

LPIC-1

Linux Professional Institute Certification

Study Guide

Second Edition



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Roderick W. Smith



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Best regards,

A handwritten signature in black ink, appearing to read 'Neil Edde', written in a cursive style.

Neil Edde
Vice President and Publisher
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About the Author

Roderick W. Smith is a Linux consultant and author. He has written over a dozen books on Linux, FreeBSD, and computer networking, including the *Linux+ Study Guide* and *Linux Administrator Street Smarts* (both from Sybex). He can be reached at rodsmith@rodsbooks.com.

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Introduction

Why should you learn about Linux? It's a fast-growing operating system, and it is inexpensive and flexible. Linux is also a major player in the small and mid-sized server field, and it's an increasingly viable platform for workstation and desktop use as well. By understanding Linux, you'll increase your standing in the job market. Even if you already know Windows or Mac OS and your employer uses these systems exclusively, understanding Linux will give you an edge when you're looking for a new job or if you're looking for a promotion. For instance, this knowledge will help you to make an informed decision about if and when you should deploy Linux.

The Linux Professional Institute (LPI) has developed its LPI-1 certification as an introductory certification for people who want to enter careers involving Linux. The exam is meant to certify that an individual has the skills necessary to install, operate, and troubleshoot a Linux system and is familiar with Linux-specific concepts and basic hardware.

The purpose of this book is to help you pass both of the LPI-1 exams (101 and 102). Because these exams cover basic Linux command-line tools, software management, hardware configuration, filesystems, the X Window System, the boot process, scripts, security, documentation, administration, and networking, those are the topics that are emphasized in this book. You'll learn enough to manage a Linux system and how to configure it for many common tasks. Even after you've taken and passed the LPI 101 and 102 exams, this book should remain a useful reference.

This book has undergone its own testing and certification by ProCert (http://www.procert.com/labs_quicklinks/q1_1atm.html). This means that you can rest assured that the book covers the LPI objectives.

What Is Linux?

Linux is a clone of the Unix operating system (OS) that has been popular in academia and many business environments for years. Formerly used exclusively on large mainframes, Unix and Linux can now run on small computers—which are actually far more powerful than the mainframes of just a few years ago. Because of its mainframe heritage, Unix (and hence also Linux) scales well to perform today's demanding scientific, engineering, and network server tasks.

Linux consists of a kernel, which is the core control software, and many libraries and utilities that rely on the kernel to provide features with which users interact. The OS is available in many different distributions, which are collections of a specific kernel with specific support programs.

Why Become LPI Certified?

Several good reasons to get your LPI certification exist. The LPI Web site suggests four major benefits:

Relevance LPI's exam was designed with the needs of Linux professionals in mind. This was done by performing surveys of Linux administrators to learn what they actually need to know to do their jobs.

Quality The LPI exams have been extensively tested and validated using psychometric standards. The result is an ability to discriminate between competent administrators and those who must still learn more material.

Neutrality LPI is a nonprofit organization that does not itself market any Linux distribution. This fact removes the motivation to create an exam that's designed as a way to market a particular distribution.

Support The LPI exams are supported by major players in the Linux world. LPI serves the Linux community.

How to Become LPI Certified

The LPI certification is available to anyone who passes the test. You don't have to work for a particular company. It's not a secret society.

To take an LPI exam, you must first register with LPI to obtain an ID number. You can do this online at <https://www.lpi.org/caf/Xamman/register>. Your ID number will be e-mailed to you. With the ID number in hand, you can register for the exam with either of the two firms that administer them: Thomson Prometric and Pearson VUE. The exams can be taken at any Thomson Prometric or Pearson VUE testing center. If you pass, you will get a certificate in the mail saying that you have passed. To find the Thomson Prometric testing center nearest you, call (800) 294-3926. Contact (877) 619-2096 for Pearson VUE information. Alternatively, register online at <http://securereg3.prometric.com> for Thomson Prometric or <http://www.vue.com/lpi/> for Pearson VUE. However you do it, you'll be asked for your name, mailing address, phone number, employer, when and where you want to take the test (i.e., which testing center), and your credit card number (arrangement for payment must be made at the time of registration).

Who Should Buy This Book

Anybody who wants to pass the LPI-1 exams may benefit from this book. If you're new to Linux, this book covers the material you will need to learn the OS from the beginning, and it continues to provide the knowledge you need up to a proficiency level sufficient to pass the LPI-1 101 and 102 exams. You can pick up this book and learn from it even if you've never used Linux before, although you'll find it an easier read if you've at least casually used Linux for a few days. If you're already familiar with Linux, this book can serve as a review and as a refresher course for information with which you might not be completely familiar. In either case, reading this book will help you to pass the LPI exam.

This book is written with the assumption that you know at least a little bit about Linux (what it is, and possibly a few Linux commands). I also assume that you know some basics about computers in general, such as how to use a keyboard, how to insert a disc into a CD-ROM drive, and so on. Chances are, you have used computers in a substantial way in the past—perhaps even Linux, as an ordinary user, or maybe you have used Windows or Mac OS. I do *not* assume that you have extensive knowledge of Linux system administration, but if you’ve done some system administration, you can still use this book to fill in gaps in your knowledge.

As a practical matter, you’ll need a Linux system with which to practice and learn in a hands-on way. Although LPI topic 102 is titled “Linux Installation and Package Management,” neither the exam nor this book covers actually installing Linux on a computer from scratch, although some of the prerequisites (such as disk partitioning) are covered. You may need to refer to your distribution’s documentation to learn how to accomplish this task. Alternatively, several vendors now sell computers with Linux pre-installed.

How This Book Is Organized

This book consists of 10 chapters plus supplementary information: a glossary, this introduction, and the assessment test after the introduction. The chapters are organized as follows:

- Chapter 1, “Exploring Linux Command-Line Tools,” covers the basic tools you need to interact with Linux. These include shells, redirection, pipes, text filters, and regular expressions.
- Chapter 2, “Managing Software,” describes the programs you’ll use to manage software. Much of this task is centered around the RPM and Debian package management systems. The chapter also covers handling shared libraries and managing processes (that is, running programs).
- Chapter 3, “Configuring Hardware,” focuses on Linux’s interactions with the hardware on which it runs. Specific hardware and procedures for using it include the BIOS, expansion cards, USB devices, hard disks, and the partitions and filesystems used on hard disks.
- Chapter 4, “Managing Files,” covers the tools used to manage files. This includes commands to manage files, ownership, and permissions, as well as Linux’s standard directory tree and tools for archiving files.
- Chapter 5, “Booting Linux and Editing Files,” explains how Linux boots up and how you can edit files in Linux. Specific topics include the LILO and GRUB boot loaders, boot diagnostics, runlevels, and the Vi editor.
- Chapter 6, “Configuring the X Window System, Localization, and Printing,” describes the Linux GUI and printing subsystems. Topics include X configuration, managing GUI logins, configuring location-specific features, enabling accessibility features, and setting up Linux to use a printer.
- Chapter 7, “Administering the System,” describes miscellaneous administrative tasks. These include user and group management, tuning user environments, managing log files, setting the clock, and running jobs in the future.

- Chapter 8, “Configuring Basic Networking,” focuses on basic network configuration. Topics include TCP/IP basics, setting up Linux on a TCP/IP network, and network diagnostics.
- Chapter 9, “Writing Scripts, Configuring E-Mail, and Using Databases,” covers these miscellaneous topics. Scripts are small programs that administrators often use to help automate common tasks. E-mail, of course, is an important topic for any computer user, particularly on Linux, which often runs an e-mail server for local or remote use. Linux can run databases that help you store and retrieve information, and these tools can be very important ones on many Linux systems.
- Chapter 7, “Securing Your System,” covers security. Specific subjects include network security, local security, and the use of encryption to improve security.

Chapters 1 through 5 cover the LPIC 101 exam, while chapters 6 through 10 cover the LPIC 102 exam. These make up Part I and Part II of the book, respectively.

Each chapter begins with a list of the LPIC objectives that are covered in that chapter. The book doesn’t cover the objectives in order. Thus, you shouldn’t be alarmed at some of the odd ordering of the objectives within the book. At the end of each chapter, you’ll find a couple of elements you can use to prepare for the exam:

Exam Essentials This section summarizes important information that was covered in the chapter. You should be able to perform each of the tasks or convey the information requested.

Review Questions Each chapter concludes with 20 review questions. You should answer these questions and check your answers against the ones provided after the questions. If you can’t answer at least 80 percent of these questions correctly, go back and review the chapter, or at least those sections that seem to be giving you difficulty.



The review questions, assessment test, and other testing elements included in this book are *not* derived from the LPI exam questions, so don’t memorize the answers to these questions and assume that doing so will enable you to pass the exam. You should learn the underlying topic, as described in the text of the book. This will let you answer the questions provided with this book *and* pass the exam. Learning the underlying topic is also the approach that will serve you best in the workplace—the ultimate goal of a certification like LPI’s.

To get the most out of this book, you should read each chapter from start to finish and then check your memory and understanding with the chapter-end elements. Even if you’re already familiar with a topic, you should skim the chapter; Linux is complex enough that there are often multiple ways to accomplish a task, so you may learn something even if you’re already competent in an area.

Bonus CD-ROM Contents

This book comes with a CD-ROM that contains several additional elements. Items available on the CD-ROM include the following:

Book contents as a PDF file The entire book is available as a fully searchable PDF that runs on all Windows platforms as well as on Linux.

Electronic “flashcards” The CD-ROM includes 150 questions in “flashcard” format (a question followed by a single correct answer). You can use these to review your knowledge of the LPIC exam objectives.

Sample tests All of the questions in this book appear on the CD-ROM—including the 30-question assessment test at the end of this introduction and the 200 questions that make up the 20-question review question sections for each chapter. In addition, there are two 50-question bonus exams.

Conventions Used in This Book

This book uses certain typographic styles in order to help you quickly identify important information and to avoid confusion over the meaning of words such as on-screen prompts. In particular, look for the following styles:

- *Italicized text* indicates key terms that are described at length for the first time in a chapter. (Italics are also used for emphasis.)
- A monospaced font indicates the contents of configuration files, messages displayed at a text-mode Linux shell prompt, filenames, text-mode command names, and Internet URLs.
- *Italicized monospaced text* indicates a variable—information that differs from one system or command run to another, such as the name of a client computer or a process ID number.
- **Bold monospaced text** is information that you’re to type into the computer, usually at a Linux shell prompt. This text can also be italicized to indicate that you should substitute an appropriate value for your system. (When isolated on their own lines, commands are preceded by non-bold monospaced \$ or # command prompts, denoting regular user or system administrator use, respectively.)

In addition to these text conventions, which can apply to individual words or entire paragraphs, a few conventions highlight segments of text:



A note indicates information that’s useful or interesting but that’s somewhat peripheral to the main text. A note might be relevant to a small number of networks, for instance, or it may refer to an outdated feature.



A tip provides information that can save you time or frustration and that may not be entirely obvious. A tip might describe how to get around a limitation or how to use a feature to perform an unusual task.



Warnings describe potential pitfalls or dangers. If you fail to heed a warning, you may end up spending a lot of time recovering from a bug, or you may even end up restoring your entire system from scratch.

Sidebars

A sidebar is like a note but longer. The information in a sidebar is useful, but it doesn't fit into the main flow of the text.



Real World Scenario

Real World Scenario

A real world scenario is a type of sidebar that describes a task or example that's particularly grounded in the real world. This may be a situation I or somebody I know has encountered, or it may be advice on how to work around problems that are common in real, working Linux environments.

EXERCISES

Exercises

An exercise is a procedure you should try out on your own computer to help you learn about the material in the chapter. Don't limit yourself to the procedures described in the exercises, though! Try other commands and procedures to really learn about Linux.

The Exam Objectives

Behind every computer industry exam you can be sure to find exam objectives—the broad topics in which exam developers want to ensure your competency. The official LPI objectives for the LPI 101 and 102 exams are listed here. (They're also printed at the start of the chapters in which they're covered.)



Exam objectives are subject to change at any time without prior notice and at LPI's sole discretion. Please visit the LPIC Certification page of LPI's website (<https://group.lpi.org/publicwiki/bin/view/Examdev/LPIC-10x>) for the most current listing of exam objectives.

