
    - deny using mesg, 173
    - of the day. *See motd file*
    - security, 480
    - sending
      - email, 572
      - wall, 572
      - write, 172, 572
    - syslog directory, 1054
    - system, 480, 574
    - truncating, 579
    - usage, 224, 892, 898, 916
  - Message Digest 5. *See MD5*
  - messages file, 200, 459, 480, 574, 578, 579, 805, 1034
  - META key, 1093
  - Metabit, 1069
  - Metacharacter, 243, 1093
  - Metacity window manager, 108, 143
  - Metadata, 1093
  - Method of last resort, kill, 409
  - Metropolitan area network, 1093
  - Microprocessor, 8
  - Middle mouse button, 116
  - MIME, 121, 1094
  - mingetty utility, 314, 431, 474
  - Minicomputer, 7
  - Mini-HOWTOs, 130
  - Minimize window, 1094
  - MINIX, 4
  - minix filesystem, 486
  - Minor device number, 484, 1094
  - Mirror site, 1036
  - misc.jobs.offered newsgroup, 393
  - Mistakes, correct typing, 138
  - MIT, 15
  - MIT, Project Athena, 256
  - MIT, X Consortium, 256
  - MITM. *See Man-in-the-middle*
  - mkdir utility, 195, 197, 731
  - mkfifo utility, 483
  - mkfs utility, 439, 489, 578
  - mkswap utility, 479
  - Modem, 1094
    - cable, 1073
  - Modifying a user, 556
  - modinfo utility, 550
  - modprobe utility, 550
  - Module, kernel, 549
  - Module, Perl, 979
  - modules directory, 199, 550
  - Monitor, LCD, subpixel smoothing, 272
  - More information
    - Apache, 843
    - Cacti, 617
    - DHCP, 452
    - DNS, 786
    - email, 672
    - FTP, 645
    - iptables, 822
    - LAN, setting up a, 617
    - MySQL, 585
    - NFS, 730
    - NIS, 698
    - OpenSSH, 624
    - PAM, 459
    - Samba, 751
    - security, 1058
    - system administration, 413
  - more utility, 150, 240, 894
  - Morris, Robert T., Jr., 1056
  - Mosaic Web browser, 395
  - motd file, 432, 474, 476, 572
  - Mount, 1094
    - automatic, 388, 1070
    - filesystem automatically, 744
    - floppy diskette, 488
    - point, 32, 487, 745, 1094
    - remote filesystem, 730
    - table, 472, 490
  - mount utility, 435, 474, 487, 488, 731, 767
  - mountd daemon, 389, 733
  - mounts file, 474
  - Mouse, 1094
    - click, 93
    - double-click timeout, 97
    - focus-strictly-under, 141
    - focus-under, 141
    - left-handed, 97, 262
    - middle button, 116
    - mouseover, 1094
    - pointer, 1094
    - pointer, hover, 93, 1086
    - preferences, setting, 97
    - remapping buttons, 262
    - right-click, 96
    - right-handed, 262
    - wheel, 262
    - window manager, 15
  - Mouseover, 1094
  - Move
    - directory using mkdir, 202
    - file using mv, 201
  - Mozilla
    - history of, 395, 396, 516
    - netnews, 393
  - mqueue file, 674
  - MS Windows. *See Windows*
  - msdos filesystem, 486
  - MS-DOS. *See DOS*
  - mt utility, 565
  - MTA, 669, 1094
    - security, 1049
  - mtab file, 474
  - MUA, 669, 1094
    - security, 1050
  - Multiboot specification, 1094
  - Multicast, 369, 1095
  - Multipurpose Internet Mail Extension. *See MIME*
  - Multitasking, 11, 241, 1095
  - Multiuser, 1095
    - about, 431
    - Linux design, 8, 10
    - mode, 431
      - extended, 431
      - initiate, 431
    - Superuser, 406
  - mv utility, 152, 201, 481
  - MX record, DNS, 681, 780
  - MySQL, 584
    - column, 585
    - database, 585
    - mysql\_secure\_installation utility, 586
    - row, 585
    - table, 585
  - mysql\_secure\_installation utility, 586
- ## N
- Name
    - command, 224
    - daemons, 388
    - domain. *See Domain, name*
    - login. *See Username*
    - server, 385, 386
    - space, 1095
    - variable, 299

- named.conf** file, 786, 793, 794, 807, 812
- named** daemon, 389, 788, 794
- named** directory, 794, 800
- named** file, 786, 805
- Named pipe, 351, 482, 483
- Namespace, 32, 1095
- NAT, 820, 1095
- National Center for Supercomputer Applications, 395
- Nautilus, 98–104
  - access permissions, 121
  - control bars, 266
  - emblems, 120, 266
  - File Browser versus Spatial windows, 99
  - File Browser window, 99, 264–270
  - file manager, 270
  - file, open with, 110
  - hidden files, displaying, 270
  - history, 266
  - location bar, 267
  - Main toolbar, 267
  - menubar, 267
  - Open With selection, 121
  - places, 266
  - Side pane, 265
  - spatial view, 270
  - status bar, 267
  - trash, 270
  - View pane, 265
- NBT, 1095
- ncpfs** filesystem, 486
- ndbm** database, 1078
- nessus utility, 1059
- net use utility (Windows), 769
- net utility, 750
- net view utility (Windows), 769
- NetBIOS, 1095
- Netboot, 729, 1095
- netcat utility, 1059
- netgroup** file, 474
- Netiquette, 1095
- Netmask, 1095
- Netnews
  - answers, finding, 394
  - archive, **groups.google.com**, 394
  - comp.lang.c** newsgroup, 393
  - comp.os.linux.announce** newsgroup, 394
  - comp.os.linux.misc** newsgroup, 393, 394
  - comp.os.linux.networking** newsgroup, 394
  - comp.os.linux.security** newsgroup, 394
  - comp.os.linux.setup** newsgroup, 394
  - comp.security.firewalls** newsgroup, 1053
  - group structure, 393
  - groups, 393
  - hierarchical structure of groups, 393
  - history of, 392
  - linux.redhat.install** newsgroup, 393, 394
  - linux.redhat.misc** newsgroup, 394
  - linux.redhat.rpm** newsgroup, 394
  - misc.jobs.offered** newsgroup, 393
  - Mozilla News, 393
  - Netscape News, 393
  - newsgroups, 393
  - nn utility, 393
  - readnews utility, 393
  - rec.skiing** newsgroup, 393
  - rn utility, 393
  - sci.med** newsgroup, 393
  - soc.singles** newsgroup, 393
  - structure of groups, 393
  - talk.politics** newsgroup, 393
  - tin utility, 393
  - xrn utility, 393
  - xvnews utility, 393
- Netscape
  - BugSplat, 516
  - history of, 395
  - Navigator, 395
  - netnews, 393
- netstat utility, 369
- Network
  - @ in an address, 374–376
  - @ with email, 376
  - 10Base2 cable, 361
  - 10BaseT cable, 361
  - 100BaseT cable, 361
  - Address Translation. *See* NAT
  - address, 1096
    - @ sign in, 374, 375, 376
    - email, 174
    - mask, 371
    - space, private, 598, 1100
  - boot, 1095
  - bottleneck, 381
  - broadcast, 360, 1072
    - address, 1072
    - multicast, compared, 370
    - packet, 367
    - unicast, compared, 367
  - browser, 395
  - Category 5 cable, 361
  - Category 5e cable, 361
  - Category 6 cable, 359, 361
  - Category 7 cable, 359
  - class, IP address, 368
  - coaxial cable, 361
  - configure using nm-applet, 599
  - configure using nm-connection-editor, 599, 600
  - connection, test using ping, 379
  - daemon, 358, 388
  - datagram, 359, 1078
  - DNS, 385
  - domain name, 385
  - dynamic IP address, 368
  - Ethernet, 357, 360–362, 1081
  - extranet, 359, 1081
  - FDDI, 1082
  - fiberoptic cable, 361
  - fileserver, 727
  - Filesystem. *See* NFS
  - firewall, 363
  - frame, 359, 1083
  - gateway, 362, 597, 1083
  - heterogeneous, 695
  - hops, 380
  - host address, 367
  - hostname
    - FQDN, 373
    - nickname, 373
  - hub, 361, 596, 1086
  - ICMP packet, 1087
  - Information Service. *See* NIS
  - interface card. *See* Network, NIC
  - Internet, 358
  - internet (*lowercase “i”*), 1088
  - intranet, 358
  - IP
    - address, 367
    - address class, 368
    - Next Generation, 373
  - local area. *See* LAN

Network, *continued*

- manager applet, 599
- metropolitan area. *See* MAN
- monitor using Cacti, 607
- multicast, 369, 1095
- nameserver, 385, 386
- netmask, 1095
- netnews. *See* Netnews
- newsgroup, 393
- NIC, 596, 597
- number. *See* Network, address
- packet, 359, 380, 1098
- packet filtering, 1098. *See also* *iptables*
- packet sniffer, 1098
- partner net, 359
- passive hub, 361, 596
- ping to test, 379
- point-to-point link, 360
- port forwarding, 1099
- PPP protocol, 367
- private address space, 598, 1100
- privileged port, 1100
- protocol, 365
- remote filesystem, 358
- resolver, 386
- route trace, 380
- router, 361, 362, 363, 597, 1104
  - SmoothWall Linux distribution, 597
- security
  - about, 1050
  - guidelines, 1051
  - solutions, 1051
- segment, 1096
- services, 358, 388
- setting up, 596
- SLIP protocol, 367
- sniff, 1107
- socket, 484
- static IP address, 368
- subnet, 371, 1109
  - about, 371
  - addresses, 1109
  - mask, 371, 1109
  - numbers, 1109
  - specifying, 443
- switch, 360, 361, 596, 1096
- switching hub. *See* Network, *hub*
- TCP/IP protocol, 365
- thicknet cable, 361
- thinnet cable, 361
- Time Protocol. *See* NTP
- token ring, 1111
- topology, shared, 1105
- trace route, 380
- transfer rate, 361
- trusted hosts, 376
- tunneling, 1112
- twisted pair cable, 361
- UDP, 365, 1112
- unicast, 367, 1113
- unicast versus broadcast, 367
- unshielded twisted pair cable, 361
- user communication, 374
- utilities, 358, 376
- UTP cable, 361
- virtual private, 359
- VPN, 359, 1114
- WAN. *See* WAN
- WAP, 597
- wide area. *See* WAN
- Wi-Fi. *See* Network, *wireless*
- wireless, 1115
  - access point, 597
  - bridge, 597
  - mode, 598
  - NIC, 605
- network file, 699, 704
- NetworkManager daemon, 599
- newaliases utility, 676
- NEWLINE key, 17, 290, 291
- News, Internet. *See* Netnews
- Newsgroup
  - comp.lang.c, 393
  - comp.os.linux.announce, 394
  - comp.os.linux.answers, 413, 1037
  - comp.os.linux.misc, 393, 394, 413, 1037
  - comp.os.linux.networking, 394
  - comp.os.linux.security, 394
  - comp.os.linux.setup, 394
  - comp.security.firewalls, 1053
  - linux.redhat.install, 394
  - linux.redhat.misc, 394
  - linux.redhat.rpm, 394
  - list of, 1037
  - misc.jobs.offered, 393
  - rec.skiing, 393
  - sci.med, 393
- soc.singles, 393
- talk.politics, 393
- NFS, 727, 728, 1096
  - /proc/fs/nfs/exports file, 738
  - all\_squash option, 742
  - attribute caching options, 732
  - block size, 734
  - client, setting up, 730
  - daemons, 389
  - data flow, 728
  - error handling options, 733
  - error message, NFS server xxx
    - not responding, 729
  - exchanging files, 606
  - export
    - device file, 738
    - directory hierarchy, 738
    - table, kernel, 738
  - exportfs utility, 742
  - exports file, 738, 739
  - filesystem, 486
  - fstab file, 731, 732, 735
  - home directories, 606
  - JumpStart
    - configuring an NFS server
      - with system-config-nfs, 737
    - mounting a remote directory, 730
  - line speed, testing, 734
  - miscellaneous options, 733
  - more information, 730
  - mount a filesystem, 730
  - mount utility, 731
  - nfsnobody, 741
  - NIS and, 741
  - options
    - all\_squash, 742
    - attribute caching, 732
    - error handling, 733
    - miscellaneous, 733
    - root\_squash, 741
  - performance, improving, 734
  - portmap daemon, 730
  - portmap utility, 743
  - prerequisites, 730, 736
  - root\_squash option, 741
  - rpcbind daemon, 730
  - security, 730
  - server-server dependency, 745
  - setuid, 731
  - showmount utility, 742
  - stop, 427