Exam 101

Topic 101: System Architecture

- 101.1 Determine and configure hardware settings
- 101.2 Boot the system
- 101.3 Change runlevels and shutdown or reboot system

Topic 102: Linux Installation and Package Management

- 102.1 Design hard disk layout
- 102.2 Install a boot manager
- 102.3 Manage shared libraries
- 102.4 Use Debian package management
- 102.5 Use RPM and YUM package management

Topic 103: GNU and Unix Commands

- 103.1 Work on the command line
- 103.2 Process text streams using filters
- 103.3 Perform basic file management
- 103.4 Use streams, pipes and redirects
- 103.5 Create, monitor and kill processes
- 103.6 Modify process execution priorities
- 103.7 Search text files using regular expressions
- 103.8 Perform basic file editing operations using vi

Topic 104: Devices, Linux Filesystems, Filesystem Hierarchy Standard

- 104.1 Create partitions and filesystems
- 104.2 Maintain the integrity of filesystems
- 104.3 Control mounting and unmounting of filesystems
- 104.4 Manage disk quotas
- 104.5 Manage file permissions and ownership
- 104.6 Create and change hard and symbolic links
- 104.7 Find system files and place files in the correct location

Exam 102

Topic 105: Shells, Scripting and Data Management

- 105.1 Customize and use the shell environment
- 105.2 Customize or write simple scripts
- 105.3 SQL data management

Topic 106: User Interfaces and Desktops

- 106.1 Install and configure X11
- 106.2 Setup a display manager
- 106.3 Accessibility

Topic 107: Administrative Tasks

- 107.1 Manage user and group accounts and related system files
- 107.2 Automate system administration tasks by scheduling jobs
- 107.3 Localisation and internationalisation

Topic 108: Essential System Services

- 108.1 Maintain system time
- 108.2 System logging
- 108.3 Mail Transfer Agent (MTA) basics
- 108.4 Manage printers and printing

Topic 109: Networking Fundamentals

- 109.1 Fundamentals of internet protocols
- 109.2 Basic network configuration
- 109.3 Basic network troubleshooting
- 109.4 Configure client side DNS

Topic 110: Security

- 110.1 Perform security administration tasks
- 110.2 Setup host security
- 110.3 Securing data with encryption



The preceding objective list includes only the basic objective titles. You should consult the complete LPI exam list to learn what commands, files, and procedures you should be familiar with before taking the exam.

Assessment Test

1. The following line appears in your X server's mouse configuration area. What can you conclude?
Option "Protocol" "PS/2"
 - A. The mouse is connected to the PS/2 hardware mouse port.
 - B. The mouse uses the PS/2 software communication standard.
 - C. The computer is an ancient IBM PS/2 system.
 - D. The mouse was designed for use with IBM's OS/2.
2. How can you tell whether your system is using `inetd` or `xinetd` as a super server? (Choose all that apply.)
 - A. Type `ps ax | grep inetd`, and examine the output for signs of `inetd` or `xinetd`.
 - B. Type `superserver` to see a report on which super server is running.
 - C. Look for the `/etc/inetd.conf` file or `/etc/xinetd.d` subdirectory, which is a sign of `inetd` or `xinetd`, respectively.
 - D. Examine the `/etc/inittab` file to see which super server is launched by `init`, which is responsible for this task.
3. How does the `lpc` utility for CUPS differ from its counterpart in BSD LPD and LPRng?
 - A. The `lpc` utility is unique to CUPS; it doesn't ship with BSD LPD or LPRng.
 - B. CUPS doesn't ship with an `lpc` command, but BSD LPD and LPRng do.
 - C. CUPS's `lpc` is much more complex than its counterpart in BSD LPD and LPRng.
 - D. CUPS's `lpc` is much simpler than its counterpart in BSD LPD and LPRng.
4. What file would you edit to restrict the number of simultaneous logins a user can employ?
 - A. `/etc/pam.d/login-limits`
 - B. `/etc/bashrc`
 - C. `/etc/security/limits.conf`
 - D. `/etc/inittab`
5. Which of the following are required when configuring a computer to use a static IP address? (Choose all that apply.)
 - A. The IP address of the DHCP server
 - B. The hostname of the NBNS server
 - C. The computer's IP address
 - D. The network mask

6. What does the following command accomplish?
`$ wc report.txt | tee wc`
- A. It launches the `wc` editor on both the `report.txt` and `wc.txt` files; each file opens in its own window.
 - B. It displays a count of the windows in which the `report.txt` file is displayed and shows that information in a new window called `wc`.
 - C. It displays a count of newlines, words, and bytes in the `report.txt` file and copies that output to the `wc` file.
 - D. It cleans up any memory leaks associated with the `tee` program's use of the `report.txt` file.
7. Which of the following lines, when entered in `/etc/lilo.conf`, begins a definition to boot Linux using the `/boot/bzImage-2.6.19` kernel when the `/boot` partition is `/dev/hda2`?
- A. `image=(hd0,1)/bzImage-2.6.19`
 - B. `kernel=/boot/bzImage-2.6.19`
 - C. `image=/boot/bzImage-2.6.19`
 - D. `kernel=(hd0,1)/boot/bzImage-2.6.19`
8. What does the number 703 represent in the following `/etc/passwd` entry?
`george:x:703:100:George Brown:/home/george:/bin/tcsh`
- A. The account's human ID (HID) number
 - B. The account's process ID (PID) number
 - C. The account's group ID (GID) number
 - D. The account's user ID (UID) number
9. What does the `grep` command accomplish?
- A. It creates a pipeline between two programs.
 - B. It searches files' contents for a pattern.
 - C. It concatenates two or more files.
 - D. It displays the last several lines of a file.
10. Which of the following are journaling filesystems for Linux? (Choose all that apply.)
- A. HPFS
 - B. JFS
 - C. Ext2fs
 - D. Ext3fs

11. You've configured your computer to use SMTP and IMAP via a tunneled SSH connection to your ISP's e-mail server for improved security. Why might you still want to use GPG encryption for your e-mails on top of the encryption provided by SSH?
 - A. The SSH tunnel only reaches as far as the first e-mail server; GPG encrypts data on all the computers all the way to or from your e-mail correspondents.
 - B. SSH encryption is notoriously poor for e-mail, although it's perfectly adequate for login sessions; thus, adding GPG encryption improves security.
 - C. SSH only doesn't encrypt the headers of the e-mail messages; GPG encrypts the headers to keep snoopers from learning your correspondents' identities.
 - D. Using GPG guarantees that your e-mail messages won't contain unwanted viruses or worms that might infect your correspondents' computers.
12. Which of the following ports are commonly used to retrieve e-mail from a mail-server computer? (Select all that apply.)
 - A. 110
 - B. 119
 - C. 139
 - D. 143
13. You're experiencing sporadic problems with a Secure Shell (SSH) login server—sometimes users can log in, and sometimes they can't. What might you try immediately after a failure to help diagnose this problem?
 - A. On the server computer, type **http://localhost:631** into a Web browser to access the SSH configuration page and check its error subpage for error messages.
 - B. Type **diagnose sshd** to run a diagnostic on the SSH server daemon (`sshd`).
 - C. Type **tail /var/log/messages** to look for error messages from the server.
 - D. Examine the `/dev/ssh` device file to look for error messages from the server.
14. What is the function of the `~/.profile` file?
 - A. It's the user configuration file for the ProFTP server.
 - B. It's one of a user's `bash` startup scripts.
 - C. It's the user configuration file for the ProFile file manager.
 - D. Its presence tells `tcsh` to ignore file modes.
15. You want your computer to remind you to get your car inspected in two years. What is the best way to do this, of the specified options?
 - A. Create a program that repeatedly checks the time and, when two years has passed, displays a message to get your car inspected.
 - B. Type **at date**, where *date* is a date specification. You can then specify a command, such as `mail` with appropriate options, to notify you of the need to get your car inspected.
 - C. Create a `cron` job that runs hourly. This job should check the date and, when the correct date comes up, use `mail` to notify you of the need for a car inspection.
 - D. Use the NTP GUI calendar program to create an alarm for the specified date. The program will then display the message you enter at the specified date and time.

16. How would you configure a computer to use the computer whose IP address is 172.24.21.1 as a gateway for all network traffic that's not otherwise configured?
- A. **gateway default 172.24.21.1**
 - B. **gateway 172.24.21.1**
 - C. **route gateway 172.24.21.1**
 - D. **route add default gw 172.24.21.1**
17. What software can you use to drive a Braille display device? (Select all that apply.)
- A. Emacspeak
 - B. BRLTTY
 - C. A 2.6.26 or later kernel
 - D. GOK
18. Which is true of source RPM packages?
- A. They consist of three files: an original source tarball, a patch file of changes, and a PGP signature indicating the authenticity of the package.
 - B. They require programming knowledge to rebuild.
 - C. They can sometimes be used to work around dependency problems with a binary package.
 - D. They are necessary to compile software for RPM-based distributions.
19. Which utility should you use to rename the file `pumpkin.txt` to `lantern.txt`?
- A. `dd`
 - B. `rm`
 - C. `cp`
 - D. `mv`
20. You want to run a lengthy scientific simulation program, called `simbigbang`, which doesn't require any user interaction; the program operates solely on disk files. If you don't want to tie up the shell from which you run the program, what should you type to run `simbigbang` in the background?
- A. **start simbigbang**
 - B. **simbigbang &**
 - C. **bg simbigbang**
 - D. **background simbigbang**
21. Which of the following commands will install an RPM package called `theprogram-1.2.3-4.i386.rpm` on a computer? (Choose all that apply.)
- A. **rpm -Uvh theprogram-1.2.3-4.i386.rpm**
 - B. **rpm -i theprogram-1.2.3-4.i386.rpm**
 - C. **rpm -U theprogram**
 - D. **rpm -e theprogram-1.2.3-4.i386.rpm**

22. What tool can diagnose and fix many common Linux filesystem problems?
- A. `mkfs`
 - B. `fsck`
 - C. `chkdsk`
 - D. `scandisk`
23. You've just installed MySQL, and you intend to use it to store information about the animals in a zoo, from the anteaters to the zebras. What command are you likely to use first, once you start MySQL?
- A. `CREATE DATABASE animals;`
 - B. `USE animals;`
 - C. `CREATE TABLE animals;`
 - D. `INSERT INTO animals;`
24. Which of the following commands displays help on *topic*, when typed in a Linux shell? (Choose all that apply.)
- A. `manual topic`
 - B. `man topic`
 - C. `? topic`
 - D. `info topic`
25. A computer's hardware clock keeps track of the time while the computer is powered off. In what formats may this time be stored on an x86 Linux system? (Choose all that apply.)
- A. Coordinated Universal Time (UTC)
 - B. Internet Time
 - C. Local time
 - D. 12-hour time
26. You want to know what kernel modules are currently loaded. What command would you type to learn this information?
- A. `insmod`
 - B. `depmod`
 - C. `modprobe`
 - D. `lsmod`
27. You want to enable all members of the `music` group to read the `instruments.txt` file, which currently has `0640 (-rw-r-----)` permissions, ownership by `root`, and group ownership by `root`. How might you accomplish this goal? (Choose all that apply.)
- A. Type `chown music instruments.txt` in the file's directory.
 - B. Type `chgrp music instruments.txt` in the file's directory.
 - C. Type `chgroup music instruments.txt` in the file's directory.
 - D. Type `chown .music instruments.txt` in the file's directory.

- 28.** You want to create a link to the `/usr/local/bin` directory in another location. Which of the following statements is true?
- A.** The link will probably have to be a symbolic link.
 - B.** You must own `/usr/local/bin` to create the link.
 - C.** You can create the link only if the link's location is on the same filesystem as the original directory.
 - D.** Only the system administrator can do this.
- 29.** Which of the following, when typed in Vi's command mode, saves a file and quits the program?
- A.** `:rq`
 - B.** `:wq`
 - C.** `:re`
 - D.** `:we`
- 30.** A user's home directory includes a file called `~/forward` that consists of one line: `|~/junkme`. What is the effect of this configuration?
- A.** The user's incoming mail is forwarded to the `junkme` user on the same system.
 - B.** The user's incoming mail is stored in the `~/junkme` file.
 - C.** The user's incoming mail is sent through the `~/junkme` program file.
 - D.** The user's incoming mail is flagged as spam and deleted.