- testing, 743
  - timeout, 733, 734
  - umount utility, 732
  - user ID mapping, 741
  - x**
    - xtab** file, 738, 743
  - nfs** file, 738
  - nfsd** daemon, 389, 743
  - nfsnobody**, 741
  - NIC, 386, 596, 597, 1096
  - Nickname, host, 373
  - nicknames** file, 698
  - NIS, 695, 696, 1096
    - adding users, 703
    - client setup, 699
    - client, test, 701
    - database, 373, 387
    - domain, 696
    - domain name, 699, 1096
    - GECOS, 710
    - login, 432
    - makedbm utility, 706
  - Makefile**, 706
  - map**, 697
    - displaying, 698
    - names, 697
    - nicknames, 698
  - master server, 696
  - more information, 698
  - need for, 373
  - network** file, 699
  - NFS and, 741
  - nicknames** file, 698
  - nisdomainname** utility, 700
  - passwd** utility, 702
  - prerequisites
    - client, 699
    - server, 703
  - removing users, 703
  - rpcinfo** utility, 701
  - securenets** file, 706
  - server setup, 703
  - server specify, 700
  - slave server, 696
  - source files, 697
  - testing, 709
  - Yellow Pages, 696
  - yp.conf** file, 700
  - ypbind** daemon, 701
  - ypbind-mt** daemon, 701
  - ypinit** utility, 708
  - yppasswd** utility, 702
  - yppasswdd** daemon, 709
  - ypserv.conf** file, 704
  - ypwhich** utility, 701
  - ypxfr** utility, 708
  - ypxfrd** daemon, 708
  - nisdomainname** utility, 700
  - nmap** utility, 1059
  - nm-applet** utility, 599
  - nmbd** daemon, 390, 750, 768, 769
  - nmblookup** utility, 769, 770
  - nm-connection-editor** utility, 599, 600
  - nn** utility, 393
  - NNTP** (Network News Transfer Protocol), 393, 1096
  - noacpi** boot parameter, 69
  - noapic** boot parameter, 69
  - noapm** boot parameter, 69
  - noclobber** variable, 235
  - Node**, 1097
  - nolisten tcp** option (X Window System), 259
  - nologin** utility, 476
  - nologin.txt** file, 462, 476
  - Nonprinting character, 1097
  - Nonrewinding tape device, 564
  - Nonvolatile storage, 1097
  - Normal mode, *vim*. *See vim, Command mode*
  - NOT** Boolean operator, 958
  - nsswitch.conf** file, 387, 432, 455, 475, 696, 785
  - nst0** file, 564
  - ntfs** filesystem, 486
  - NTP**, 1097
  - ntp.conf** file, 389
  - ntpd** daemon, 389
  - Null**
    - builtin (:), 945, 949
    - device, 237
    - string, 926, 1097
  - null** file, 237, 469, 471, 579, 907, 946
  - Number**
    - block, 1071
    - gibibyte, 1084
    - gigabyte, 1084
    - hexadecimal, 1085
    - job, 241
    - kilo-, 1090
    - large, 1090
    - magic, 1092
    - mebibyte, 1093
    - megabyte, 1093
  - octal, 1097
  - sexillion, 1105
  - tera-, 1110
  - undecillion, 1113
- ## O
- o** Boolean operator, 951
  - o** filename extension, 191
  - Object**, 92
    - click, 93
    - Clock, 96
    - context menu, 96, 119
    - copying, 104, 116
    - cut and paste, 116
    - dragging, 98
    - moving on a panel, 113
    - panel. *See Panel*
    - preferences, setting, 96
    - Properties window, 120–122
    - right-click, 96
    - selecting, 104
    - trash, moving to, 104
    - Update Notifier, 104
  - ObjectClass**, LDAP, 712
  - Octal** number, 1097
  - od** utility, 471
  - OLDPWD** variable, 346
  - One-time** password, 1054
  - One-way** hash, 1097
  - Online documentation, 383
  - Open** file, 921
  - Open Group**, 256
  - OpenLDAP**, 710
  - OpenOffice.org**, 102, 109
  - OpenPGP** Message Format, 1048
  - OpenSSH**, 1097
    - .ssh** directory, 623
    - authentication, 622, 624
    - authorized keys, 634
    - authorized\_keys** file, 623
    - automatic login, 634
    - clients, 625, 633
    - compression, 641
    - config** file, 631
    - configuration files, 631, 636
    - debugging, 638
    - diff** utility, 628
    - encryption, 624
    - files, 622
    - firewall, 640
    - global files, 623
    - host key, 624

OpenSSH, *continued*

- how it works, 624
- initial connection to, 626
- JumpStart
  - starting the `sshd` daemon, 633
  - using `ssh` and `scp`, 625
- known hosts, 626
- `known_hosts` file, 624, 626, 627
- log file, 637
- more information, 624
- NFS shared home directories and, 606
- port forwarding, 638
- prerequisites, 625, 633
- protocol versions 1 and 2, 622
- public key encryption, 622
- recommended settings, 626, 634
- remote commands, 628
- rhost authentication, 623
- `scp` utility, 625
- security, 621
- server authentication, 626
- session key, 624
- setup, 626
- `sftp` utility, 631
- shell, remote, 628
- `ssh` directory, 623
- `ssh` utility, 622, 625, 627, 628
- `ssh_config` file, 631
- `ssh_known_hosts` file, 623, 626, 627
- `sshd` daemon, 633
- `ssh_config` file, 636
- `ssh-keygen` utility, 634
- troubleshooting, 637
- tunneling, 638
- user files, 623
- X11 forwarding, 626, 632, 637, 638

Operating system, 1097

- generic, 8
- proprietary, 7

Operations menu, Window, 116

Operator

- `bash`, 953
  - in expressions, 953
  - redirection, 286
- bitwise
  - `&`, 954, 957
  - `^`, 954

- `l`, 954
- `AND`, 370, 371
- Boolean, 956
- `!`, 313, 954, 958
- `&&`, 313, 515, 951, 955, 956, 958
- `ll`, 313, 951, 955, 956, 957
- `-a`, 895, 951
- `NOT`, 958
- `-o`, 951
- decrement, 955
- increment, 955
- list. *See Character, class*
- postdecrement, 955
- postincrement, 955
- predecrement, 955
- preincrement, 955
- relational, 952
- short-circuiting, 956
- table of, 953
- OPIE utility, 1054
- `/opt` directory, 36
- `opt` directory, 199, 513
- `OPTARG` variable, 947
- `OPTIND` variable, 947
- Option, 1097
  - `bash`. *See bash, features*
  - boot, 68
  - combining, 225
  - defined, 225
- OR operator, 951
- Order file using sort, 155
- Order of expansion, command line, 301
- Ordinary file, 189, 1097
- Organize a filesystem, 188
- Other access, 203
- `out` shell script, 893
- Output, 1097
  - append. *See Append, standard output*
  - redirect, 158
  - standard. *See Standard, output*
- Overlay a shell, 290
- Owner
  - access, 203
  - file, name of, display using `ls`, 203, 288

## P

- P2P, 1097
- Pack archive file using `tar`, 163

- Package variable, Perl, 979
- Package, Perl, 979
- Package. *See Software, package*
- Packet, 1098
  - broadcast, 367
  - filtering, 1098. *See also iptables*
  - network, 359, 380
  - sniffer, 1098
  - unicast, 367
- Page break, 181
- Pager, 125, 150, 1098
- Paging, 479, 1098
- palimpsest utility, 78
- PAM, 458, 1098
  - features, 432
  - more information, 459
  - security, login, 1054
  - stack, 461
- `pam.conf` file, 463
- `pam.d` directory, 458, 459, 461, 463, 475
- Panel, 92, 110
  - (context) menu, 111
  - object, 110, 113
    - adding, 111
    - moving, 113
  - Object context menus, 113
  - orientation, 112
  - Properties window, 112
- Parameter
  - expansion, 346
  - positional, 930
  - shell, 299
  - special, 928
  - substitution, 301
- Parent
  - directory, 189, 190
  - of all processes, 425
  - process, 314, 941, 1098
- Parentheses
  - grouping commands, 293
  - shell functions, 336
- Parse, 227, 342
- parted utility, 568
- Partition, 30, 1098
  - `/boot`, 550, 571
  - create, guided, 34
  - creating, about, 33
  - deleting, 80
  - Disk Druid, 71
  - extended, 31
  - filesystem, 31