Answers to Assessment Test

1. B. “PS/2” can refer to both a hardware interface and a software protocol, but used in the context of the `Protocol` option, it unambiguously refers to the software protocol. Option A *might* be correct, but the specified line is insufficient evidence of that; USB mice generally use the PS/2 protocol or a variant of it, such as the Intellimouse PS/2 protocol. Although the PS/2 hardware port and protocol originated with the IBM PS/2 computer mentioned in option C, many other computers now use them. Mice that use the PS/2 protocol may be used with just about any OS, not just IBM’s OS/2. For more information, please see Chapter 6, “Configuring the X Window System, Localization, and Printing.”
2. A, C. Examining a process listing (obtained from `ps`) for signs of the super server is the most reliable way to determine which one is actually running. The presence of the super server’s configuration file or files (as in option C) is also a good diagnostic, although some older systems that have been upgraded may have both sets of configuration files. There is no standard `superserver` utility to report on which one is used. Most distributions launch the super server through a SysV startup script; the `/etc/inittab` file isn’t directly involved in this process, so examining it would be pointless. For more information, please see Chapter 10, “Securing Your System.”
3. D. The `lpc` utility is used to start, stop, change the priority of, and otherwise control jobs in a print queue. CUPS ships with an `lpc` utility, but it’s quite rudimentary compared to the `lpc` utilities of BSD LPD and LPRng. Instead, CUPS relies on its Web-based interface to provide the ability to control print jobs. For more information, please see Chapter 6, “Configuring the X Window System, Localization, and Printing.”
4. C. The `/etc/security/limits.conf` file defines various limits on user resources, including the number of simultaneous logins individual users are permitted. Thus, option C is correct. The `/etc/pam.d/login-limits` file is fictitious, although login limits do rely on the `pam_limits` module to the Pluggable Authentication System (PAM). The `/etc/bashrc` file is a global bash startup script file, but it’s not normally used to impose login limits. The `/etc/inittab` file is a key Linux startup file, but it doesn’t have any direct bearing on imposing login limits. For more information, please see Chapter 10, “Securing Your System.”
5. C, D. The computer’s IP address and network mask (a.k.a. subnet mask or netmask) are the most critical components in TCIP/IP network configuration. (Additional information you may need to provide on many networks includes the IP address of 1–3 DNS servers, the hostname or IP address of a router, and the computer’s hostname.) You shouldn’t need the IP address of a Dynamic Host Configuration Protocol (DHCP) server—and if a DHCP server is present, chances are you should be using DHCP rather than static IP address assignment. A NetBIOS Name Service (NBNS) server converts between names and IP addresses on NetBIOS networks. The hostname of such a computer isn’t likely to be a critical configuration element, although you may need to provide this information to Samba for some operations to function correctly when sharing files. For more information, please see Chapter 8, “Configuring Basic Networking.”

6. C. The `wc` command displays a count of newlines, words, and bytes in the specified file (`report.txt`). Piping this data through `tee` causes a copy of the output to be stored in the new file (`wc` in this example—you shouldn't run this command in the same directory as the `wc` executable file!). Thus, option C is correct. Contrary to option A, `wc` isn't an editor, and the remaining syntax wouldn't cause two files to open in separate windows even if `wc` were an editor. Contrary to option B, `wc` doesn't count windows or open a new window. Contrary to option D, `wc` has nothing to do with cleaning up memory leaks, and `tee` doesn't directly use the `report.txt` file. For more information, please see Chapter 1, "Exploring Linux Command-Line Tools."
7. C. The `image=` line in `/etc/lilo.conf` identifies a kernel image to be booted using normal Linux filenames, so `/boot/bzImage-2.6.19` is the correct notation. There is no `kernel=` option in LILO's configuration file. The `(hd0,1)` notation in options A and D is a GRUB hard-disk identifier; this notation isn't used in LILO. Option D also uses both the GRUB disk identifier notation and the `/boot` Linux filesystem specification. For more information, please see Chapter 5, "Booting Linux and Editing Files."
8. D. The third field of `/etc/passwd` entries holds the UID number for the account. Linux doesn't use any standard identifier called a human ID (HID), although the acronym HID stands for human interface device, a class of USB devices. Accounts don't have PID numbers; those belong to running processes. The account's GID number is stored in the fourth field of `/etc/passwd`—100 in this example. For more information, please see Chapter 7, "Administering the System."
9. B. The `grep` command scans files to find those that contain a specified string or pattern. In the case of text files, it displays the matching line or lines; for binary files, it reports that the file matches the pattern. The method of creating a pipeline involves separating two commands with a vertical bar (`|`). The `grep` command can be used in a pipeline, but it doesn't create one. The command that concatenates files is `cat`, and the command that displays the last several lines of a file is `tail`. For more information, please see Chapter 1, "Exploring Linux Command-Line Tools."
10. B, D. The Journaling Filesystem (JFS) is a journaling filesystem written by IBM for AIX and OS/2 and later ported to Linux. The Third Extended Filesystem (`ext3fs`) is a journaling filesystem based on the older non-journaling Second Extended Filesystem (`ext2fs`). The High-Performance Filesystem (HPFS) is a non-journaling filesystem designed by Microsoft for OS/2. For more information, please see Chapter 3, "Configuring Hardware."
11. A. Option A correctly describes the features of SSH and GPG in this context. Option B is incorrect because SSH should do a fine job of encrypting your e-mail so that it can't be decoded between your system and your ISP's e-mail server. Option C has it backward; e-mail transferred via SSH will be completely encrypted, including its headers. GPG doesn't encrypt headers, just message bodies. Option D is incorrect because GPG isn't a virus scanner, just an encryption tool. For more information, please see Chapter 10, "Securing Your System."

12. A, D. Port 110 is assigned to the Post Office Protocol (POP), and port 143 is assigned to the Internet Message Access Protocol (IMAP), both of which may be used to retrieve e-mail messages from an e-mail server system. Port 119 is assigned to the Network News Transfer Protocol (NNTP), and port 139 is assigned to the Server Message Block/Common Internet File System (SMB/CIFS) protocol, neither of which is commonly used for e-mail retrieval. For more information, please see Chapter 8, “Configuring Basic Networking.”
13. C. Log files, such as `/var/log/messages` and sometimes others in `/var/log`, often contain useful information concerning server errors. The `tail` program displays the last few lines of a file, so using it to examine log files immediately after a problem occurs can be a useful diagnostic procedure. The `http://localhost:631` URL accesses the Common Unix Printing System (CUPS) configuration utility, which has nothing to do with SSH. There is no standard `diagnose` utility to help diagnose server problems, and there is no standard `/dev/ssh` file. For more information, please see Chapter 5, “Booting Linux and Editing Files.”
14. B. The `~/.profile` file is one of several `bash` startup scripts. It has nothing to do with the ProFTP server or the `tcsh` shell. The ProFile file manager mentioned in option C is fictitious. For more information, please see Chapter 9, “Writing Scripts, Configuring E-mail, and Using Databases.”
15. B. The `at` utility was created to run programs at one specified point in the future. Thus, option B will accomplish the stated goal. Options A and C might also work; but neither is the *best* way to accomplish this goal. Option A will tie up CPU time, and if the program crashes or the system is shut down during the intervening two years, the message will never display. Option C would be more reliable, but it adds unnecessary complexity to your hourly cron job schedule. A GUI calendar program, as specified in option D, might work; but NTP is the Network Time Protocol, a protocol and like-named program for synchronizing clocks across a network. Thus, NTP isn’t the tool for the job, and option D is incorrect. For more information, please see Chapter 7, “Administering the System.”
16. D. Option D provides the correct command to add 172.24.21.1 as the default gateway. Options A and B both use the fictitious `gateway` command, which doesn’t exist and therefore won’t work unless you create a script of this name. Option C uses the correct `route` command, but there is no `gateway` option to `route`; you must use `add default gw`, as in option D. For more information, please see Chapter 8, “Configuring Basic Networking.”
17. B, C. The BRLTTY package is an add-on daemon for handling a Braille display device, and some features for using these devices have been added to the 2.6.26 kernel, so options B and C are correct. Emacspeak is speech-synthesis software; it can be used to “speak” a text display to a user, but it doesn’t interface with Braille displays. GOK (<http://www.gok.ca>) is an on-screen keyboard, not a Braille display tool. For more information, please see Chapter 6, “Configuring the X Window System, Localization, and Printing.”
18. C. Some dependencies result from dynamically linking binaries to libraries at compile time and so can be overcome by recompiling the software from a source RPM. Option A describes Debian source packages, not RPM packages. Recompiling a source RPM requires only issuing an appropriate command, although you must also have appropriate compilers and libraries installed. Source tarballs can also be used to compile software for RPM systems, although this results in none of RPM’s advantages. For more information, please see Chapter 2, “Managing Software.”

19. D. The `mv` utility can be used to rename files as well as move them from one location to another. The `dd` utility is used to copy files to backups, whereas `rm` is used to remove (delete) files and `cp` copies files. For more information, please see Chapter 4, “Managing Files.”
20. B. Appending an ampersand (&) to a command causes that command to execute in the background. The program so launched still consumes CPU time, but it won’t monopolize the shell you used to launch it. The `start` and `background` commands are fictitious. Although `bg` does place a job into the background, it doesn’t launch a program that way; it places a process that’s been suspended (by pressing Ctrl+Z) into the background. For more information, please see Chapter 2, “Managing Software.”
21. A, B. The `-Uvh` parameter issues an upgrade command (which installs the program whether or not an earlier version is installed) and creates a series of hash marks to display the command’s progress. The `-i` parameter installs the program if it’s not already installed but causes no progress display. Option C uses a package name, not a complete filename, and so it will fail to install the package file. The `-e` option removes a package. For more information, please see Chapter 2, “Managing Software.”
22. B. Option B, `fsck`, is Linux’s filesystem check utility. It’s similar in purpose to the DOS and Windows `CHKDSK` and `ScanDisk` utilities, but these DOS and Windows utilities don’t work on Linux filesystems like `ext2fs` or `ReiserFS`. Option A, `mkfs`, creates new filesystems; it doesn’t diagnose or fix filesystem problems. For more information, please see Chapter 3, “Configuring Hardware.”
23. A. A freshly installed MySQL database is unlikely to have a ready-made database of animals, so your first task is to create that database with the `CREATE DATABASE` command, as shown in option A. (You could call the database something other than `animals`, of course.) The `USE` command in option B will only be useful once the database has been created. Once the database is created, you can use `CREATE TABLE`, as in option C, to create a table; but you’ll need an existing database first, and this command also requires information about the type of data to be stored, which option C doesn’t provide. Option D’s `INSERT INTO` command stores data into a table once it’s been created, so it’s far from the first command you’ll use. It also requires additional specification of the data to be stored, so it’s incomplete. For more information, please see Chapter 9, “Writing Scripts, Configuring E-mail, and Using Databases.”
24. B, D. The correct answers, `man` and `info`, are two common Linux help packages. Although `?` is a common help command within certain interactive programs, it isn’t a help command in `bash` or other common Linux shells. There is no common command called `manual`. For more information, please see Chapter 1, “Exploring Linux Command-Line Tools.”
25. A, C. Unix systems traditionally store time in UTC (a.k.a. Greenwich Mean Time), and Linux may do so as well. Most other x86 PC OSs traditionally store time as the local time however, so Linux also supports this option. Internet Time is an alternative to the 24-hour clock in which the day is broken into 1,000 “beats.” Standard PC BIOSs don’t support this time format. Likewise, a 12-hour clock isn’t terribly useful to computers because it doesn’t differentiate a.m. from p.m. For more information, please see Chapter 7, “Administering the System.”