- logical, 31
- LVM, 38
- naming, 33
- parted editor, 568
- primary, 31
- RAID, 37, 495
- sizes, suggested, 34
- swap, 34
- table, 30
- UUID number, 490
- working with using palimpsest, 78
- Partner net, 359
- PASC, 280
- Passive FTP. *See* **FTP**, **PASV**
- Passive hub, 361, 596
- Passphrase, 1098
- passwd** database, 556
- passwd** file, 305, 431, 475, 574, 695, 903, 904
- passwd** utility, 405, 406, 478, 702
- Password, 1098
  - breaking, 577
  - change, 136, 405
  - generate using pwgen, 137
  - group, 472
  - hashed, 477
  - one-time, 1054
  - Samba, 752
  - Superuser, 577
- PASV FTP. *See* **FTP**, **PASV**
- Path, search, 166
- PATH** variable, 306
  - inherited, 300
  - login, 432
  - Superuser, 412
  - usage, 915
- Pathname, 1098
  - / within, 32
  - ~ (tilde) in a, 193
  - absolute, 193, 228, 1068
  - completion, 328
  - defined, 189
  - elements, 1099
  - expansion, 243, 302, 349, 350
  - last element of, 1098
  - relative, 194, 195, 228, 1103
  - using, 201
- PC processor architecture, 27
- pdf** filename extension, 191
- Peer, BitTorrent, 507
- PEM encryption, 1049
- Period special character, 1025
- Period, leading in a filename, 244
- Peripheral device. *See* **Device**
- Perl, 975–1018
  - \$!** variable, 1002
  - \$array** variable, 988
  - \$.** variable, 999
  - \$\_** variable, 999
  - .** (dot) operator, 988
  - ..** (range) operator, 989
  - ::**, use of, 979, 1013
  - @\_** array, 1006
  - array, 979
  - block, 979
  - chomp** function, 993, 1001
  - chop** function, 1001
  - closedir** function, 1017
  - comparison operators, 992
  - compound statement, 979
  - CPAN, 1013
  - defined** function, 985
  - die** function, 993, 1002
  - distribution, 979
  - e** option, 1008
  - error checking, 1002
  - file handle, magic, 1000
  - file test operators, 991
  - for** control structure, 995–998
  - foreach** control structure, 995–998
  - foreach** statement, postfix syntax, 996
  - greedy matching, 1010
  - handle, 1000
  - if** control structure, 991
  - if** statement, postfix syntax, 992, 1008
  - if...else** control structure, 993
  - if...elsif...else** control structure, 994
  - keys** function, 990
  - l** option, 1008
  - last** statement, 996
  - lexical variable, 979
  - list, 979
  - magic file handle, 1000
  - module, 979, 1013
  - my** function, 1005
  - namespace, 979, 1013
  - next** statement, 996
  - nongreedy matching, 1010
  - opendir** function, 1017
  - operators, comparison, 992
  - options, combining, 1008
  - package, 979
  - package variable, 979
  - parsimonious matching, 1010
  - perldoc** utility, 977
  - pop** function, 989
  - postfix syntax, 992, 996
  - push** function, 989
  - readdir** function, 1017
  - regular expressions, 1007–1013
  - replacement string, 1009
  - reverse** function, 1003
  - say** function, 981
  - shift** function, 989, 1007, 1016
  - slice, array, 989
  - sort** function, 1003
  - splice** function, 989
  - split** function, 1017
  - statement, compound, 979
  - statements, 981
  - subroutines, 1005–1007
  - substr** function, 1015
  - syntax, 981
  - uc** function, 996
  - unless** control structure, 991
  - until** control structure, 998
  - use feature 'say'**, 981
  - use** function, 981
  - use strict** statement, 977
  - use warnings** statement, 977, 985
  - values** function, 990
  - w** option, 985
  - while** control structure, 998
- perldoc** utility, 977
- Permission
  - access
    - change using **chmod**, 204
    - control of, 204
    - directory, 206
    - display using **ls**, 203
    - execute, 288
    - read, 288
    - types of, 204
  - execute, 288
  - file access, 204, 472
  - read, 288
  - setgid, 205
  - setuid, 205
  - set using **chmod**, 406
- Persistent, 1099
- PGP encryption, 1048

- pgpkey** file. *See .pgpkey file*
- Philosophy, UNIX, 374
- Phish, 1099
- php** filename extension, 854
- Physical
- device, 1099
  - security, 1056
  - volume. *See LVM, PV*
- Pick a Color window, 273
- Pick a Font window, 272
- PID, 314, 1099
- \$! variable and, 930
  - \$\$ variable, 929
  - background process and, 241, 292
  - fg, 294
  - number 1, 314, 425
  - temporary file, use in name of, 917
- pidof utility, 411
- pinfo utility, 128
- ping utility, 379, 439, 477, 769
- ping6 utility, 380
- Pipe, 1099
- | symbol in extended regular expressions, 1030
  - at end of line, 904
  - command separator, 292
  - defined, 238
  - filter, 14, 240
  - introduction, 158
  - named, 351, 482, 483
  - noclobber** and, 235
  - standard error and, 285
  - syntax exception, 904
- Pipeline. *See Pipe*
- pirut utility, 505
- Pixel, 1099
- Places menu, 114
- Plaintext, 1044, 1099
- plan** file. *See .plan file*
- Pluggable Authentication Module. *See PAM*
- Plus sign in extended regular expressions, 1030
- Pointer to a file, 212
- Point-to-point link, 360, 603, 1099
- Point-to-Point Protocol. *See PPP*
- POP, email, 689
- pop3-login** daemon, 689
- popd builtin, 298
- Port, 387, 1099
- forwarding, 1099
  - forwarding, OpenSSH, 638
  - privileged, 387, 1050
- Portability, 8, 9
- portmap** daemon, 389, 392, 730
- portmap utility, 743
- Portmapper, 1100
- Positional parameter, 300, 930
- POSIX, 8, 280
- Postdecrement operator, 955
- Postfix, 691
- postfix** daemon, 1050
- Postincrement operator, 955
- Postmaster, 577
- PostScript Printer Definition. *See PPD files*
- Postscript, brace expansion, 344
- Power management, 388
- Power, turn off, 435
- poweroff utility, 433
- ppd** directory (CUPS), 535
- PPD files, 533
- PPID. *See Parent, process*
- PPP protocol, 367, 477, 603
- pppd** daemon, 389
- praliases utility, 676
- Preamble, brace expansion, 344
- Preboot Execution Environment. *See PXE*
- Predecrement operator, 955
- Preferences submenu, 114
- Preferences, setting, 96
- Preincrement operator, 955
- Prerequisites
- Apache, 843
  - automount, 744
  - BitTorrent, 508
  - DHCP client, 452
  - DHCP server, 453
  - DNS, 785
  - FTP, 645
  - iptables, 823
  - NFS, 730, 736
  - NIS client, 699
  - NIS server, 703
  - Samba, 751
  - sendmail**, 671
  - vsftpd**, 654
- Pretty Good Privacy. *See PGP encryption*
- Primary
- buffer, 116
  - master server, DNS, 778
- Print file, 153
- Printable character, 1100
- printcap** file, 476
- Printer
- See also CUPS; Printing*
  - capability database, 476
  - classes, 533
  - configure using **lpadmin**, 534–536
  - configure using **system-config-printer**, 524–527
  - control characters, 914
  - daemon, 389, 427
  - disable using **cupsreject**, 536
  - enable using **cupsaccept**, 536
  - IPP protocol, 520
  - lpr** and, 153
  - page break, 181
  - print queue, 520
  - queue, managing, 523, 536
  - remote, configuring, 527
  - sharing, 537
  - skip to top of page, 181
  - top of form, 181
  - using, 153
- Printing
- See also CUPS; Printer*
  - command line, from the, 530
  - quotas, 536
  - system, 519
  - UNIX traditional, 530
  - Windows
    - from using CUPS, 538
    - from using Samba, 539
    - to using CUPS, 540
- Privacy Enhanced Mail. *See PEM encryption*
- Private address space, 598, 1100
- Private key, 1045
- Privilege, least, 406, 1091
- Privileged port, 387, 1050, 1100
- Privileges, **root**. *See Superuser*
- proc** filesystem, 199, 478, 486, 487, 562
- Procedural language, 958
- Procedure, 1100
- Process, 1100
- background, 314, 316, 1070
  - child, 314, 316, 1074
  - defined, 229, 314
  - die, 314, 316
  - first, 425
  - fork, 314



- foreground, 1083
  - ID. *See* **PID**
  - init**, 425
  - kill, 409
  - parent, 314, 1098
  - parent of all, 425
  - parent-child relationship, 314
  - search for using **ps** and **grep**, 410
  - sleep, 229, 316
  - spawn. *See* **Fork**
  - spontaneous, 314
  - start, 229
  - structure, 314
  - substitution, 351
  - wake up, 229, 314, 316
  - Processing a command line, 227
  - Processor architecture, 26
  - procmail** daemon, 670, 685
  - procmail** utility, 174
  - .profile** file, 1100
  - profile** file, 281, 412, 432, 476
  - Program, 1100
    - See also* **Builtin**; **Utility**
    - running, 93-95
    - structures, 958
    - terminating, 98, 140
  - Project Athena, 256
  - project** file. *See* **.project** file
  - PROM, 1100
  - Prompt, 1100
    - #**, 405
    - \$**, 17
    - %**, 17
    - bash**, 307
    - job control and, 294
    - login, 431
    - PS2**, 336
    - PS3**, 918
    - representation, 17
    - root**, 405
    - secondary, 904
    - shell, 224
    - Superuser, 405
  - Proprietary operating system, 7
  - Protocol, 1100
    - connection-oriented, 366, 1076
    - connectionless, 1076
    - datagram-oriented, 367
    - defined, 365
    - DHCP, 451
    - HTTP, 396
    - HTTPS, 396, 877
    - ICMP, 380
    - IPP, 520
    - IPSec, 1051
    - ISO model, 365
    - network, 365
    - NNTP, 393
    - Point-to-Point (PPP), 367, 603
    - SLIP, 367
    - TCP/IP, 365
    - TELNET, 390
    - UDP, 365
  - protocols** file, 476, 829
  - Proxy 391, 1101
    - gateway, 391, 1101
    - server, 391, 1101
  - ps** filename extension, 191
  - ps** utility, 242, 314, 575, 579, 929
  - PS1** variable, 283, 307
  - PS2** variable, 309, 336
  - PS3** variable, 918
  - PS4** variable, 900
  - Pseudographical interface, 28, 138
  - Pseudoterminal, 469
  - pstree** utility, 315
  - pts** file, 469
  - pub** directory, 649
  - Public key encryption, 1045
    - OpenSSH, 622
  - Public License, GNU. *See* **GNU**, *General Public License*
  - public\_html** directory, 853
  - pushd** builtin, 297
  - pwd** builtin, 192, 196, 949
  - pwd** utility, 195, 217
  - PWD** variable, 346
  - pwgen** utility, 137
  - PXE, 729
  - Python, 1101
- ## Q
- Qmail, 691, 1050
  - qnx4** filesystem, 486
  - Qt toolkit, 263
  - Question mark in extended
    - regular expressions, 1030
  - Questions, finding answers to, 394
  - Quick substitution, 325
  - Quiescent, 430
  - quiet** boot parameter, 54
  - quota utility, 582
  - quotaon utility, 582
  - Quotation mark
    - double, 301, 348, 889, 933
    - in Perl, 982
    - removal, 343
    - single, 148, 301, 904
    - single versus double, 333, 350
    - usage message, 898
  - Quoting, 1101
    - characters, 148, 291
    - parentheses in regular
      - expressions, 1028
    - shell variables, 301
    - special characters, 302
    - special characters in regular
      - expressions, 1027
    - whitespace, 301
- ## R
- Radio button, 1101
  - RAID, 37, 494, 558, 1101
  - RAM, 1102
    - disk, 39, 1102
    - swap and, 34, 479
    - testing, 53
  - Random access memory. *See* **RAM**
  - Random bytes, generating, 470
  - random** file, 470
  - Random number generator, 470
  - RANDOM** variable, 965
  - RAS, 1055, 1102
  - Raw
    - device, 485
    - mode, 484
  - rbac** utility, 1059
  - rc** file, 426
  - rc** scripts, 426
  - rc.d**
    - about, 429
    - directory, 476
    - init.d** directory, 426, 428
  - rc.local** file, 427
  - rc.sysinit** file, 426, 492
  - rc2** file, 422
  - RC5 encryption, 1047
  - rcn.d** directory, 426
  - rcp** utility, 376
  - RDF, 1102