26. D. Typing `lsmod` produces a list of the modules that are currently loaded. The `insmod` and `modprobe` programs both load modules—either a single module or a single module and all those on which it depends, respectively. The `depmod` command generates the `modules.dep` file that contains module dependency information. For more information, please see Chapter 3, “Configuring Hardware.”
27. B, D. The `chgrp` and `chown` commands can both change the group ownership of a file. The `chgrp` command takes a group name and a filename as parameters, as in option B. The `chown` command normally changes a file’s owner; but if you provide a group name preceded by a dot (`.`), as in option D, it changes the group of a file. The `chown` command shown in option A will change the primary ownership of the file to the `music` user, if such a user exists on the system; it won’t change the group ownership. There is no standard `chgroup` command, as in option C. For more information, please see Chapter 4, “Managing Files.”
28. A. Hard links to directories aren’t permitted by most filesystems, so you’ll probably have to create a symbolic link, as noted in option A. Contrary to option B, anybody may create a link, not just the original’s owner. Option C describes a restriction of hard links; but because this link will probably have to be a symbolic link, this restriction is unimportant and option C is incorrect. Option D describes a more severe restriction than option B, but it’s incorrect for the same reasons. For more information, please see Chapter 4, “Managing Files.”
29. B. The colon (`:`) starts `ex` mode, from which you can enter commands. In `ex` mode, `r` includes a file in an existing one, `w` writes a file, `e` loads an entirely new file, and `q` quits the program. Thus, the desired combination is `:wq`. For more information, please see Chapter 5, “Booting Linux and Editing Files.”
30. C. The `~/ .forward` file is a user e-mail forwarding file. The vertical bar character (`|`) at the start of such a file is a code to send the e-mail through the specified program file, so option C is correct. To do as option A describes, the file would need to read `junkme` or `junkme@hostname`, where `hostname` is the computer’s hostname. To do as option B describes, the leading vertical bar would have to be omitted. It’s conceivable that the `~/junkme` script does as option D describes, but there’s no way of knowing this for certain. For more information, please see Chapter 9, “Writing Scripts, Configuring E-mail, and Using Databases.”

The LPI 101 Exam (60 Weights)

PART

I



Chapter 1

Exploring Linux Command-Line Tools

THE FOLLOWING LINUX PROFESSIONAL INSTITUTE OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ 1.103.1 Work on the command line (weight: 4)
- ✓ 1.103.2 Process text streams using filters (weight: 3)
- ✓ 1.103.4 Use streams, pipes, and redirects (weight: 4)
- ✓ 1.103.7 Search text files using regular expressions (weight: 2)





Linux borrows heavily from Unix, and Unix began as a text-based operating system (OS). Unix and Linux retain much of this heritage, which means that to understand how to use and, especially, administer Linux, you must understand at least the basics of its command-line tools. Thus, this book begins with an introduction to Linux *shells* (the programs that accept and interpret text-mode commands) and many of the basic commands and procedures you can use from a shell.

This chapter begins with basic shell information, including shell options and procedures for using them. From there, this chapter covers streams, pipes, and redirects, which you can use to shunt input and output between programs or between files and programs. These techniques are frequently combined with text processing using *filters*—commands you can use to manipulate text without the help of a conventional text editor. Sometimes you must manipulate text in an abstract way, using codes to represent several different types of text. This chapter therefore covers this topic.

Understanding Command-Line Basics

Before you do anything else with Linux, you should understand how to use a Linux shell. Several shells are available, but most provide similar capabilities. Understanding a few basics will take you a long way in your use of Linux, so I describe some of these techniques and commands. You should also understand shell *environment variables*, which are placeholders for data that may be useful to many programs. Finally, on the topic of command-line basics, you should know how to get help with commands you're trying to use.

Exploring Your Linux Shell Options

As with many key software components, Linux provides a range of options for shells. A complete list would be quite long, but the more common choices include the following:

bash The GNU Bourne Again Shell (bash) is based on the earlier Bourne shell for Unix but extends it in several ways. In Linux, bash is the most common default shell for user accounts, and it's the one emphasized in this book and on the Linux Professional Institute (LPI) exam.

bsh The Bourne shell upon which bash is based also goes by the name bsh. It's not often used in Linux, although the bsh command is usually a symbolic link to bash.

tcsh This shell is based on the earlier C shell (csh). It's a fairly popular shell in some circles, but no major Linux distributions make it the default shell. Although it's similar to bash in many respects, some operational details differ. For instance, you don't assign environment variables in the same way in tcsh as in bash.

csh The original C shell isn't much used on Linux, but if a user is familiar with csh, tcsh makes a good substitute.

ksh The Korn shell (ksh) was designed to take the best features of the Bourne shell and the C shell and extend them further. It has a small but dedicated following among Linux users.

zsh The Z shell (zsh) takes shell evolution further than the Korn Shell, incorporating features from earlier shells and adding still more.

In addition to these shells, dozens more obscure ones are available. In Linux, most users run bash because it's the default. Some other OSs use csh or tcsh as the default, so if your users have backgrounds on non-Linux Unix-like OSs, they may be more familiar with these other shells. You can change a user's default shell by editing the account, as described in Chapter 7, "Administering the System."

The file `/bin/sh` is a symbolic link to the system's default shell—normally `/bin/bash` for Linux. This practice enables you to point to a shell (say, at the start of a simple shell script, as described in Chapter 9, "Writing Scripts, Configuring E-Mail, and Using Databases") and be assured that a shell will be called, even if the system's available shells change. This feature is particularly important when developing shell scripts that might be run on other computers, as described in Chapter 9.

Using a Shell

Linux shell use is fairly straightforward for anybody who's used a text-mode OS before: You type a command, possibly including options to it, and the computer executes the command. For the most part, Linux commands are external—that is, they're separate programs from the shell. A few commands are internal to the shell, though, and knowing the distinction can be important. You should also know some of the tricks that can make using the command shell easier—how to have the computer complete a long command or filename, retrieve a command you've recently run, or edit a command you've recently used (or haven't yet fully entered).



NOTE

One class of commands—those for handling basic file management—is very important but isn't described here in great detail. For more information on these commands, consult Chapter 4, "Managing Files."

Starting a Shell

If you log into Linux using a text-mode login screen, chances are you'll be dropped directly into your default shell—it's the shell that presents the prompt and accepts subsequent commands.

If you log into Linux using a graphical user interface (GUI) login screen, though, you'll have to start a shell manually. Some GUIs provide a menu option to start a program called a terminal, `xterm`, `Konsole`, or something similar. These programs enable you to run text-mode programs within Linux, and by default they come up running your shell. If you can't find such a menu option, look for one that enables you to run an arbitrary command. Select it, and type `xterm` or `konsole` as the command name; this will launch an `xterm`-type program that will run a shell.

Using Internal and External Commands

Internal commands are, as you might expect, built into the shell. Most shells offer a similar set of internal commands, but shell-to-shell differences do exist; consult your shell's `man` page (as described later, in “Getting Help”) for details, particularly if you're using an exotic shell. Internal commands you're likely to use enable you to perform some common tasks:

Change the working directory Whenever you're running a shell, you're working in a specific directory. When you refer to a file without providing a complete path to the file, the shell works on the file in the current working directory. (Similar rules apply to many programs.) The `cd` command changes the current working directory. For instance, typing `cd /home/sally` changes to the `/home/sally` directory. The tilde (`~`) character is a useful shortcut; it stands for your home directory, so `cd ~` will have the same effect as `cd /home/sally` if your home directory is `/home/sally`.

Display the working directory The `pwd` command displays (“prints” to the screen) the current working directory.

Display a line of text The `echo` command displays the text you enter; for instance, typing `echo Hello` causes the system to display the string `Hello`. This may seem pointless, but it's useful in scripts (described in Chapter 9), and it can also be a good way to review the contents of environment variables (described later in this chapter, in “Using Environment Variables”).

Execute a program The `exec` command runs an external program that you specify, as in `exec myprog` to run `myprog`. In most cases, this is better accomplished by typing the name of the program you want to run. The `exec` command has one special feature, though: Rather than create a new process that runs alongside the shell, the new process *replaces* the shell. When the new process terminates, it's as if you terminated the shell.

Time an operation The `time` command times how long subsequent commands take to execute. For instance, typing `time pwd` tells you how long the system took to execute the `pwd` command. The time is displayed after the full command terminates. Three times are displayed: total execution time (a.k.a. real time), user CPU time, and system CPU time. The final two values tell you about CPU time consumed, which is likely to be much less than the total execution time.

Set options In its most basic form, `set` displays a wide variety of options relating to `bash` operation. These options are formatted much like environment variables, but they aren't the same things. You can pass various options to `set` to have it affect a wide range of shell operations.

Terminate the shell The `exit` and `logout` commands both terminate the shell. The `exit` command terminates any shell, but the `logout` command terminates only login shells—that is, those that are launched automatically when you initiate a text-mode login as opposed to those that run in `xterm` windows or the like.



This list isn't complete. Later sections of this chapter and later chapters describe some additional internal commands. Consult your shell's documentation for a complete list of its internal commands.

Some of these internal commands are duplicated by external commands that do the same thing, but these external commands aren't always installed on all systems. Even when these external commands are installed, the internal command takes precedence unless you provide the complete path to the external command on the command line, as in typing `/bin/pwd` rather than `pwd`.



Real World Scenario

Confusion over Internal and External Commands

When duplicate internal and external commands exist, they sometimes produce subtly different results or accept different options. These differences can occasionally cause problems. For instance, consider the `pwd` command and symbolic links to directories. (Symbolic links are described in more detail in Chapter 4. For now, know that they're files that point to other files or directories and for most intents and purposes act just like the files or directories to which they point when they're accessed.) Suppose you create a symbolic link to `/bin` within your home directory and then `cd` into that directory. You then want to know where you are. The `pwd` command that's internal to `bash` will produce a different result from the external `pwd` command:

```
$ pwd
/home/sally/binlink
$ /bin/pwd
/usr/bin
```

As you can see, `bash`'s internal `pwd` shows the path via the symbolic link, whereas the external command shows the path to which the link points. Sometimes these differences can cause confusion, such as if you read the man page or other documentation that describes one version but you use the other and a difference is important. You may wonder why the command isn't operating as you expect. If in doubt, look up the documentation for, and type the complete path to, the external command to be sure you use it.

When you type a command that's not recognized by the shell as one of its internal commands, the shell checks its *path* to find a program by that name to execute it. The path is a list of directories in which commands can be found. It's defined by the PATH environment variable, as described shortly in "Using Environment Variables." A typical user account has about half a dozen or a dozen directories in its path. You can adjust the path by changing the PATH environment variable in a shell configuration file, as described in "Exploring Shell Configuration."

You can run programs that aren't on the path by providing a complete path on the command line. For instance, typing `./myprog` runs the `myprog` program in the current directory, and `/home/arthur/thisprog` runs the `thisprog` program in the `/home/arthur` directory.



The root account should normally have a shorter path than ordinary user accounts. Typically, you'll omit directories that store GUI and other user-oriented programs from root's path in order to discourage use of the root account for routine operations, thus minimizing the risk of security breaches related to buggy or compromised binaries being run by root. Most important, root's path should *never* include the current directory (`./`). Placing this directory in root's path makes it possible for a local miscreant to trick root into running replacements for common programs, such as `ls`, by having root change into a directory with such a program. Indeed, omitting the current directory from ordinary user paths is also generally a good idea. If this directory must be part of the ordinary user path, it should appear at the *end* of the path so that the standard programs take precedence over any replacement programs in the current directory.

In the case of both programs on the path and those whose complete paths you type as part of the command, the program file must be marked as executable. This is done via the execute bit that's stored with the file. Standard programs are marked executable when they're installed, but if you need to adjust a program's executable status, you can do so with the `chmod` command, as described in Chapter 4.

Performing Some Shell Command Tricks

Many users find typing commands to be tedious and error prone. This is particularly true of slow or sloppy typists. For this reason, Linux shells include various tools that can help speed up operations. The first of these is *command completion*: Type part of a command or (as an option to a command) a filename, and then press the Tab key. The shell tries to fill in the rest of the command or the filename. If just one command or filename matches the characters you've typed so far, the shell fills it in and places a space after it. If the characters you've typed don't uniquely identify a command or filename, the shell fills in what it can and then stops. Depending on the shell and its configuration, it may beep. If you press the Tab key again, the system responds by displaying the possible completions. You can then type another character or two and, if you haven't completed the command or filename, press the Tab key again to have the process repeat.

The most fundamental Linux commands have fairly short names—`mv`, `ls`, `set`, and so on. Some other commands are much longer, though, such as `traceroute` or `sane-find-scanner`. Filenames can also be quite lengthy—up to 255 characters on many filesystems. Thus, command completion can save a lot of time when you're typing. It can also help you avoid typos.



The most popular Linux shells, including `bash` and `tcsh`, support command and filename completion. Some older shells, though, don't support this helpful feature.

Another helpful shell shortcut is the *history*. The history keeps a record of every command you type (stored in `~/.bash_history` in the case of `bash`). If you've typed a long command recently and want to use it again, or use a minor variant of it, you can pull the command out of the history. The simplest way to do this is to press the Up arrow key on your keyboard; this brings up the previous command. Pressing the Up arrow key repeatedly moves through multiple commands so you can find the one you want. If you overshoot, press the Down arrow key to move down the history. The `Ctrl+P` and `Ctrl+N` keystrokes double for the Up and Down arrow keys, respectively.