- Read
  - access, 203, 288
  - user input, 937
- read builtin, 907, 908, 913, 937, 938, 950
- Readline Library, 318, 326, 328
- readnews utility, 393
- readonly builtin, 303–305, 950
- Readonly memory. *See* ROM
- Readonly variable, 299
- Reboot system, 434
- reboot utility, 433, 434
- Rebuilding Linux, 543
- rec.skiing newsgroup, 393
- Recovery mode, root password, 425
- Recursion, 959
  - infinite, alias, 332, 335
- Recursive plunge. *See* Recursion, *infinite, alias*
- Red Hat
  - Directory Server, 711
  - Enterprise Linux. *See* RHEL
  - Knowledgebase, 1036
  - Linux, Druid, 1080
  - Network. *See* RHN
  - Package Manager. *See* RPM
  - security information, 1060
- Redirect
  - operators, bash, 286
  - output, 158
  - standard
    - error, 941, 946
    - input, 234, 941
    - output, 232, 235, 941
    - output and append, 236
    - output and error, 285
    - output of background job, 242
    - output using tee, 240
- Redirection, 13, 232, 1102
- Redundant array of inexpensive disks. *See* RAID
- Reentrant code, 1102
- Reexecuting commands, 318
- Refresh screen, 173
- Regular character, 1102
- Regular expression, 1023, 1103
  - \(...\) brackets expressions, 1028
  - ampersand in replacement strings, 1029
  - anchors, 1026
  - asterisks, 1026
  - brackets, 1025, 1028
  - carets, 1026
  - character class, 1074
  - characters, 1024
  - delimiters, 1024
  - dollar signs, 1026
  - empty, 1028
  - extended, 1029
    - pipes, 1030
    - plus signs, 1030
    - question marks, 1030
    - summary, 1031
  - full, 1029
  - list operator. *See* Character, *class*
  - longest match, 1027
  - periods, 1025
  - Perl, 1007–1013
  - quoted digits, 1029
  - quoted parentheses, 1028
  - quoting special characters, 1027
  - replacement strings, 1028
  - rules, 1027
  - simple strings, 1024
  - special characters, 1024, 1024, 1027
  - summary, 1031
- reiserfs filesystem, 486
- Relational operator, 952
- Relative pathname, 194, 195, 228, 1103
- Religious statue, miniature. *See* Icon
- Remainder operator, 956
- Remapping mouse buttons, 262
- Remote
  - access security, 1055
  - computing and local displays, 258
  - filesystem, 358, 1103
  - login, 135
  - procedure call. *See* RPC
- Remove
  - directory using rmdir, 200
  - file using rm, 150
  - link using rm, 218
  - software package, 497, 512
  - user, 558
  - variable, 303
- Rename
  - directory using mv, 202
  - file using mv, 152, 201
- Repair filesystem, 436
- Repairing a broken system using recovery mode, 56
- Replacement strings in regular expressions, 1028
- REPLY variable, 918, 938
- repo filename extension, 499
- Reports, system, 566
- Request for comments. *See* RFC
- Rescue mode, 46, 56, 411
- Reserved port. *See* Privileged port
- reset utility, 439
- Resolution of display, changing, 142
- resolv.conf file, 476, 602, 787
- Resolver, 386, 476, 776, 1103
- Resource Description Framework, 1102
- Resource record, DNS, 779
- Respawn, 473
- Restore, 1103
- restore utility, 563
- Return code. *See* Exit, status
- RETURN key, 17, 227, 290
- Reverse name resolution, DNS, 783
- rexecd daemon, 390
- RFC, 1103
- RHEL
  - errata, 516
  - rescue mode, 56
  - software, adding, 505
  - versus Fedora, 28
- RHN (Red Hat Network), 516
  - database, 516
  - entitle, 516
  - rhnsd daemon, 517
  - server, 517
- rhnsd daemon, 517
- rhost Authentication, OpenSSH, 623
- Right-click, mouse, 96
- Right-handed mouse, 262
- Ring of trust, 1048
- Ritchie, Dennis, 9
- rlogin utility, 358
- rlogind daemon, 1054
- rm utility, 150, 218, 334, 481, 894
- rmdir utility, 200
- rmmod utility, 550

- rn utility, 393
  - Roam, 1103
  - ROM, 1103
  - romfs filesystem, 486
  - Root
    - See also Superuser*
    - directory (*/*), 32, 34, 188, 190, 198, 1104
    - domain, DNS, 776
    - filesystem (*/*), 1104
    - login, 405, 577, 1104
    - window, 110, 117, 1104
    - password and recovery mode, 425
  - root user. *See Superuser*
  - Rotate file, 579, 1104
  - routed daemon, 390
  - Router, 1104
    - discussion, 597
    - network, 361–363
    - setting up with iptables, 835
    - SmoothWall Linux
      - distribution, 597
  - Routing daemon, 390
  - Row, 585
  - RPC, 391, 697, 1104
  - rpc file, 392, 477
  - rpcbind daemon, 392, 443, 730
  - rpcinfo utility, 443, 701
  - RPM
    - about, 510
    - binary package, 510
    - database, 512
    - install, 512
    - install kernel binary, 512
    - query file, 511
    - query package, 511
    - rpm utility, 580
    - source package, 510
    - SRPMS, 510
    - uninstall, 512
    - upgrade, 512
  - rpm utility, 580
  - rpmnew filename extension, 30
  - rquotad daemon, 389
  - RSA encryption, 1046, 1104
  - rsh utility, 358, 376
  - rshd daemon, 1054
  - rsyslog file, 584
  - rsyslog utility, 390
  - rsyslog.conf file, 390, 583
  - rsyslogd daemon, 200, 390, 579, 582, 1054
  - Run, 1104
    - Application window, 94, 274
    - background command, 241
    - command script, 476. *See also rc scripts*
    - program, 433
    - shell script, 289
  - Runlevel, 424, 1104
    - 2, 431
    - 3. *See Multiuser*
    - 4, 431
    - 5, 431
    - emulation in Upstart, 419
    - initdefault, and, 423, 425, 474
    - table of, 424
  - runlevel utility, 419, 435, 424
  - ruptime utility, 575
- ## S
- S/Key utility, 1054
  - safedit shell script, 915
  - saint utility, 1060
  - Samba, 1105
    - [homes] share, 765
    - about, 749
    - administration. *See Samba, swat utility*
    - browser parameters, 763
    - browsing Linux shares from Windows, 765
    - communication parameters, 764
    - daemons, 750
    - global parameters, 760
    - home directories, sharing, 765
    - JumpStart, configuring a Samba server with system-config-samba, 753
    - Linux shares
      - accessing from Windows, 765
      - setting up, 754
    - logging parameters, 763
    - manual configuration, 759
    - mapping a share, 766
    - more information, 751
    - NBT, 1095
    - net use utility (Windows), 769
    - net utility, 750
    - net view utility (Windows), 769
    - NetBIOS, 1095
    - nmbd daemon, 750, 768, 769
    - nmblookup utility, 769, 770
    - password, 752
    - ping utility, 769
    - prerequisites, 751
    - printing from Windows, 539
    - security parameters, 760
    - share, 1105
    - share parameters, 764
    - shared directory, 607
    - SMB, 1106
    - smb.conf file, 759
    - smbclient utility, 750, 767, 770
    - smbd daemon, 750, 768
    - smbpasswd file, 752
    - smbstatus utility, 750, 768
    - smbtree utility, 750, 766
    - smbusers file, 752
    - suite of programs, 750
    - swat utility, 755
    - system-config-samba utility, 753
    - testparm utility, 768
    - testprns utility, 768
    - troubleshooting, 768
    - user
      - adding, 754
      - map, 752
      - name, 752
      - nobody, 754
    - utilities, 750
    - Web Administration Tool. *See Samba, swat utility*
    - Windows, 1105
      - networks, browsing, 767
      - shares
        - accessing from Linux, 766
        - connecting to, 767
        - displaying, 766
        - mounting, 767
    - WINS, 1115
    - xinetd daemon, 756
    - samhain utility, 1053, 1060
    - SANS security training and education, 1060
    - sara utility, 1060
    - Save window, 103
    - sbin directory, 200
    - Scheduling
      - jobs, 10
      - routine tasks, 565
    - Schema, 1105

- Schneier, Bruce, 1060
- sci.med newsgroup, 393
- scp utility, 358, 484, 625. *See also OpenSSH*
- Screen
  - login, 133
  - number, X Window System, 260
  - refresh, 173
- Script
  - init, 476
  - shell. *See Shell script*
- script utility, 160
- Scroll, 1105
- Scrollbar, 1105
- sdn file, 468
- Search
  - engine, 396
    - database, 396
    - index, 397
    - Web crawler, 396
  - for files using gnome-search-tool, 274
  - for files using Search for Files window, 274
  - for keywords using apropos, 127, 167
  - path, 166
  - string using grep, 153
- Secondary prompt, 904
- Secondary server, DNS, 778
- Secret key encryption. *See Symmetric key encryption*
- Secunia vulnerability
  - monitoring, 1060
- secure file, 459, 480, 1034
- Secure Sockets Layer. *See SSL*
- securenets file, 706
- securetty file, 407
- Security
  - access permission, 203, 204
  - accton utility, 1054
  - ACL, 1068
  - AIDE utility, 413, 1053, 1058
  - ANI, 1056
  - Apache security directives, 868
  - authentication, 1070
  - automatic number
    - identification, 1056
  - back door, 1070
  - BIND. *See Security, DNS*
  - BIOS, 577
  - Bugtraq, 1054
  - caller ID, 1056
  - CERT, 577, 1054, 1058
  - checksum, 1074
  - chkrootkit utility, 1058
  - chroot jail. *See chroot jail*
  - cipher, 1075
  - ciphertext, 1075, 1044
  - cleartext, 1075
  - CLID, 1056
  - cookie, 1076
  - cracker, 1077
  - crack utility, 577
  - cryptography, 1077
  - cypher, 1075
  - DDoS attack, 1078
  - DoS attack, 1080
  - digital signature, 1046
  - DNS, 774, 804
  - DragonSquire IDS, 1053
  - dsniff utility, 1058
  - email, 1049
  - encryption. *See Encryption*
  - Enhanced Linux. *See SELinux*
  - ethereal utility, 1058
  - Fedora, 1053
  - file, 1049
  - finger utility, 375
  - firewall, 363
  - Firewall toolkit, 1059
  - Freefire solutions, 1058
  - FTP, 650, 655
  - fwtk utility, 1059
  - GIAC certification and training, 1059
  - hole, 515
  - host, 1053
    - host-based trust, 377
    - trusted, 376
  - hosts.equiv file, 376
  - hping utility, 1059
  - in.rexecd daemon, 390
  - Internet, root access, 407
  - IP spoofing, 377, 1089
  - IPng, 373
  - IPSec, 1051
  - IPv6, 373
  - ISC2, 1059
  - John the Ripper utility, 1059
  - keep the system secure, 577
  - Kerberos, 1059, 1090
  - kill, 409
  - lids utility, 1059
  - Linux features, 12
  - LinuxSecurity.com, 1059
  - locktty script, 909
  - login, 1054
    - account, 377
    - last, 136
    - shell, 476
  - LWN.net, 1059
  - mailing list, Bugtraq, 1058
  - man-in-the-middle, 803, 1048, 1051
  - messages, 480
  - MD5 encryption, 1093
  - MITM. *See Man-in-the-middle*
  - more information, 1058
  - MTA, 1049
  - MUA, 1050
  - nessus utility, 1059
  - netcat utility, 1059
  - network
    - about, 1050
    - guidelines, 1051
    - solutions, 1051
  - NFS, 730
  - nmap utility, 1059
  - one-time password, 1054
  - OpenSSH. *See OpenSSH*
  - OPIE utility, 1054
  - PAM, 432, 1054
  - passphrase, 1098
  - password, 136, 475, 1098
  - PATH and Superuser, 409
  - PATH variable, 307
  - physical, 1056
  - plaintext, 1044
  - priv utility, 406
  - RAS, 1055
  - rbac utility, 1059
  - Red Hat information, 1060
  - remote access, 1055
  - resources, 1058
  - ring of trust, 1048
  - rlogind daemon, 1054
  - root access, Internet, 407
  - RSA encryption, 1104
  - rshd daemon, 1054
  - rsyslogd daemon, 1054
  - saint utility, 1060
  - samhain utility, 1053, 1060
  - SANS training and certification, 1060
  - sara utility, 1060
  - Schneier, Bruce, 1060

- Secunia vulnerability monitoring, 1060
- SecurityFocus tools and lists, 1060
- SELinux, 414
- setgid, 205
- setuid, 205, 406, 577
- SHA1 hash algorithm, 1105
- shadow file**, 477
- smartcard, 1055
- snort utility, 1060
- software, up-to-date, 515
- spoofing, 377, 1089
- srp utility, 1060
- ssh. *See ssh utility*
- SSL, 1049
- STARTTLS, 691, 1049
- su utility, 408
- sudo utility, 406
- Superuser and **PATH**, 409
- Superuser password, 577
- swatch utility, 1060
- TCP wrappers, 447
- telnet, 378
- telnetd** daemon, 1054
- TLS, 1049
- Treachery, tools, 1060
- tripwire utility, 1053, 1060
- Trojan horse, 412, 1112
- trust, 377
- trusted host, 376
- up-to-date software, 515
- virtual private network, 359
- virus, 1056, 1114
- VPN, 359
- vsftpd**, 660
- wiping a file, 470
- worm, 1056, 1116
- xhost, 260
- xinetd** daemon. *See xinetd daemon*
- security** directory, 458, 461
- SecurityFocus, security tools and lists, 1060
- sed utility, 579
- Seed, BitTorrent, 507
- Segment, network, 1096
- select control structure, 917
- Selection buffer, 116
- Self-signed certificate, 689, 690, 878
- SELinux, 414
- selinux** file, 415
- sendmail**. *See Mail*
- sendmail** daemon, 390, 471, 669, 670, 674, 676, 1050
- sendmail**, masquerade, 1093
- sendmail.cf** file, 677
- sendmail.mc** file, 672, 678
- Separating commands, 290
- Server, 1105
  - DNS
    - cache, 797
    - full-functioned, 807
    - master, 778
    - primary master, 778
    - secondary, 778
    - slave, 810
    - split horizon, 811
    - types of, 778
  - file, 727
  - FTP, 654
  - mail list, 376, 1037
  - Message Block protocol. *See Samba, SMB*
  - name, 385, 386
  - process, 384
  - proxy, 391
  - setting up, 441, 606
  - vsftpd**, 654
  - X, 257, 261, 1116
- service utility, 427
- Service, directory, 1079
- Services
  - daemons providing, 388
  - Internet, 392
  - network, 388
  - nsswitch.conf** file, 455
  - Upstart, 419
- services** file, 388, 392, 477
- Session, 1105
  - failsafe, 1082
  - key, OpenSSH, 624
  - manager, 108
- sestatus utility, 416
- set builtin, 304, 897, 899, 900, 934, 935, 950
- Set group ID. *See Setgid*
- Set user ID. *See Setuid*
- setenforce utility, 416
- Setgid, 205, 1105
  - root**, files belonging to the group, 205, 406
- setserial utility, 440
- Setuid, 205, 406, 1105
  - at, 406
  - crontab, 406
  - finding files using find, 412
  - grant privileges, 406
  - mount, 488, 731
  - NFS, 731
  - nosuid** option to mount, 488, 731
  - root**, files owned by, 205, 406
  - security, 577
- Sexillion, 1105
- sftp utility, 631
- sh Shell, 280, 282, 1072
- SHA1 hash algorithm, 1105
- sha1sum utility, 45
- shadow** file, 431, 477
- shar** shell script, 920
- Share, 1105
- share** directory, 200
- Shared network topology, 1105
- Shares, adding Linux (Samba), 754
- Sharing an Internet connection, 835
- Shell, 223, 1105
  - archive, 920
  - arithmetic (bash), 950
  - Bourne (original), 1072
  - calling program, name of, 931
  - command
    - grouping, 290, 293
    - interpreter, 118
    - separation, 290
    - substitution, 899, 916
  - comment, 898
  - comparing strings, 952
  - control structure
    - break**, 910
    - case**, 911
    - continue**, 910
    - do**, 901, 902, 904, 908
    - done**, 901, 902, 904, 908
    - elif**, 895
    - else**, 892
    - esac**, 911
    - fi**, 888, 895
    - for**, 901, 902, 945
    - for...in**, 901, 902
    - if**, 888, 892, 895
    - if...then**, 888
    - if...then...elif**, 895
    - if...then...else**, 892
    - in**, 901
    - then**, 888, 892, 895
    - until**, 908
    - while**, 904, 945

Shell, *continued*

- csh, 1073
- environment variable, 299, 926
- exit from, 296
- features, 338
- function, 335, 1106
- job control, 294
- keyword variable, 300
- login, 314, 432, 476, 1092
- name of the calling program, 931
- options. *See Shell, features*
- parameter, 299
  - positional, 300
  - special, 300
- prompt, 17, 224, 307
- readonly variable, 299
- sh, 280, 282, 1072
- sleep, 229
- strings, comparing, 952
- user-created variable, 299
- variable. *See Shell variable*

Shell script, 279, 286, 1106

- # comment, 289
- #! shell to use, 288
- /dev/tty for a terminal, 942
- addbanner, 945
- bash, 958
- birthday, 919
- bundle, 920
- chkargs, 890, 892
- command\_menu, 913
- comment, 289
- configure, 514
- count, 905
- cpdir, 293
- create, 286
- debug, 900
- double quotation marks, 933, 938
- error message, 899, 916
- executing, 287, 289
- Here document, 919
- infinite loop, 944
- invocation, 289
- is\_regfile, 891
- links, 896
- locktty, 909
- makepath, 959
- menu, 913
- out, 893
- PATH usage, 916

- quiz, 962
- quote in, 889, 898, 904, 933
- read user input, 937
- recursion, 959
- running, 289
- safedit, 915
- shar, 920
- specifying a shell, 288
- spell\_check, 906
- temporary filename, 917, 929
- usage message, 892, 898, 916
- user input, 937
- whos, 903
- whoson, 287

SHELL variable, 432

Shell variable

- \$\_, 930
- #, 915, 931
- \$\$, 917, 929
- \*, 932
- ?, 930
- @, 903, 932
- \$0, 931
- BASH\_ENV, 282
- CDPATH, 311
- COLUMNS, 918
- ENV, 282
- FCEDIT, 320
- HISTFILESIZE, 316
- HISTSIZE, 316
- HOME, 300, 305, 432, 945
- IFS, 309
- INPUTRC, 329
- keyword, 305
- LINES, 918
- LOGNAME, 432
- MAIL, 307, 432
- MAILCHECK, 307
- MAILPATH, 307
- naming, 299
- noclobber, 235
- OLDPWD, 346
- OPTARG, 947
- OPTIND, 947
- PATH, 306
  - example, 915
  - keyword shell variable, 300
  - login, 432
  - security, 412
- PS1, 283, 307
- PS2, 309, 336
- PS3, 918
- PS4, 900

- PWD, 346
- quoting, 301
- RANDOM, 965
- readonly, 299
- REPLY, 918, 938
- SHELL, 432
- TERM, 432, 468

shells file, 439

shift builtin, 933, 948, 950

Short-circuiting operator, 956

Shortcut. *See Link*

showmount utility, 742

shtml filename extension, 854

shutdown utility, 422, 433, 479

Side pane, Nautilus, 265

Signal, 1106

- defined, 943
- hang up, 944
- HUP, 575
- KILL, 575
- kill, 944
- list of, 943
- names, 943, 946
- quit, 944
- software termination, 944
- terminal interrupt, 944

Signature, digital, 1046

Silicon Graphics, 395

Simple filename, 193, 195, 228, 1106

Single quotation mark, 148, 904

Single versus double quotation marks, 333

Single-user

- from multiuser, 435
- maintenance, 430
- mode, about, 430
- Superuser, 406
- system, 1106

Size of file, display using ls, 203

skel directory, 557

Skip to top of page, 181

slapcat utility, 717

slappasswd utility, 714, 715

Slave server, DNS, 778, 810

Sleep, shell, 229

sleep system call, 316

Slice. *See Partition*

Slider, 1106

SLIP protocol, 367

Sloppy focus, 141

Slow system, 575

SMART disk monitoring, 81

- Smartcard, 1055
- SMB. *See Samba, SMB*
- smb.conf** file, 759
- smbclient utility, 750, 767, 770
- smbd** daemon, 390, 750, 768
- smbfs** filesystem, 486
- smbpasswd** file, 752
- smbstatus utility, 750, 768
- smbtree utility, 750, 766
- smbusers** file, 752
- SMF, 417
- Smiley, 1106
- Smilies, *plural of smiley*
- SmoothWall, Linux router distribution, 597
- SMTP, 379, 669, 1106
- Snap, window, 1107
- SNAT, 836
- Sneakernet, 1107
- Sniff, 1107
- snort utility, 1060
- SOA record, DNS, 781
- soc.singles** newsgroup, 393
- Socket, 483
  - UNIX domain, 482
- SOCKS, 1107
- Soft link. *See Symbolic, link*
- Software
  - add, 505
  - bug, 515
  - free, definition, 1063
  - installing, 497
  - keeping up-to-date, 515
  - package, 497
    - adding/removing, 122, 512
    - information, 511
    - remove, 512
  - termination signal, 944
  - Update Notifier, 104
  - updating, 104, 497
- Sort, 1107
- sort utility, 14, 155, 239, 240
- source builtin, 283
- SPACE, 148, 1107
- Spam, 1107
  - SpamAssassin, 682
  - whois and, 382
- SpamAssassin
  - configuring, 684
  - running on a mail server using **procmail**, 685
- spamd** daemon, 682
- Sparse file, 1107
- Spatial versus File Browser windows, Nautilus, 99
- Spawn. *See Fork*
- Special
  - character, 1024, 1107
    - \***, 244
    - ?**, 243
    - []**, 245
  - defined, 148, 243
  - filename generation, 243
  - Here document, 920
  - pathname expansion, 243
  - quoting, 301, 302
  - regular expressions, 1023
  - standard input, 920
  - file, 1074
    - about, 482
    - block, 482
    - character, 482
    - parameters, shell, 300, 928
- Speed, Internet, 359
- spell\_check** shell script, 906
- Spin box, 1107
- Spinner. *See Spin box*
- splash** boot parameter, 54
- Split horizon server, DNS, 811
- Splitting, word, 309
- Spontaneous process, 314
- Spoofing, IP, 1089
- Spool, 1108
- spool** directory, 579, 1034
- SQL, 1108
- Square bracket, 1108
  - test, 891
- SquirrelMail, 686
- src** directory, 200, 544
- srp utility, 1060
- ssh** directory, 623
- ssh utility, 358, 388, 484, 603, 622, 625, 627, 628, 1055, 1060. *See also OpenSSH*
- ssh\_config** file, 631
- ssh\_known\_hosts** file, 623, 626, 627
- sshd** daemon, 388, 390
- sshd\_config** file, 636
- ssh-keygen utility, 634
- SSL
  - Apache, 877
  - email, 690
  - security, 1049
- st0** file, 564
- Stack
  - defined, 296
  - directory, manipulation, 296
  - LAMP, 608
  - LIFO, 296
  - PAM, 461
- Stallman, Richard, 2
- Stand-alone computer, 357
- Standard
  - directories and files, 198
  - error, 230, 284, 899, 921, 1108
    - exec, 941
    - file descriptor, 284, 921
    - shell script, 898
    - trap, 946
  - input, 230, 1108
    - exec, 941
    - file descriptor, 284, 921
    - pipe (|), 292
    - redirect, 234
    - special character, 920
  - output, 230, 1108
    - append, 236
    - exec, 941
    - file descriptor, 284, 921
    - pipe (|), 292
    - redirect, 232, 240
- Standards
  - Free Standards Group (FSG), 198
  - FSSTND, 198
  - Linux Filesystem Hierarchy Standard (FHS), 198
  - Linux Standard Base (LSB), 198
  - OpenPGP Message Format, 1048
  - option handling, 949
- STARTTLS, security, 691, 1049
- Startup file, 192, 1108
  - .bash\_login** file, 281
  - .bash\_logout** file, 281
  - .bash\_profile**, 281, 468
  - .bashrc**, 194, 281, 468
  - .cshrc**, 1077
  - .inputrc**, 329
  - .login**, 1092
  - .logout**, 1092
  - .profile**, 281, 468, 1100
  - .toprc**, 568