Another way to use the command history is to search through it. Press `Ctrl+R` to begin a backward (reverse) search, which is what you probably want, and begin typing characters that should be unique to the command you want to find. The characters you type need not be the ones that begin the command; they can exist anywhere in the command. You can either keep typing until you find the correct command or, after you've typed a few characters, press `Ctrl+R` repeatedly until you find the one you want. The `Ctrl+S` keystroke works similarly but searches forward in the command history, which might be handy if you've used a backward search or the Up arrow key to look back and have overshoot. In either event, if you can't find the command you want or change your mind and want to terminate the search, press `Ctrl+G` to do so.

Frequently, after finding a command in the history, you want to edit it. The `bash` shell, like many shells, provides editing features modeled after those of the Emacs editor:

Move within the line Press `Ctrl+A` or `Ctrl+E` to move the cursor to the start or end of the line, respectively. The Left and Right arrow keys move within the line a character at a time. `Ctrl+B` and `Ctrl+F` do the same, moving backward and forward within a line. Pressing `Ctrl` plus the Left or Right arrow key moves backward or forward a word at a time, as does pressing `Esc` and then `B` or `F`.

Delete text Pressing `Ctrl+D` or the Delete key deletes the character under the cursor, whereas pressing the Backspace key deletes the character to the left of the cursor. Pressing `Ctrl+K` deletes all text from the cursor to the end of the line. Pressing `Ctrl+X` and then Backspace deletes all the text from the cursor to the beginning of the line.

Transpose text Pressing `Ctrl+T` transposes the character before the cursor with the character under the cursor. Pressing `Esc` and then `T` transposes the two words immediately before (or under) the cursor.

Change case Pressing Esc and then U converts text from the cursor to the end of the word to uppercase. Pressing Esc and then L converts text from the cursor to the end of the word to lowercase. Pressing Esc and then C converts the letter under the cursor (or the first letter of the next word) to uppercase, leaving the rest of the word unaffected.

Invoke an editor You can launch a full-fledged editor to edit a command by pressing Ctrl+X followed by Ctrl+E. The `bash` shell attempts to launch the editor defined by the `$FCEDIT` or `$EDITOR` environment variable or Emacs as a last resort.

These editing commands are just the most useful ones supported by `bash`; consult its man page to learn about many more obscure editing features. In practice, you're likely to make heavy use of command and filename completion, the command history, and perhaps a few editing features.

The `history` command provides an interface to view and manage the history. Typing `history` alone displays all the commands in the history (typically the latest 500 commands); adding a number causes only that number of the latest commands to appear. Typing `history -c` clears the history, which can be handy if you've recently typed commands you'd rather not have discovered by others (such as commands that include passwords).

In Exercise 1.1, you'll experiment with your shell's completion and command-editing tools.

EXERCISE 1.1

Editing Commands

To experiment with your shell's completion and command-editing tools, follow these steps:

1. Log in as an ordinary user.
2. Create a temporary directory by typing `mkdir test`. (Directory and file manipulation commands are described in more detail in Chapter 4.)
3. Change into the test directory by typing `cd test`.
4. Create a few temporary files by typing `touch one two three`. This command creates three empty files named one, two, and three.
5. Type `ls -l t`, and without pressing the Enter key, press the Tab key. The system may beep at you or display `two three`. If it doesn't display `two three`, press the Tab key again, and it should do so. This reveals that either `two` or `three` is a valid completion to your command, because these are the two files in the test directory whose file-names begin with the letter `t`.
6. Type `h`, and again without pressing the Enter key, press the Tab key. The system should complete the command (`ls -l three`), at which point you can press the Enter key to execute it. (You'll see information on the file.)
7. Press the Up arrow key. You should see the `ls -l three` command appear on the command line.

EXERCISE 1.1 (continued)

8. Press Ctrl+A to move the cursor to the beginning of the line.
 9. Press the Right arrow key once, and type `es` (without pressing the Enter key). The command line should now read `less -l three`.
 10. Press the Right arrow key once, and press the Delete key three times. The command should now read `less three`. Press the Enter key to execute the command. (Note that you can do so even though the cursor isn't at the end of the line.) This invokes the `less` pager on the `three` file. (The `less` pager is described more fully later, in "Getting Help.") Because this file is empty, you'll see a mostly empty screen.
 11. Press the Q key to exit from the `less` pager.
-

Exploring Shell Configuration

Shells, like many Linux programs, are configured through files that hold configuration options in a plain-text format. The `bash` configuration files are actually `bash` shell scripts, which are described more fully in Chapter 9. For now, you should know that the `~/.bashrc` and `~/.profile` files are the main user configuration files for `bash`, and `/etc/bash.bashrc` and `/etc/profile` are the main global configuration files.

Even without knowing much about shell scripting, you can make simple changes to these files. Edit them in your favorite text editor, and change whatever needs changing. For instance, you can add directories to the `$PATH` environment variable, which takes a colon-delimited list of directories.



Be careful when changing your `bash` configuration, and particularly the global `bash` configuration files. Save a backup of the original file before making changes, and test your changes immediately by logging in using another virtual terminal. If you spot a problem, revert to your saved copy until you can learn the cause and create a working file.

Using Environment Variables

Environment variables are like variables in programming languages—they hold data to be referred to by the variable name. Environment variables differ in that they're part of the environment of a program, and other programs, such as the shell, can modify this environment. Programs can rely on environment variables to set information that can apply to many different programs. For instance, suppose a computer hosts several different Usenet news readers. These programs all need to know what Usenet news server to use; if they all agree to use an environment variable, such as `$NNTPSERVER`, to hold this information, you can set this

environment variable once as part of your shell startup script and then forget it. You needn't set this feature individually for all the news readers installed on the system.

Chapter 9 describes environment variables and their manipulation in more detail. For the moment, you should know that you can set them in `bash` by using an assignment (`=`) operator followed by the `export` command:

```
$ NNTPSERVER=news.abigisp.com
$ export NNTPSERVER
```

You can combine these two commands into a single form:

```
$ export NNTPSERVER=news.abigisp.com
```

Either method sets the `$NNTPSERVER` environment variable to `news.abigisp.com`. (When setting an environment variable, you omit the dollar sign, but subsequent references include a dollar sign to identify the environment variable as such.) Thereafter, programs that need this information can refer to the environment variable. In fact, you can do so from the shell yourself, using the `echo` command:

```
$ echo $NNTPSERVER
news.abigisp.com
```

You can also view the entire environment by typing `env`. The result is likely to be several dozen lines of environment variables and their values. Chapter 9 describes what many of these variables are in more detail.

To delete an environment variable, use the `unset` command, which takes the name of an environment variable (without the leading `$` symbol) as an option. For instance, `unset NNTPSERVER` removes the `$NNTPSERVER` environment variable.

Getting Help

Linux provides a text-based help system known as `man`. This command's name is short for *manual*, and its entries (its `man` pages) provide succinct summaries of what a command, file, or other feature does. For instance, to learn about `man` itself, you can type `man man`. The result is a description of the `man` command.

The `man` utility uses the `less` pager to display information. This program displays text a page at a time. Press the spacebar to move forward a page, `Esc` followed by `V` to move back a page, the arrow keys to move up or down a line at a time, the slash (`/`) key to search for text, and so on. (Type `man less` to learn all the details, or consult the upcoming section “Paging Through Files with `less`.”) When you're done, press `Q` to exit `less` and the `man` page it's displaying.

Linux `man` pages are categorized into several sections, which are summarized in Table 1.1. Sometimes a single keyword has entries in multiple sections; for instance, `passwd` has entries under both section 1 and section 5. In most cases, `man` returns the entry in the lowest-numbered section; but you can force the issue by preceding the keyword by the section number. For instance, typing `man 5 passwd` returns information on the `passwd` file format rather than the `passwd` command.

TABLE 1.1 Manual Sections

Section Number	Description
1	Executable programs and shell commands
2	System calls provided by the kernel
3	Library calls provided by program libraries
4	Device files (usually stored in /dev)
5	File formats
6	Games
7	Miscellaneous (macro packages, conventions, and so on)
8	System administration commands (programs run mostly or exclusively by root)
9	Kernel routines

Some programs have moved away from `man` pages to `info` pages. The basic purpose of `info` pages is the same as that for `man` pages, but `info` pages use a hypertext format so that you can move from section to section of the documentation for a program. Type **info info** to learn more about this system.

Both `man` pages and `info` pages are usually written in a terse style. They're intended as reference tools, not tutorials; they frequently assume basic familiarity with the command, or at least with Linux generally. For more tutorial information, you must look elsewhere, such as this book or the Web. The Linux Documentation Project (<http://tldp.org>) is a particularly relevant Web-based resource for learning about various Linux topics.

Using Streams, Redirection, and Pipes

Streams, *redirection*, and *pipes* are some of the more powerful command-line tools in Linux. Linux treats the input to and output from programs as a stream, which is a data entity that can be manipulated. Ordinarily, input comes from the keyboard and output goes to the screen (which in this context can mean a full-screen text-mode login session, an `xterm` or a similar window, or the screen of a remote computer via a remote login session). You can redirect these input and output streams to come from or go to other sources, though, such as files. Similarly, you can pipe the output of one program into another program. These facilities can be great tools to tie together multiple programs.



Part of the Unix philosophy to which Linux adheres is, whenever possible, to do complex things by combining multiple simple tools. Redirection and pipes help in this task by enabling simple programs to be combined together in chains, each link feeding off the output of the preceding link.

Exploring Types of Streams

To begin understanding redirection and pipes, you must first understand the different types of input and output streams. Three are most important for this topic:

Standard input Programs accept keyboard input via *standard input*, or `stdin`. In most cases, this is the data that comes into the computer from a keyboard.

Standard output Text-mode programs send most data to their users via *standard output* (a.k.a. `stdout`), which is normally displayed on the screen, either in a full-screen text-mode session or in a GUI window such as an `xterm`. (Fully GUI programs such as GUI word processors don't use standard output for their regular interactions, although they might use standard output to display messages in the `xterm` from which they were launched. GUI output isn't handled via an output stream in the sense I'm describing here.)

Standard error Linux provides a second type of output stream, known as *standard error*, or `stderr`. This output stream is intended to carry high-priority information such as error messages. Ordinarily, standard error is sent to the same output device as standard output, so you can't easily tell them apart. You can redirect one independently of the other, though, which can be handy. For instance, you can redirect standard error to a file while leaving standard output going to the screen so that you can interact with the program and then study the error messages later.

Internally, programs treat these streams just like data files—they open them, read from or write to the files, and close them when they're done. Put another way, ordinary files are streams from a program's point of view. These streams just happen to be the ones used to interact with users.

Redirecting Input and Output

To redirect input or output, you use symbols following the command, including any options it takes. For instance, to redirect the output of the `echo` command, you would type something like this:

```
$ echo $NNTPSERVER > nntpserver.txt
```

The result is that the file `nntpserver.txt` contains the output of the command (in this case, the value of the `$NNTPSERVER` environment variable). Redirection operators exist to achieve several effects, as summarized in Table 1.2.

TABLE 1.2 Common Redirection Operators

Redirection Operator	Effect
>	Creates a new file containing standard output. If the specified file exists, it's overwritten.
>>	Appends standard output to the existing file. If the specified file doesn't exist, it's created.
2>	Creates a new file containing standard error. If the specified file exists, it's overwritten.
2>>	Appends standard error to the existing file. If the specified file doesn't exist, it's created.
&>	Creates a new file containing both standard output and standard error. If the specified file exists, it's overwritten.
<	Sends the contents of the specified file to be used as standard input.
<<	Accepts text on the following lines as standard input.
<>	Causes the specified file to be used for both standard input and standard output.

Most of these redirectors deal with output, both because there are two types of output (standard output and standard error) and because you must be concerned with what to do in case you specify a file that already exists. The most important input redirector is <, which takes the specified file's contents as standard input.



A common trick is to redirect standard output or standard error to `/dev/null`. This file is a device that's connected to nothing; it's used when you want to get rid of data. For instance, if the `whine` program is generating too many error messages, you can type `whine 2> /dev/null` to run it and discard its error messages.