Startup file, *continued*  
/etc

**bashrc**, 281, 432

**profile**, 281, 432, 476

**bash**, 281

**BASH\_ENV** variable, 282

  check for problems, 574

**ENV** variable, 282

**startx** utility, 258

**stat** utility, 440

**std** daemon, 389

  Statements, Perl, 981

  Static IP address, 368

  Status bar, Nautilus, 267

  Status line, 1108

**status** utility, 420

  Status, exit, 1081

  Sticky bit, 1108

  Stopping a job using the **suspend**  
  key, 241

  Stopping a program, 140

  Streaming tape, 1108

  Streams. *See Connection-*  
  *oriented protocol*

  String, 1108

    comparing, 952

    double quotation marks, 301

    finding using **grep**, 153

    null, 1097

    pattern matching (**bash**), 952

  Stroustrup, Bjarne, 9

  Structured Query Language. *See*  
  MySQL; SQL

**stty** utility, 139, 468, 909

  Stylesheet. *See* CSS

**su** utility, 406, 408, 577

  Subdirectory, 188, 1109

  Subdomain, 776

  Subnet, 371, 1109

    address, 1109

    mask, 371, 1109

    number, 1109

    specifying, 443

  Subpixel hinting, 1109

  Subpixel smoothing, 272

  Subroutine. *See Procedure*

  Subshell, 289, 293, 1109

  Substitution

    command, 348

    parameter, 301

**sudo** utility, 406. *See also*  
  Superuser

**sudoers** file, 406

Sun Microsystems, 373, 695, 727

  Superblock, 1109

  Supercomputers, 8

  Superserver. *See xinetd daemon*

  Superuser, 90, 405, 1109

    becoming, 406

    multiuser mode, 406

    password, 577

**PATH** and security, 409

    powers, 205

    privileges, 405

    prompt, 405

**setuid**, 406

    single-user mode, 406

**su** utility, 406

**sudo** utility, 406

  Suspend key (**CONTROL-Z**), 139, 140,  
  181, 241, 295, 943

  SVID. *See System, V Interface*  
  Definition

  Swap, 479, 1109

    filesystem, 34, 479

    RAM and, 34, 479

    space, 1110

**swapon** utility, 479

  Swarm, BitTorrent, 508

**swat** utility, 755

**swatch** utility, 1060

  Switch, network, 1096

  Switcher, Workspace, 95, 96

  Switching hub, 361, 596

**sylpheed** utility, 174

  Symbolic

    hostname, 387

    link, 216, 481, 482

      creating using **ln**, 216

      deleting using **rm**, 218

  Symlink. *See Symbolic, link*

  Symmetric key encryption, 1046

**sync** utility, 434

  Syntax, command-line, 224

**sys** file, 544

**sysconfig**, 478

**sysctl** utility, 543, 544

**sysctl.conf** file, 543, 544

  System

    administration

      at utility, 565

**authconfig** utility, 437

      back up files, 563

      bug, 515

**chkconfig** utility, 429

      client, specifying, 442

  communicating with users,  
  572

  configuration file rules, 441

**consolehelper** utility, 409,  
  434

**crontab** utility, 565

**cupsdisable** utility, 537

**cupsenable** utility, 537

**cupsreject** utility, 537

**dmesg** utility, 439

**dump** utility, 563

**e2label** utility, 439

**edquota** utility, 582

**exportfs** utility, 435

  file

    backup, 558

    growing, 578

  filesystem

    integrity, 492

    mount remote, 730

    repair, 436

  free space, disk, 578

**fsck** utility, 436, 492

  group, add, 558

**groupadd** utility, 558

**groupdel** utility, 558

**groupmod** utility, 558

**halt** utility, 433, 435

  host, specifying, 442

**hosts.allow** file, 444

**hosts.deny** file, 444

  init scripts, 426

**init** utility, 431

  Kickstart utility, 82

**kill** builtin, 408, 410

**killall** utility, 411

  log, machine, 576

  login problem, 574

**logwatch** utility, 578

**ls** of utility, 576

**memtest86+** utility, 53

**mkfs** utility, 439

  more information, 413

  mount remote filesystem,  
  730

**mount** utility, 435

  multiuser mode, 431

  multiuser/graphical mode,  
  431

**parted** utility, 568

  password, modify, 557

**pidof** utility, 411

**poweroff** utility, 433



- problems, 574
  - ps utility, 242, 314, 575, 579
  - quota utility, 582
  - quotaon utility, 582
  - reboot utility, 433, 434
  - reports, 566
  - rescue mode, 411
  - restore utility, 563
  - rpcinfo utility, 443
  - rpm utility, 510
  - rsyslogd daemon, 582
  - runlevels, 424
  - schedule tasks, 565
  - SELinux, 414
  - service utility, 427
  - setuid files, finding, 412
  - shutdown utility, 433
  - single-user mode, 430, 435
  - slow system, 575
  - su utility, 408
  - subnet, specifying, 443
  - sync utility, 434
  - system does not boot, 436
  - telinit utility, 435
  - top utility, 567
  - Trojan horse, 412
  - trouble alias, 576
  - tune2fs utility, 439, 492
  - umask builtin, 440
  - umount utility, 435, 490
  - uname utility, 441
  - user
    - add, 556, 557
    - cannot log in, 574
    - getting information to, 572
    - modify, 556, 557
    - remove, 558
  - useradd utility, 557
  - userdel utility, 558
  - usermod utility, 558
  - vmstat utility, 566
  - wall utility, 435
  - wget utility, 517
  - xinetd daemon, 445
  - administrator, 90
  - powers, 205, 405
  - responsibilities, 403
  - Superuser. *See Superuser*
  - booting, 425
  - bring down, 433
  - bug, 515
  - call
    - bad, trapping, 943
    - defined, 10
    - device, raw, 485
    - exec(), 289
    - fork(), 289, 314, 316
    - gethostbyname(), 785
    - sleep(), 316
  - console, 430
  - crash, 436
  - dataless, 729, 1078
  - diskless, 728
  - does not boot, 436
  - error messages, 480
  - initialization, customize, 426
  - logging in, 91
  - logs, 582
  - maintenance, 430
  - menu, 114
  - messages, 480, 582
  - mode, 1110
  - operation, 424
  - powering down, 435
  - rebooting, 434
  - reports, 566
  - rescue mode, 46
  - security, 577
  - shutdown, 433
  - single-user, 1106
  - system-config-nfs utility, 737
  - V Interface Definition, 9
  - well-maintained, 404
  - System V, 1110
    - init daemon, 417
  - system-config-bind utility, 789
  - system-config-date utility, 437
  - system-config-display utility, 84
  - system-config-firewall utility, 824
  - system-config-httpd utility, 846
  - system-config-keyboard utility, 437
  - system-config-kickstart utility, 82
  - system-config-language utility, 438
  - system-config-lvm utility, 38
  - system-config-network utility, 601
  - system-config-network-cmd utility, 438
  - system-config-nfs utility, 737
  - system-config-printer utility, 524–527
  - system-config-rootpassword utility, 438
  - system-config-samba utility, 753
  - system-config-securitylevel utility, 824, 833
  - system-config-selinux utility, 416
  - system-config-services utility, 428
  - system-config-soundcard utility, 438
  - system-config-users utility, 556
  - sysv filesystem, 486
  - SysVinit, 417
- ## T
- T-1 line, 360
  - T-3 line, 360
  - TAB key, 148
  - Table, 585
  - Table, hash, 1085
  - tail utility, 154, 242
  - talk utility, 376, 390
  - talk.politics newsgroup, 393
  - talkd daemon, 390
  - Tanenbaum, Andrew, 4, 486
  - Tape
    - archive. *See tar utility*
    - device, 563, 564
    - mt utility, 565
    - nonrewinding, 564
    - streaming, 1108
  - tar file, 163
  - tar utility, 163, 293, 560, 562
  - tar.bz2 filename extension, 164
  - tar.gz filename extension, 164
  - tar.Z filename extension, 164, 191
  - Tarball, 163
  - Task, Upstart, 419
  - tbz filename extension, 164
  - TC Shell, 1110
  - TCP, 1110
  - TCP wrappers, 447
  - TCP/IP, 365, 391
  - tcsh, 1110
  - tee utility, 240
  - Teletypewriter, 1112
  - telinit utility, 419, 422, 424, 431, 435
  - telnet utility, 358, 377, 378, 875, 1050
  - telnetd daemon, 390, 1054
  - Temporary file, 917
  - Tera-, 1110
  - TERM signal, 140
  - TERM variable, 135, 432, 468