One redirection operator that requires elaboration is <<. This operator implements a *here document*, which takes text from the following lines as standard input. Chances are you won't use this redirector on the command line, though; the following lines *are* standard input, so there's no need to redirect them. Rather, you might use this command as part of a script in order to pass data to a command. Unlike most redirection operators, the text immediately following the << code isn't a filename; instead, it's a word that's used to mark

the end of input. For instance, typing **someprog << EOF** causes **someprog** to accept input until it sees a line that contains *only* the string EOF (without even a space following it).



Some programs that take input from the command line expect you to terminate input by pressing Ctrl+D. This keystroke corresponds to an end-of-file marker using the American Standard Code for Information Interchange (ASCII).

A final redirection tool is the **tee** command. This command splits standard input so that it's displayed on standard output and on as many files as you specify. Typically, **tee** is used in conjunction with data pipes so that a program's output can be both stored and viewed immediately. For instance, to view and store the output of **someprog**, you might type this:

```
$ someprog | tee output.txt
```



The vertical bar (|) is the pipe character. It implements a pipe, as described in the next section.

Ordinarily, **tee** overwrites any files whose names you specify. If you want to append data to these files, pass the **-a** option to **tee**.

Piping Data Between Programs

Programs can frequently operate on other programs' outputs. For instance, you might use a text-filtering command (such as the ones described shortly, in "Processing Text Using Filters") to manipulate text output by another program. You can do this with the help of redirection operators; send the first program's standard output to a file, and then redirect the second program's standard input to read from that file. This solution is awkward, though, and it involves the creation of a file that you might easily overlook, leading to unnecessary clutter on your system.

The solution is to use data pipes (a.k.a. pipelines). A pipe redirects the first program's standard output to the second program's standard input and is denoted by a vertical bar (|):

```
$ first | second
```

For instance, suppose that **first** generates some system statistics, such as system uptime, CPU use, number of users logged in, and so on. This output might be lengthy, so you want to trim it a bit. You might therefore use **second**, which could be a script or command that echoes from its standard input only the information in which you're interested. (The **grep** command, described in "Using *grep*," is often used in this role.)

Pipes can be used in sequences of arbitrary length:

```
$ first | second | third | fourth | fifth | sixth [...]
```

Generating Command Lines

Sometimes you'll find yourself constructing a series of commands that are similar to each other but not similar enough to enable you to use their normal options to substitute a single command. For instance, suppose you want to remove every file in a directory tree with a name that ends in a tilde (~). (This filename convention denotes backup files created by certain text editors.) With a large directory tree, this task can be daunting; the usual file-deletion command (`rm`, described in more detail in Chapter 4) doesn't provide an option to search for and delete every file in a directory tree that matches such a specific criterion. One command that can do the search part of the job, though, is `find`, which is also described in more detail in Chapter 4. This command displays all the files that match criteria you provide. If you could combine the output of `find` to create a series of command lines using `rm`, the task would be solved. This is precisely the purpose of the `xargs` command.

The `xargs` command builds a command from its standard input. The basic syntax for this command is as follows:

```
xargs [options] [command [initial-arguments]]
```

The *command* is the command you want to execute, and *initial-arguments* is a list of arguments you want to pass to the command. The *options* are `xargs` options; they aren't passed to *command*. When you run `xargs`, it runs *command* once for every word passed to it on standard input, adding that word to the argument list for *command*. If you want to pass multiple options to the command, you can protect them by enclosing the group in quotation marks.

For instance, consider the task of deleting all those backup files, denoted by tilde characters. You can do this by piping the output of `find` to `xargs`, which then calls `rm`:

```
$ find ./ -name "*~" | xargs rm
```

The first part of this command (`find ./ -name "*~"`) finds all the files in the current directory (`./`) or its subdirectories with a name that ends in a tilde (`*~`). This list is then piped to `xargs`, which adds each one to its own `rm` command.

A tool that's similar to `xargs` in many ways is the backtick (`), which is a character to the left of the 1 key on most keyboards. The backtick is *not* the same as the single quote character ('), which is located to the right of the semicolon (;) on most keyboards.

Text within backticks is treated as a separate command whose results are substituted on the command line. For instance, to delete those backup files, you can type the following command:

```
$ rm `find ./ -name "*~"`
```

Processing Text Using Filters

In keeping with Linux's philosophy of providing small tools that can be tied together via pipes and redirection to accomplish more complex tasks, many simple commands to manipulate text are available. These commands accomplish tasks of various types, such as combining files, transforming the data in files, formatting text, displaying text, and summarizing data.



Many of the following descriptions include input-file specifications. In most cases, you can omit these input-file specifications, in which case the utility reads from standard input instead.

File-Combining Commands

The first group of text-filtering commands are those used to combine two or more files into one file. Three important commands in this category are `cat`, `join`, and `paste`, which join files end to end, based on fields in the file, or by merging on a line-by-line basis, respectively.

Combining Files with `cat`

The `cat` command's name is short for *concatenate*, and this tool does just that: It links together an arbitrary number of files end to end and sends the result to standard output. By combining `cat` with output redirection, you can quickly combine two files into one:

```
$ cat first.txt second.txt > combined.txt
```

Although `cat` is officially a tool for combining files, it's also commonly used to display the contents of a short file. If you type only one filename as an option, `cat` displays that file. This is a great way to review short files; but for long files, you're better off using a full-fledged pager command, such as `more` or `less`.

You can add options to have `cat` perform minor modifications to the files as it combines them:

Display line ends If you want to see where lines end, add the `-E` or `--show-ends` option. The result is a dollar sign (\$) at the end of each line.

Number lines The `-n` or `--number` option adds line numbers to the beginning of every line. The `-b` or `--number-nonblank` option is similar, but it numbers only lines that contain text.

Minimize blank lines The `-s` or `--squeeze-blank` option compresses groups of blank lines down to a single blank line.

Display special characters The `-T` or `--show-tabs` option displays tab characters as `^I`. The `-v` or `--show-nonprinting` option displays most control and other special characters using carat (^) and M- notations.

The `tac` command is similar to `cat`, but it reverses the order of lines in the output.

Joining Files by Field with `join`

The `join` command combines two files by matching the contents of specified fields within the files. Fields are typically space-separated entries on a line, although you can specify another character as the field separator with the `-t char` option, where `char` is the character you want to use. You can cause `join` to ignore case when performing comparisons by using the `-i` option.

The effect of `join` may best be understood through a demonstration. Consider Listings 1.1 and 1.2, which contain data on telephone numbers—Listing 1.1 shows the names associated with those numbers, and Listing 1.2 shows whether the numbers are listed or unlisted.

Listing 1.1: Demonstration File Containing Telephone Numbers and Names

```
555-2397 Beckett, Barry
555-5116 Carter, Gertrude
555-7929 Jones, Theresa
555-9871 Orwell, Samuel
```

Listing 1.2: Demonstration File Containing Telephone Number Listing Status

```
555-2397 unlisted
555-5116 listed
555-7929 listed
555-9871 unlisted
```

You can display the contents of both files using `join`:

```
$ join listing1.1.txt listing1.2.txt
555-2397 Beckett, Barry unlisted
555-5116 Carter, Gertrude listed
555-7929 Jones, Theresa listed
555-9871 Orwell, Samuel unlisted
```

By default, `join` uses the first field as the one to match across files. Because Listings 1.1 and 1.2 both place the phone number in this field, it's the key field in the output. You can specify another field by using the `-1` or `-2` option to specify the join field for the first or second file, respectively, as in `join -1 3 -2 2 cameras.txt lenses.txt` to join using the third field in `cameras.txt` and the second field in `lenses.txt`. The `-o FORMAT` option enables more complex specifications for the output file's format; consult the man page for `join` for more details.

The `join` command can be used at the core of a set of simple customized database-manipulation tools using Linux text-manipulation commands. It's very limited by itself, though; for instance, it requires its two files to have the same ordering of lines. (You can use the `sort` command to ensure this is so.)

Merging Lines with *paste*

The `paste` command merges files line by line, separating the lines from each file with tabs, as shown in the following example, using Listings 1.1 and 1.2 again:

```
$ paste listing1.1.txt listing1.2.txt
555-2397 Beckett, Barry 555-2397 unlisted
555-5116 Carter, Gertrude      555-5116 listed
555-7929 Jones, Theresa 555-7929 listed
555-9871 Orwell, Samuel 555-9871 unlisted
```

You can use `paste` to combine data from files that aren't keyed with fields suitable for use by `join`. Of course, to be meaningful, the files' line numbers must be exactly equivalent. Alternatively, you can use `paste` as a quick way to create a two-column output of textual data; however, the alignment of the second column may not be exact if the first column's line lengths aren't exactly even, as shown in the preceding example.

File-Transforming Commands

Many of Linux's text-manipulation commands are aimed at transforming the contents of files. These commands don't actually change files' contents, though; rather, they send the changed file to standard output. You can then pipe this output to another command or redirect it into a new file.



An important file-transforming command is `sed`. This command is very complex and is covered later in this chapter, in "Using `sed`."

Converting Tabs to Spaces with `expand`

Sometimes text files contain tabs but programs that need to process the files don't cope well with tabs; or perhaps you want to edit a text file in an editor that uses a different amount of horizontal space for the tab than the editor that created the file. In such cases, you may want to convert tabs to spaces. The `expand` command does this.

By default, `expand` assumes a tab stop every eight characters. You can change this spacing with the `-t num` or `--tabs=num` option, where `num` is the tab spacing value.

Displaying Files in Octal with `od`

Some files aren't easily displayed in ASCII; most graphics files, audio files, and so on, use non-ASCII characters that look like gibberish. Worse, these characters can do strange things to your display if you try to view such a file with `cat` or a similar tool. For instance, your font may change, or your console may begin beeping uncontrollably. Nonetheless, you may sometimes want to display such files, particularly if you want to investigate the structure of a data file. You may also want to look at an ASCII file in a way that eliminates certain ambiguities, such as whether a gap between words is a tab or several spaces. In such cases, `od` (whose name stands for *octal dump*) can help. It displays a file in an unambiguous format—octal (base 8) numbers by default. For instance, consider Listing 1.2 as parsed by `od`:

```
$ od Listing1.2.txt
```

```
0000000 032465 026465 031462 033471 072440 066156 071551 062564
0000020 005144 032465 026465 030465 033061 066040 071551 062564
0000040 005144 032465 026465 034467 034462 066040 071551 062564
0000060 005144 032465 026465 034071 030467 072440 066156 071551
0000100 062564 005144
0000104
```


The first field on each line is an index into the file in octal. For instance, the second line begins at octal 20 (16 in base 10) bytes into the file. The remaining numbers on each line represent the bytes in the file. This type of output can be difficult to interpret unless you're well versed in octal notation and perhaps in the ASCII code.

Although `od` is nominally a tool for generating octal output, it can generate many other output formats, such as hexadecimal (base 16), decimal (base 10), and even ASCII with escaped control characters. Consult the man page for `od` for details on creating these variants.

Sorting Files with *sort*

Sometimes you'll create an output file that you want sorted. To do so, you can use a command that's called, appropriately enough, `sort`. This command can sort in several ways, including the following:

Ignore case Ordinarily, `sort` sorts by ASCII value, which differentiates between uppercase and lowercase letters. The `-f` or `--ignore-case` option causes `sort` to ignore case.

Month sort The `-M` or `--month-sort` option causes the program to sort by three-letter month abbreviation (JAN through DEC).

Numeric sort You can sort by number by using the `-n` or `--numeric-sort` option.

Reverse sort order The `-r` or `--reverse` option sorts in reverse order.

Sort field By default, `sort` uses the first field as its sort field. You can specify another field with the `-k field` or `--key=field` option. (The *field* can be two numbered fields separated by commas, to sort on multiple fields.)

As an example, suppose you wanted to sort Listing 1.1 by first name. You could do so like this:

```
$ sort -k 3 listing1.1.txt
555-2397 Beckett, Barry
555-5116 Carter, Gertrude
555-9871 Orwell, Samuel
555-7929 Jones, Theresa
```

The `sort` command supports a large number of additional options, many of them quite exotic. Consult `sort`'s man page for details.

Breaking a File into Pieces with *split*

The `split` command can split a file into two or more files. Unlike most of the text-manipulation commands described in this chapter, this command requires you to enter an output filename—or more precisely, an output filename prefix, to which is added an alphabetic code. You must also normally specify how large you want the individual files to be:

Split by bytes The `-b size` or `--bytes=size` option breaks the input file into pieces of *size* bytes. This option can have the usually undesirable consequence of splitting the file mid-line.

Split by bytes in line-sized chunks You can break a file into files of no more than a specified size without breaking lines across files by using the `-C=size` or `--line-bytes=size` option. (Lines will still be broken across files if the line length is greater than *size*.)

Split by number of lines The `-l lines` or `--lines=lines` option splits the file into chunks with no more than the specified number of lines.

As an example, consider breaking Listing 1.1 into two parts by number of lines:

```
$ split -l 2 listing1.1.txt numbers
```

The result is two files, `numbersaa` and `numbersab`, that together hold the original contents of `listing1.1.txt`.

Translating Characters with *tr*

The `tr` command changes individual characters from standard input. Its syntax is as follows:

```
tr [options] SET1 [SET2]
```

You specify the characters you want replaced in a group (*SET1*) and the characters with which you want them to be replaced as a second group (*SET2*). Each character in *SET1* is replaced with the one at the equivalent position in *SET2*. Here's an example using Listing 1.1:

```
$ tr BCJ bc < listing1.1.txt
555-2397 beckett, barry
555-5116 carter, Gertrude
555-7929 cones, Theresa
555-9871 Orwell, Samuel
```

This example translates some, but not all, of the uppercase characters to lowercase. Note that *SET2* in this example was shorter than *SET1*. The result is that `tr` substitutes the last available letter from *SET2* for the missing letters. In this example, the `J` in Jones became a `c`. The `-t` or `--truncate-set1` option causes `tr` to truncate *SET1* to the size of *SET2* instead.

Another `tr` option is `-d`, which causes the program to delete the characters from *SET1*. When using `-d`, you can omit *SET2* entirely.

The `tr` command also accepts a number of shortcuts, such as `[:alnum:]` (all numbers and letters), `[:upper:]` (all uppercase letters), `[:lower:]` (all lowercase letters), and `[:digit:]` (all digits). You can specify a range of characters by separating them with dashes (`-`), as in `A-M` for characters between `A` and `M`, inclusive. Consult `tr`'s man page for a complete list of these shortcuts.

Converting Spaces to Tabs with *unexpand*

The `unexpand` command is the logical opposite of `expand`; it converts multiple spaces to tabs. This can help compress the size of files that contain many spaces and can be helpful if a file is to be processed by a utility that expects tabs in certain locations.

Like `expand`, `unexpand` accepts the `-t num` or `--tabs=num` option, which sets the tab spacing to once every *num* characters. If you omit this option, `unexpand` assumes a tab stop every eight characters.

Deleting Duplicate Lines with *uniq*

The `uniq` command removes duplicate lines. It's most likely to be useful if you've sorted a file and don't want duplicate items. For instance, suppose you want to summarize Shakespeare's vocabulary. You might create a file with all of the Bard's works, one word per line. You can then sort this file using `sort` and pass it through `uniq`. Using a shorter example file containing the text to be or not to be, that is the question (one word per line), the result looks like this:

```
$ sort shakespeare.txt | uniq
be
is
not
or
question
that
the
to
```

Note that the words `to` and `be`, which appeared in the original file twice, appear only once in the `uniq`-processed version.

File-Formatting Commands

The next three commands—`fmt`, `n1`, and `pr`—reformat the text in a file. The first of these is designed to reformat text files, such as if a program's `README` documentation file uses lines that are too long for your display. The `n1` command numbers the lines of a file, which can be helpful in referring to lines in documentation or correspondence. Finally, `pr` is a print-processing tool; it formats a document in pages suitable for printing.

Reformatting Paragraphs with *fmt*

Sometimes text files arrive with outrageously long line lengths, irregular line lengths, or other problems. Depending on the problem, you may be able to cope simply by using an appropriate text editor or viewer to read the file. If you want to clean up the file a bit, though, you can do so with `fmt`. If called with no options (other than the input filename, if you're not having it work on standard input), the program attempts to clean up paragraphs, which it assumes are delimited by two or more blank lines or by changes in indentation. The new paragraph formatting defaults to no more than 75 characters wide. You can change this with the `-width`, `-w width`, or `--width=width` options, which set the line length to *width* characters.

Numbering Lines with *n1*

As described earlier, in “Combining Files with *cat*,” you can number the lines of a file with that command. The *cat* line-numbering options are limited, though, so if you need to do complex line numbering, *n1* is the tool to use. In its simplest case, you can use *n1* alone to accomplish much the same goal as *cat -b* achieves: numbering all the non-blank lines in a file. You can add many options to *n1* to achieve various special effects:

Body numbering style You can set the numbering style for the bulk of the lines with the *-b style* or *--body-numbering=style* option, where *style* is a style format code, described shortly.

Header and footer numbering style If the text is formatted for printing and has headers or footers, you can set the style for these elements with the *-h style* or *--header-numbering=style* option for the header and *-f style* or *--footer-numbering=style* option for the footer.

Page separator Some numbering schemes reset the line numbers for each page. You can tell *n1* how to identify a new page with the *-d=code* or *--section-delimiter=code* option, where *code* is a code for the character that identifies the new page.

Line-number options for new pages Ordinarily, *n1* begins numbering each new page with line 1. If you pass the *-p* or *--no-renumber* option, though, it doesn’t reset the line number with a new page.

Number format You can specify the numbering format with the *-n format* or *--number-format=format* option, where *format* is *ln* (left justified, no leading zeros), *rn* (right justified, no leading zeros), or *rz* (right justified with leading zeros).

The body, header, and footer options enable you to specify a numbering style for each of these page elements:

Number only non-blank lines The default behavior is to number lines that aren’t empty. This corresponds to a *style* of *t*.

Number all lines If you want empty lines to be numbered, specify a *style* of *a*.

Number no lines To omit line numbers (say, for headers or footers), specify a *style* of *n*.

Number lines matching a regular expression A *style* of *pREGEXP* numbers only those lines that match the regular expression *REGEXP*. (Regular expressions are described later, in “Using Regular Expressions.”)

As an example, suppose you’ve created a script, *buggy*, but you find that it’s not working as you expect. When you run it, you get error messages that refer to line numbers, so you want to create a version of the script with lines that are numbered for easy reference. You can do so by calling *n1* with the option to number blank lines (*-b a*):

```
$ n1 -b a buggy > numbered-buggy.txt
```



Because the input file doesn’t have any explicit page delimiters, the output will be numbered in a single sequence; *n1* doesn’t try to impose its own page-length limits.

The `numbered-buggy.txt` file created by this command isn't useful as a script because of the line numbers that begin each line. You can, however, load it into a text editor or display it with a pager such as `less` to view the text and see the line numbers along with the commands they contain.

Preparing a File for Printing with `pr`

If you want to print a plain-text file, you may want to prepare it with headers, footers, page breaks, and so on. The `pr` command was designed to do this. In its most basic form, you pass the command a file:

```
$ pr myfile.txt
```

The result is text formatted for printing on a line printer—that is, `pr` assumes an 80-character line length in a monospaced font. Of course, you can also use `pr` in a pipe, either to accept input piped from another program or to pipe its output to another program. (The recipient program might be `lpr`, which is used to print files, as described in Chapter 6, “Configuring the X Window System, Localization, and Printing.”)

By default, `pr` creates output that includes the original text with headers that include the current date and time, the original filename, and the page number. You can tweak the output format in a variety of ways, including the following:

Generate multi-column output Passing the `-numcols` or `--columns=numcols` option creates output with `numcols` columns. Note that `pr` doesn't reformat text; if lines are too long, they're truncated or run over onto multiple columns.

Generate double-spaced output The `-d` or `--double-space` option causes double-spaced output from a single-spaced file.

Use form feeds Ordinarily, `pr` separates pages by using a fixed number of blank lines. This works fine if your printer uses the same number of lines that `pr` expects. If you have problems with this issue, you can pass the `-F`, `-f`, or `--form-feed` option, which causes `pr` to output a form-feed character between pages. This works better with some printers.

Set page length The `-l lines` or `--length=lines` option sets the length of the page in lines.

Set the header text The `-h text` or `--header=text` option sets the text to be displayed in the header, replacing the filename. To specify a multi-word string, enclose it in quotes, as in `--header="My File"`. The `-t` or `--omit-header` option omits the header entirely.

Set left margin and page width The `-o chars` or `--indent=chars` option sets the left margin to `chars` characters. This margin size is added to the page width, which defaults to 72 characters and can be explicitly set with the `-w chars` or `--width chars` option.

These options are just the beginning; `pr` supports many more, which are described in its man page. As an example of `pr` in action, consider printing a double-spaced and numbered version of a configuration file (say, `/etc/profile`) for your reference. You can do this by piping together `cat` and its `-n` option to generate a numbered output, `pr` and its `-d` option to double-space the result, and `lpr` to print the file:

```
$ cat -n /etc/profile | pr -d | lpr
```

The result should be a printout that might be handy for taking notes on the configuration file. One caveat, though: If the file contains lines that approach or exceed 80 characters in length, the result can be single lines that spill across two lines. The result will be disrupted page boundaries. As a workaround, you can set a somewhat short page length with `-l` and use `-f` to ensure that the printer receives form feeds after each page:

```
$ cat -n /etc/profile | pr -df1 50 | lpr
```



The `pr` command is built around assumptions about printer capabilities that were reasonable in the early 1980s. It's still useful today, but you might prefer to look into GNU Enscript (<http://www.codento.com/people/mtr/genscript/>). This program has many of the same features as `pr`, but it generates PostScript output that can take better advantage of modern printer features.

File-Viewing Commands

Sometimes you just want to view a file or part of a file. A few commands can help you accomplish this goal without loading the file into a full-fledged editor.



As described earlier, the `cat` command is also handy for viewing short files.

Viewing the Starts of Files with *head*

Sometimes all you need to do is see the first few lines of a file. This may be enough to identify what a mystery file is, for instance; or you may want to see the first few entries of a log file to determine when that file was started. You can accomplish this goal with the `head` command, which echoes the first 10 lines of one or more files to standard output. (If you specify multiple filenames, each one's output is preceded by a header to identify it.) You can modify the amount of information displayed by `head` in two ways:

Specify the number of bytes The `-c num` or `--bytes=num` option tells `head` to display *num* bytes from the file rather than the default 10 lines.

Specify the number of lines You can change the number of lines displayed with the `-n num` or `--lines=num` option.

Viewing the Ends of Files with *tail*

The `tail` command works just like `head`, except that `tail` displays the *last* 10 lines of a file. (You can use the `-c/--bytes` and `-n/--lines` options to change the amount of data displayed, just as with `head`.) This command is useful for examining recent activity in log files or other files to which data may be appended.

The `tail` command supports several options that aren't present in `head` and that enable the program to handle additional duties, including the following:

Track a file The `-f` or `--follow` option tells `tail` to keep the file open and to display new lines as they're added. This feature is helpful for tracking log files because it enables you to see changes as they're added to the file.

Stop tracking on program termination The `--pid=pid` option tells `tail` to terminate tracking (as initiated by `-f` or `--follow`) once the process with a process ID (PID) of *pid* terminates. (PIDs are described in more detail in Chapter 2, "Managing Software.")

Some additional options provide more obscure capabilities. Consult `tail`'s man page for details.

Paging Through Files with *less*

The `less` command's name is a joke; it's a reference to the `more` command, which was an early file pager. The idea was to create a better version of `more`, so the developers called it `less`.

The idea behind `less` (and `more`, for that matter) is to enable you to read a file a screen at a time. When you type `less filename`, the program displays the first few lines of *filename*. You can then page back and forth through the file:

- Pressing the spacebar moves forward through the file a screen at a time.
- Pressing Esc followed by V moves backward through the file a screen at a time.
- The Up and Down arrow keys move up or down through the file a line at a time.
- You can search the file's contents by pressing the slash (/) key followed by the search term. For instance, typing `/portable` finds the first occurrence of the string `portable` after the current position. Typing a slash followed by the Enter key moves to the next occurrence of the search term. Typing `n` alone repeats the search forward, while typing `N` alone repeats the search backward.
- You can search backward in the file by using the question mark (?) key rather than the slash key.
- You can move to a specific line by typing `g` followed by the line number, as in `g50` to go to line 50.
- When you're done, type `q` to exit from the program.

Unlike most of the programs described here, `less` can't be readily used in a pipe, except as the final command in the pipe. In that role, though, `less` is very useful because it enables you to readily examine lengthy output.



Although `less` is quite common on Linux systems and is typically configured as the default text pager, some Unix-like systems use `more` in this role. Many of `less`'s features, such as the ability to page backward in a file, don't work in `more`.