- Termcap, 1041
  - termcap** file, 1110
  - Terminal, 1110
    - ASCII, 1069
    - character-based, 1074
    - emulator, 118, 135, 275
    - file, 230
    - interrupt signal, 944
    - name
      - ansi**, 1041
      - linux**, 1041
      - vt100**, 468, 1041
      - vt102**, 1041
      - vt220**, 1041
      - xterm**, 1041
    - pseudoterminal, 469
    - Server Project, Linux, 728
    - specifying, 1040
    - standard input, 231
    - standard output, 231
    - X, 1116
  - Terminating execution, 140
  - Terminfo, 1041
  - terminfo** database, 175
  - terminfo** file, 1110
  - Terminology
    - desktop, 110
    - filesystem naming, 33
    - GNOME, 110
    - partition name, 33
    - Upstart daemon, 418
  - Ternary operator, 955, 957
  - test** builtin, 889–891, 895, 899, 902, 904, 950
  - test** utility, 890
  - testparm** utility, 768
  - testprns** utility, 768
  - Text
    - box, 1110
    - echo, 159
    - file, 174
  - Textual
    - application, running from a GUI, 94
    - interface, 28
  - tfpd** utility, 729
  - tfpd** daemon, 390
  - tgz** filename extension, 191
  - Theme, 106, 1111
  - then** control structure, 888, 892, 895
  - Thicknet, 361, 1111
  - Thinner, 361, 1111
  - Thompson, Ken, 9, 1070
  - Thread safe. *See Reentrant code*
  - Three-finger salute, 434
  - Thumb, 1111
  - Tick, 1111
  - Tick box. *See Check box*
  - .tif** filename extension, 191, 1111
  - .tiff** filename extension, 191, 1111
  - Tilde expansion, 193, 305, 345
  - Tiled windows, 1111
  - time builtin, 950
  - Time-series data, 607
  - Time to live. *See TTL*
  - timed** daemon, 390
  - tin** utility, 393
  - Titlebar, 98, 115
  - TLS, security, 1049
  - tmp** directory, 579, 917
  - Toggle, 1111
  - Token, 224, 342, 1111
  - Token ring network, 1111
  - Toolbar, 116
  - Toolbar, Nautilus, 267
  - Tooltip, 110, 1111
  - Top of form, 181
  - top** utility, 567, 575
  - Top-down design, 964
  - torrent** filename extension, 508
  - Torrent, BitTorrent, 508
  - torrentinfo-console** utility, 509
  - Torvalds, Linus, 1, 2, 3, 6, 1090
  - touch** utility, 201
  - tput** builtin, 909
  - tr** utility, 161, 238, 285
  - traceroute** utility, 380
  - traceroute6** utility, 381
  - Tracker, BitTorrent, 507
  - Transactions signatures, DNS.  
*See DNS, TSIG*
  - Transfer rate, network, 361
  - Transient window, 1111
  - Transmission Control Protocol.  
*See TCP*
  - Transmission Control Protocol/Internet Protocol. *See TCP/IP*
  - Transport Layer Security. *See TLS, security*
  - trap** builtin, 909, 943, 950
  - Trap door. *See Back door*
  - Trash, emptying, 104
    - Nautilus, 270
  - Treachery, security tools, 1060
  - Tree structure, 188
  - tripwire** utility, 1053, 1060
  - Trojan horse, 412, 1112
  - Trolltech, 263
  - Troubleshooting DNS, 805
  - true** utility, 945
  - Trusted host, 376
  - tset** utility, 439
  - TTL, 1112
    - DNS, 781
  - tty** file, 942
  - tty** utility, 230
  - TTY. *See Teletypewriter*
  - tty1** file, 423
  - tune2fs** utility, 439, 492
  - Tunneling, 638, 1112
  - Tutorial
    - FTP, 646
    - using vim to create and edit a file, 174
  - Twisted pair cable, 361
  - txt** filename extension, 191, 245
  - type** builtin, 937, 950
  - Type of file, display using **ls**, 203
  - Typeface conventions, 17
  - typescript** file, 160
  - typeset** builtin, 303, 928
  - tz** filename extension, 164
- ## U
- U.S. Library of Congress, 378
  - UCE. *See Spam*
  - udev** utility, 482
  - UDP (User Datagram Protocol), 365, 1112
  - UDP/IP, 391
  - ufs** filesystem, 486
  - ufsdump** utility, 471
  - UID, 1112
    - effective, 1081
    - in **passwd** file, 475
  - umask** builtin, 440, 476, 950
  - umount** utility, 435, 474, 490, 732
  - umsdos** filesystem, 486
  - unalias** builtin, 332, 335
  - uname** utility, 441
  - uncompress** utility, 191
  - Undecillion, 1113
  - Undeclared variable, 926
  - Unicast packet, 367, 1113

- Unicast versus broadcast, 367
- Unicode, 1113
- uniq utility, 156
- Unique filename, 917, 929
- University of Illinois, 395
- UNIX
  - Bourne Shell, 280
  - domain socket, 482
  - philosophy, 374
  - printing, traditional, 530
  - System V, 6, 1110
  - System V Interface Definition. *See System, V Interface Definition*
- unix2dos utility, 161, 650
- Unmanaged window, 1113
- Unmount a busy filesystem, 490
- Unpack archive file using tar, 163
- unset builtin, 303, 336, 950
- Unshielded twisted pair. *See UTP cable*
- until** control structure, 908
- unzip utility, 163
- Update Manager window, 105
- Update Notifier, 104
- updatedb utility, 67, 168
- Upgrade. *See Fedora, installing*
- Upgrading software, 497
- Upstart daemon, 417–424
  - communicate with Upstart using initctl, 419
  - event, 418
  - job definition files, 422–424
  - jobs, 418, 420–424
  - rc2 task, 422
  - rc-default task, 423
  - runlevel emulation, 419
  - runlevel utility, 419
  - service, 419
  - shutdown utility, 422
  - starting, 425
  - status utility, 420
  - task, 419
  - telinit utility, 419, 422
  - terminology, 418
  - ttyn tasks, 423
- Uptime, display using w, 172
- uptime utility, 172
- urandom file, 470
- URI, 1113
- URL, 396, 1113
- Usage message, 224, 892, 898, 916, 1113. *See also Error, message; Message*
- Usenet, 392, 396
- User
  - accounts, manage, 556
  - add, 556, 557
  - authentication, 432
  - cannot log in, 574
  - communication, network, 374
  - created variable, 299, 300
  - Datagram Protocol. *See UDP*
  - finger, 169
  - ID. *See UID*
  - interface, 1113
  - map, Samba, 752
  - mode, 1113
  - modify, 556, 557
  - name. *See Username*
  - name, Samba, 752
  - nfsnobody, 741
  - nobody, Samba, 754
  - private groups, 472
  - remove, 558
  - root. *See Superuser*
  - Samba, 754
  - Superuser. *See Superuser*
  - w, 171
  - who, 169
- user\_list file (vsftpd), 666
- useradd utility, 557
- userdel utility, 558
- usermod utility, 558
- Username, 475, 477, 1113
- Userspace, 1113
- /usr directory, 36
- UTC, 1114
- UTF-8, 1114
- Utility, 1114
  - accton, 1054
  - adduser, 557
  - AIDE, 413, 1053, 1058
  - amanda, 560
  - anacron, 565
  - apm, 435
  - apropos, 67, 167, 1035
  - aspell, 905, 907
  - at, 388, 471, 565
  - authconfig, 437
  - automount, 744
  - basename, 915, 916, 945
  - bison, 16
  - bittorrent-curses, 508
  - builtin versus, 890
  - bunzip2, 162, 166
  - bzcat, 163
  - bzip2, 162, 166, 562
  - bzip2recover, 163
  - cat, 149, 231, 233, 234, 284, 894
  - chkconfig, 429
  - chkrootkit, 1058
  - chmod, 204, 288
  - chsh, 439
  - clear, 439
  - compress, 163, 191
  - consolehelper, 409, 434
  - cp, 151, 202, 293
  - cpio, 561, 562
  - crack, 577
  - crontab, 471, 565
  - cupsaccept, 537
  - cupsdisable, 537
  - cupsenable, 537
  - cupsreject, 537
  - cut, 347
  - date, 159, 237
  - depmod, 550
  - df, 729
  - dhclient, 452
  - diff, 157, 628
  - dig, 382, 784, 788, 806
  - dmesg, 439, 553
  - dos2unix, 161, 650
  - DragonSquire, 1053
  - dsniff, 1058
  - dump, 563
  - e2label, 439
  - edquota, 582
  - emacs, 174
  - ethereal, 1058
  - Evolution, 174
  - exportfs, 435, 742
  - fdformat, 489
  - file, 157, 480, 579
  - find, 413, 579, 897, 900
  - find using whereis, 166
  - find using which, 166
  - finger, 169, 374, 375, 389, 903
  - flex, 16
  - fsck, 436, 485, 492, 578
  - ftp, 358, 476, 644, 650
  - fuser, 490
  - ftwk, 1059
  - gawk, 903, 904
  - gcc, 9

Utility, *continued*

- gdm, 433
- getenforce, 416
- getty, 314
- gopher, 395
- gprof, 16
- gq, 722
- grep, 153, 239, 903, 904, 907, 919
- groupadd, 558
- groupdel, 558
- groupmod, 558
- groups, 472
- grub, 551
- gunzip, 163
- gzip, 163
- halt, 433, 435
- head, 154
- host, 382, 785
- hostname, 151, 374
- hping, 1059
- id, 408
- info, 247, 1035
- init, 314, 425, 431, 473
- insmod, 550
- ipchains, 820
- iptables, 819
- iptables-restore, 832
- iptables-save, 832
- iwconfig, 605
- John the Ripper, 1059
- jwhois, 382
- kerberos, 1055, 1059
- Kickstart, 82
- killall, 411
- kudzu, 598
- ldapadd, 717
- ldapmodify, 716
- ldapsearch, 716
- less, 150, 240, 292, 894
- lids, 1059
- links, 396
- ln, 214, 216, 481
- locate, 67, 168
- lock, 909
- login, 314, 431
- logresolve, 860
- logrotate, 579
- logwatch, 578
- lpq, 153
- lpr, 153, 239, 241
- lprm, 153
- lpstat, 153
- ls, 149, 195, 203, 206, 215, 244, 288
- lsmod, 550
- lsuf, 576
- lynx, 396
- mail, 174, 577
- mailq, 676
- mailstats, 677
- make, 164
- makedbm, 706
- makemap, 677
- makewhatis, 67, 127, 168
- man, 14
- md5sum, 45
- memtest86+, 53
- mesg, 173
- mingetty, 314, 431, 474
- mkdir, 195, 197, 731
- mkfifo, 483
- mkfs, 439, 489, 578
- mkswap, 479
- modinfo, 550
- modprobe, 550
- more, 150, 240, 894
- mount, 435, 474, 487, 488, 731, 767
- mt, 565
- mv, 152, 201, 481
- mysql\_secure\_installation, 586
- names, typeface, 17
- nessus, 1059
- net, 750
- net use (Windows), 769
- net view (Windows), 769
- netcat, 1059
- netstat, 369
- network, 358, 376
- newaliases, 676
- nisdomainname, 700
- nmap, 1059
- nmblookup, 769, 770
- nn, 393
- nologin, 476
- od, 471
- OPIE, 1054
- option, 225
- palimpsest, 78
- parted, 568
- passwd, 405, 406, 478, 702
- pidof, 411
- ping, 379, 439, 477, 769
- ping6, 380
- pirut, 505
- portmap, 743
- poweroff, 433
- praliases, 676
- procmail, 174
- ps, 242, 314, 575, 579, 929
- pstree, 315
- pwd, 195, 217
- qmail, 1050
- quota, 582
- quotaon, 582
- rbac, 1059
- rcp, 376
- readnews, 393
- reboot, 433, 434
- reset, 439
- restore, 563
- rlogin, 358
- rm, 150, 218, 334, 481, 894
- rmdir, 200
- rmmod, 550
- rn, 393
- rpcinfo, 443, 701
- rpm, 580
- rsh, 358, 376
- rsyslog, 390
- runlevel, 435
- ruptime, 575
- S/Key, 1054
- saint, 1060
- samhain, 1053, 1060
- sara, 1060
- scp, 358, 484, 625. *See also* *OpenSSH*
- script, 160
- sed, 579
- service, 427
- sestatus, 416
- setenforce, 416
- setserial, 440
- sftp, 631
- sha1sum, 45
- showmount, 742
- shutdown, 433, 479
- slapcat, 717
- slappasswd, 714, 715
- smbclient, 750, 767, 770
- smbstatus, 750, 768
- smbtree, 750, 766
- snort, 1060
- sort, 14, 155, 239, 240
- srp, 1060

ssh, 358, 388, 484, 603, 622, 625, 627, 628, 1055, 1060. *See also OpenSSH*  
 ssh-keygen, 634  
 stat, 440  
 stty, 468, 909  
 su, 406, 408, 577  
 sudo, 406  
 swapon, 479  
 swat, 755  
 swatch, 1060  
 sylpheed, 174  
 sync, 434  
 sysctl, 543, 544  
 system-config-bind, 789  
 system-config-date, 437  
 system-config-display, 84  
 system-config-firewall, 824  
 system-config-httpd, 846  
 system-config-keyboard, 437  
 system-config-kickstart, 82  
 system-config-language, 438  
 system-config-lvm, 38  
 system-config-network, 601  
 system-config-network-cmd, 438  
 system-config-nfs, 737  
 system-config-rootpassword, 438  
 system-config-samba, 753  
 system-config-securitylevel, 824, 833  
 system-config-selinux, 416  
 system-config-services, 428  
 system-config-soundcard, 438  
 system-config-users, 556  
 tail, 154, 242  
 talk, 376, 390  
 tar, 163, 293, 560, 562  
 tee, 240  
 telinit, 431, 435  
 telnet, 358, 377, 378, 875, 1050  
 test, 889, 890, 895, 899, 950  
 testparm, 768  
 testprns, 768  
 tftp, 729  
 tin, 393  
 top, 567, 575  
 torrentinfo-console, 509  
 touch, 201  
 tr, 161, 238, 285  
 traceroute, 380  
 traceroute6, 381  
 tripwire, 1053, 1060  
 true, 945

tset, 439  
 tty, 230  
 tune2fs, 439, 492  
 typeset, 303  
 udev, 482  
 ufsdump, 471  
 umount, 435, 474, 490, 732  
 uname, 441  
 uncompress, 191  
 uniq, 156  
 unix2dos, 161, 650  
 unzip, 163  
 updatedb, 67, 168  
 uptime, 172  
 useradd, 557  
 userdel, 558  
 usermod, 558  
 uucp, 393  
 vimtutor, 174  
 vmstat, 566  
 w, 171, 575  
 wall, 435, 572  
 wc, 347  
 webalizer, 881  
 wget, 517  
 whatis, 67, 168  
 whereis, 167  
 which, 166  
 who, 169, 230, 237, 239, 475, 581  
 whois, 382  
 write, 169, 172, 572  
 xargs, 579  
 xrn, 393  
 xvnews, 393  
 ypinit, 708  
 yppasswd, 702  
 ypwhich, 701  
 ypxfr, 708  
 yum. *See yum*  
 yumdownloader, 505  
 zcat, 163  
 zip, 163  
 UTP cable, 361  
 uucp utility, 393  
 UUID, 1114  
   device, 469  
   fstab, in, 490

## V

/var directory, 35  
 var filename extension, 854  
 Variable, 299, 1114

braces, 302  
 completion, 329  
 default value, assign, 935  
 display error message, 936  
 environment, 299  
 expansion, 346, 935  
 exported, 941  
 global, 299, 941  
 keyword, 300  
 local, 316, 941  
 modifiers, 935  
 naming, 299  
 Perl lexical, 979  
 Perl package, 979  
 readonly, 299  
 remove, 303  
 shell, 299  
 substitute default value, 935  
 substitution, 301  
 undeclared, 926  
 user-created, 299, 300  
 VeriSign, 1046  
 vfat filesystem, 486  
 VG. *See LVM, VG*  
 View pane, Nautilus, 265  
 viewport. *See Workspace*  
 vim  
   bash command-line editor, 326  
   case sensitivity, 1073  
   Command mode, 176  
   correct a mistake, 179, 180  
   create a file, 174  
   d command, 180  
   dd command, 180  
   delete text, 180  
   edit a file, 174  
   end a session, 181  
   enter text, 177  
   exit, 181  
   emergency, 175  
   getting started, 175  
   Input mode, 176, 177  
   insert text, 180  
   Last Line mode, 177  
   move the cursor, 179  
   Normal mode. *See vim, Command mode*  
   page break, 181  
   quit, 181  
   safedit script, 915  
   starting, 175  
   terminal specification, 1040  
   u command, 180

vim, *continued*

- undo changes, 180
- Work buffer, 181
- x command, 180
- ZZ command, 181

vimtutor utility, 174

Virtual

- console, 137, 1114
- filesystem, 487
- memory, 479
- private network. *See* VPN

virtustable file, 681, 682

Virus, 1056, 1114

VLAN, 1114

vmstat utility, 566

Volume group. *See* LVM, VG

Volume label, 439

VPN, 359, 1114

vsftpd

*See also* FTP

- chroot jail, 658
- configuration file, 656
- connection parameters, 664
- display, 662
- downloading files, 660
- files, 666
- log, 663
- logging in (users), 657
- messages, 662
- PASV connections, 664
- PORT connections, 664
- prerequisites, 654
- security, 660
- server, 654
- stand-alone mode, 654, 657
- starting, 655
- testing, 655
- uploading files, 660

vsftpd.conf file, 656

vsftpd.log file, 666

vt100 terminal, 468, 1041

vt102 terminal, 1041

vt220 terminal, 1041

Vulcan death grip, 434

## W

w utility, 171, 575

W2K, 1114

W3. *See* World Wide Web

W3C, 1114

wait builtin, 950

Wake up a process, 316

wall utility, 435, 572

Wall, Larry, 975

WAN, 16, 360, 362, 363, 1114

WAP, 597, 1115

wc utility, 347

Web

*See also* World Wide Web

crawler, 396

ring, 1115

webalizer utility, 881

Webmail, 686

Weissman, Terry, 516

wget utility, 517

whatis database, 67, 127, 168

whatis utility, 67, 127, 168

wheel group, 463

whereis utility, 167

which utility, 166

while control structure, 904,  
940, 945, 948

Whitespace, 1115

command line, 291

defined, 148

quoting, 301

who am i, 169

who utility, 169, 230, 237, 239,  
475, 581

whois utility, 382

whos shell script, 903

whoson shell script, 287

Wide area network. *See* WAN

Widget, 1115. *See also* GUI

Wi-Fi, 1115

Wiggly windows, 108

Wildcard, 1115. *See also*  
*Metacharacter*

Window, 110, 115–118, 1115

active, 141

Add/Remove Applications,  
123

Appearance Preferences, 106

Browse/Save, 103

cascading, 1073

clipboard, 117

cut and paste, 116

cycling, 116

decorations, 142

file, 230

File Browser. *See* Nautilus

focus, input, 116, 141

GNOME Help Browser, 125

ignored, 1087

input focus, 141

List applet, 113

manager, 15, 16, 142,  
263–264, 1115

Compiz, 108, 143

GNUSStep, 264

Metacity, 108, 143

WindowMaker, 264

minimize, 1094

moving, 98

Nautilus File Browser. *See*  
*Nautilus*

Object Properties, 120–122

Operations menu, 116

Panel Properties, 112

Pick a Color, 273

Pick a Font, 272

Preferences window, 141

resizing, 98

root, 110, 117, 1104

Run Application, 94, 274

Save, 103

scrollbar, 1105

Search for Files, 274

slider, 1106

snap, 1107

thumb, 1111

tiled, 1111

titlebar, 98, 115

toolbar, 116

transient, 1111

unmanaged, 1113

Update Manager, 105

wiggly, 108

Window Preferences, 141

working with, 98

Workspace Switcher, 96

Workspace Switcher  
Preferences, 96

WindowMaker window  
manager, 264

Windows

convert files, 161

dual-boot system, 82

file namespace vs. Linux, 32

filename limitation, 190

formatting, 30

integration. *See* Samba

- net use utility (Samba), 769
  - net view utility (Samba), 769
  - networks, browsing using Samba, 767
  - print
    - from, using CUPS, 538
    - from, using Samba, 539
    - to, using CUPS, 540
  - Samba. *See Samba*
  - shares
    - See also Samba, share*
    - from Linux, accessing using Samba, 766
    - connecting to using Samba, 767
    - displaying using Samba, 766
    - mounting, 767
  - WINS, 1115
  - Wiping a file, 470
  - Wire. *See Cable*
  - Wireless
    - See also Network, wireless*
    - 802.11 specification, 1068
    - access point, 1115
    - configuring, 600
  - Word, 139, 224, 938, 1115
    - delete using CONTROL-W, 139
    - designator, 322
    - erase key, 227
    - parse a command line, 342
    - splitting (bash), 309
  - Work buffer, 1115
    - vim, 181
  - Working directory, 1115
    - change using cd, 196
    - defined, 192
    - execute a file in, 307
    - PATH**, 287
    - relative pathnames and, 194
    - significance of, 194
    - versus home directory, 197
  - Workspace, 110, 1116
    - desktop and, 93
    - GNOME, 15
    - Switcher, 95
  - Workstation, 7, 1116
  - World Wide Web
    - about, 395
    - Berners-Lee, Tim, 395
    - CERN, 395
    - Consortium, 1114
    - Enquire, 395
    - HTML, 395
    - hypermedia, 396
    - hypertext, 395
    - link, hypertext, 395
    - Mosaic browser, 395
    - name, 395
    - origins, 395
    - overview, 395
    - search engine, 396
    - URL, 396
    - Web crawler, 396
  - Worm, 1056, 1116
  - Write access, 203
  - write utility, 169, 172, 572
  - wtmp** file, 200, 581
  - www** directory, 849
  - WWW. *See World Wide Web*
  - WYSIWYG, 1116
- ## X
- X Consortium, 256
  - X server, 1116
  - X terminal, 1116
  - X utility. *See X Window System*
  - X Window System, 15, 84, 256, 1116
    - client and server, 257
    - color depth, 261
    - display number, 260
    - display** option, 261
    - DISPLAY** variable, 260
    - display, access to, 259
    - events, 257
    - exiting from, 261
    - freedesktop.org group, 264
    - ID string, 260
    - library, 143
    - mouse. *See Mouse*
    - nolisten tcp** option, 259
    - remote computing and local displays, 258
    - screen number, 260
    - server, 257
    - server process, 575
    - setup, system-config-display utility, 84
    - starting, 258
    - startx utility, 258
  - X servers, running multiple, 261
  - X stack, 256
  - X terminal, 1116
  - X11 forwarding, OpenSSH, 626, 632, 637, 638
  - X11R7.0, 84
  - xev utility, 258
  - XFree86 versus X.org, 256
  - xhost utility, 259
  - Xinerama, 1116
  - Xlib, 256
    - xmodmap utility, 262
  - X.org, 84
  - X11** directory, 84, 199
  - X11R7.0, 84
  - x86 processor architecture, 27
  - xargs utility, 579
  - XDMCP, 1116
  - xDSL, 1116
  - xev utility, 258
  - xfs** filesystem, 486
  - xhost utility, 259
  - Xinerama, 1116
  - xinetd** daemon, 388, 390, 428, 429, 445, 756
  - xinetd.conf** file, 428, 445
  - xinetd.d** directory, 428, 446
  - XINU, 4
  - Xlib, 256
  - XML, 1116
  - xmodmap utility, 262
  - Xorg utility, 256
  - Xremote, 367
  - xrn utility, 393
  - XSM, 1116
  - xtab** file, 738, 743
  - xterm** terminal name, 1041
  - xvnews utility, 393
- ## Y
- Yellow Pages, 696
  - yp.conf** file, 700
  - ypbind** daemon, 701
  - ypbind-mt** daemon, 701
  - ypinit utility, 708
  - yppasswd utility, 702
  - yppasswdd** daemon, 709
  - yppasswdd** file, 710
  - ypserv.conf** file, 704

ypwhich utility, 701  
ypxfr utility, 708  
ypxfrd daemon, 708  
yum, 498  
    automatically running, 504  
    configuration file, 498  
    install option, 501  
    remove option, 502  
    update option, 500  
    using, 500  
yum.conf file, 498

yum.repos.d directory, 498  
yum.repos.d file, 499  
yumdownloader utility, 505  
yum-updatesd daemon, 504  
yum-updatesd.conf file, 504

## Z

Z filename extension, 163, 191  
Z Shell, 1116  
zcat utility, 163

zero file, 470  
Zimmerman, Phil, 1048  
zip utility, 163  
Zone, DNS, defined, 776  
zsh shell, 1116  
Zulu time. *See UTC*