One additional `less` feature can be handy: Typing `h` displays `less`'s internal help system. This display summarizes the commands you may use, but it's long enough that you must use the usual `less` paging features to view it all! When you're done with the help screens, type `q`, just as if you were exiting from viewing a help document with `less`. This action will return you to your original document.

File-Summarizing Commands

The final text-filtering commands I describe are used to summarize text in one way or another. The `cut` command takes segments of an input file and sends them to standard output, while the `wc` command displays some basic statistics on the file.

Extracting Text with `cut`

The `cut` command extracts portions of input lines and displays them on standard output. You can specify what to cut from input lines in several ways:

By byte The `-b list` or `--bytes=list` option cuts the specified list of bytes from the input file. (The format of a *list* is described shortly.)

By character The `-c list` or `--characters=list` option cuts the specified list of characters from the input file. In practice, this method and the by-byte method usually produce identical results. (If the input file uses a multi-byte encoding system, though, the results won't be identical.)

By field The `-f list` or `--fields=list` option cuts the specified list of fields from the input file. By default, a field is a tab-delimited section of a line, but you can change the delimiting character with the `-d char`, `--delim=char`, or `--delimiter=char` option option, where *char* is the character you want to use to delimit fields. Ordinarily, `cut` echoes lines that don't contain delimiters. Including the `-s` or `--only-delimited` option changes this behavior so that the program doesn't echo lines that don't contain the delimiter character.

Many of these options take a *list*, which is a way to specify multiple bytes, characters, or fields. You make this specification by number; it can be a single number (such as 4), a closed range of numbers (such as 2-4), or an open range of numbers (such as -4 or 4-). In this final case, all bytes, characters, or fields from the beginning of the line to the specified number or from the specified number to the end of the line are included in the list.

The `cut` command is frequently used in scripts to extract data from some other command's output. For instance, suppose you're writing a script and the script needs to know the hardware address of your Ethernet adapter. This information can be obtained from the `ifconfig` command (described in more detail in Chapter 8, "Configuring Basic Networking"):

\$ `ifconfig eth0`

```
eth0      Link encap:Ethernet  HWaddr 00:0C:76:96:A3:73
          inet addr:192.168.1.3  Bcast:192.168.1.255  Mask:255.255.255.0
          inet6 addr: fe80::20c:76ff:fe96:a373/64  Scope:Link
          UP BROADCAST NOTRAILERS RUNNING MULTICAST  MTU:1500  Metric:1
```



```
RX packets:7127424 errors:0 dropped:0 overruns:0 frame:0
TX packets:5273519 errors:0 dropped:0 overruns:0 carrier:0
collisions:0 txqueuelen:1000
RX bytes:6272843708 (5982.2 Mb) TX bytes:1082453585 (1032.3 Mb)
Interrupt:10 Base address:0xde00
```

Unfortunately, most of this information is extraneous for the desired purpose. The hardware address is the 6-byte hexadecimal number following `HWaddr`. To extract that data, you can combine `grep` (described shortly, in “Using *grep*”) with `cut` in a pipe:

```
$ ifconfig eth0 | grep HWaddr | cut -d " " -f 11
00:0C:76:96:A3:73
```

Of course, in a script you would probably assign this value to a variable or otherwise process it through additional pipes. Chapter 9 describes scripts in more detail.

Obtaining a Word Count with *wc*

The `wc` command produces a word count (that’s where it gets its name), as well as line and byte counts, for a file:

```
$ wc file.txt
 308  2343 15534 file.txt
```

This file contains 308 lines (or, more precisely, 308 newline characters); 2,343 words; and 15,534 bytes. You can limit the output to the newline count, the word count, the byte count, or a character count with the `--lines (-l)`, `--words (-w)`, `--bytes (-c)`, or `--chars (-m)` option, respectively. You can also learn the maximum line length with the `--max-line-length (-L)` option.



For an ordinary ASCII file, the character and byte counts will be identical. These values may diverge for files that use multi-byte character encodings.

Using Regular Expressions

Many Linux programs employ *regular expressions*, which are tools for expressing patterns in text. Regular expressions are similar in principle to the wildcards that can be used to specify multiple filenames. At their simplest, regular expressions can be plain text without adornment. Certain characters are used to denote patterns, though. Because of their importance, I describe regular expressions here. I also cover two programs that make heavy use of regular expressions: `grep` and `sed`. These programs search for text within files and permit editing of files from the command line, respectively.

Understanding Regular Expressions

Two forms of regular expression are common: basic and extended. Which form you must use depends on the program; some accept one form or the other, but others can use either type, depending on the options passed to the program. (Some programs use their own minor or major variants on either of these classes of regular expression.) The differences between basic and extended regular expressions are complex and subtle, but the fundamental principles of both are similar.

The simplest type of regular expression is an alphabetic string, such as `Linux` or `HWaddr`. These regular expressions match any string of the same size or longer that contains the regular expression. For instance, the `HWaddr` regular expression matches `HWaddr`, `This is the HWaddr`, and `The HWaddr is unknown`. The real strength of regular expressions comes in the use of non-alphabetic characters, which activate advanced matching rules:

Bracket expressions Characters enclosed in square brackets (`[]`) constitute bracket expressions, which match any one character within the brackets. For instance, the regular expression `b[aeiou]g` matches the words `bag`, `beg`, `big`, `bog`, and `bug`.

Range expressions A range expression is a variant on a bracket expression. Instead of listing every character that matches, range expressions list the start and end points separated by a dash (`-`), as in `a[2-4]z`. This regular expression matches `a2z`, `a3z`, and `a4z`.

Any single character The dot (`.`) represents any single character except a newline. For instance, `a.z` matches `a2z`, `abz`, `aQz`, or any other three-character string that begins with `a` and ends with `z`.

Start and end of line The caret (`^`) represents the start of a line, and the dollar sign (`$`) denotes the end of a line.

Repetition operators A full or partial regular expression may be followed by a special symbol to denote how many times a matching item must exist. Specifically, an asterisk (`*`) denotes zero or more occurrences, a plus sign (`+`) matches one or more occurrences, and a question mark (`?`) specifies zero or one match. The asterisk is often combined with the dot (as in `.*`) to specify a match with any substring. For instance, `A.*Lincoln` matches any string that contains `A` and `Lincoln`, in that order—`Abe Lincoln` and `Abraham Lincoln` are just two possible matches.

Multiple possible strings The vertical bar (`|`) separates two possible matches; for instance, `car|truck` matches either `car` or `truck`.

Parentheses Ordinary parentheses (`()`) surround subexpressions. Parentheses are often used to specify how operators are to be applied; for example, you can put parentheses around a group of words that are concatenated with the vertical bar, to ensure that the words are treated as a group, any one of which may match, without involving surrounding parts of the regular expression.

Escaping If you want to match one of the special characters, such as a dot, you must *escape* it—that is, precede it with a backslash (`\`). For instance, to match a computer host-name (say, `twain.example.com`), you must escape the dots, as in `twain\.example\.com`.

The preceding descriptions apply to extended regular expressions. Some details are different for basic regular expressions. In particular, the `?`, `+`, `|`, `(`, and `)` symbols lose their special meanings. To perform the tasks handled by these characters, some programs, such as `grep`, enable you to recover the functions of these characters by escaping them (say, using `\|` instead of `|`). Whether you use basic or extended regular expressions depends on which form the program supports. For programs, such as `grep`, that support both, you can use either; which you choose is mostly a matter of personal preference.

Regular expression rules can be confusing, particularly when you're first introduced to them. Some examples of their use, in the context of the programs that use them, will help. The next couple of sections provide such examples.

Using *grep*

The `grep` command is extremely useful. It searches for files that contain a specified string and returns the name of the file and (if it's a text file) a line of context for that string. The basic `grep` syntax is as follows:

```
grep [options] regexp [files]
```

The *regexp* is a regular expression, as just described. The `grep` command supports a large number of options. Some of the more common options enable you to modify the way the program searches files:

Count matching lines Instead of displaying context lines, `grep` displays the number of lines that match the specified pattern if you use the `-c` or `--count` option.

Specify a pattern input file The `-f file` or `--file=file` option takes pattern input from the specified file rather than from the command line.

Ignore case You can perform a case-insensitive search, rather than the default case-sensitive search, by using the `-i` or `--ignore-case` option.

Search recursively The `-r` or `--recursive` option searches in the specified directory and all subdirectories rather than simply the specified directory. You can use `rgrep` rather than specify this option.

Use an extended regular expression The `grep` command interprets *regexp* as a basic regular expression by default. To use an extended regular expression, you can pass the `-E` or `--extended-regexp` option. Alternatively, you can call `egrep` rather than `grep`; this variant command uses extended regular expressions by default.

A simple example of `grep` uses a regular expression with no special components:

```
$ grep -r eth0 /etc/*
```

This example finds all the files in `/etc` that contain the string `eth0` (the identifier for the first Ethernet device). Because the example includes the `-r` option, it searches recursively, so files in subdirectories of `/etc` are examined as well as those in `/etc` itself. For each matching text file, the line that contains the string is printed.



Some files in `/etc` can't be read by ordinary users. Thus, if you type this command as a non-root user, you'll see some error messages relating to `grep`'s inability to open files.

Ramping up a bit, suppose you want to locate all the files in `/etc` that contain the string `eth0` or `eth1`. You can enter the following command, which uses a bracket expression to specify both variant devices:

```
$ grep eth[01] /etc/*
```

A still more complex example searches all files in `/etc` that contain the hostname `twain.example.com` or `bronto.pangaea.edu` and, later on the same line, the number `127`. This task requires using several of the regular expression features. Expressed using extended regular expression notation, the command looks like this:

```
$ grep -E "(twain\.example\.com|bronto\.pangaea\.edu).*127" /etc/*
```

This command illustrates another feature you may need to use: shell quoting. Because the shell uses certain characters, such as the vertical bar and the asterisk, for its own purposes, you must enclose certain regular expressions in quotes lest the shell attempt to parse the regular expression as shell commands.

You can use `grep` in conjunction with commands that produce a lot of output in order to sift through that output for the material that's important to you. (Several examples throughout this book use this technique.) For example, suppose you want to find the process ID (PID) of a running `xterm`. You can use a pipe to send the result of a `ps` command (described in Chapter 2) through `grep`:

```
# ps ax | grep xterm
```

The result is a list of all running processes called `xterm`, along with their PIDs. You can even do this in series, using `grep` to further restrict the output on some other criterion, which can be useful if the initial pass still produces too much output.

Using *sed*

The `sed` command directly modifies the contents of files, sending the changed file to standard output. Its syntax can take one of two forms:

```
sed [options] -f script-file [input-file]  
sed [options] script-text [input-file]
```

In either case, *input-file* is the name of the file you want to modify. (Modifications are temporary unless you save them in some way, as illustrated shortly.) The script (*script-text* or the contents of *script-file*) is the set of commands you want `sed` to perform. When you pass a script directly on the command line, the *script-text* is typically enclosed in single quote marks. Table 1.3 summarizes a few `sed` commands that you can use in its scripts.

TABLE 1.3 Common sed Commands

Command	Addresses	Meaning
=	0 or 1	Display the current line number.
a\text	0 or 1	Append <i>text</i> to the file.
i\text	0 or 1	Insert <i>text</i> into the file.
r filename	0 or 1	Append text from <i>filename</i> into the file.
c\text	Range	Replace the selected range of lines with the provided <i>text</i> .
s/regexp/replacement	Range	Replace text that matches the regular expression (<i>regexp</i>) with <i>replacement</i> .
w filename	Range	Write the current pattern space to the specified file.
q	0 or 1	Immediately quit the script, but print the current pattern space.
Q	0 or 1	Immediately quit the script.



Table 1.3 is incomplete; sed is quite complex, and this section merely introduces this tool.

The Addresses column of Table 1.3 requires elaboration: sed commands operate on addresses, which are line numbers. Commands may take no addresses, in which case they operate on the entire file; one address, in which case they operate on the specified line; or two addresses (a range), in which case they operate on that range of lines, inclusive.

In operation, sed looks something like this:

```
$ sed 's/2008/2009/' ca1-2008.txt > ca1-2009.txt
```

This command processes the input file, *ca1-2008.txt*, using sed's *s* command to replace the first occurrence of 2008 on each line with 2009. (If a single line may have more than one instance of the search string, you must perform a global search by appending *g* to the command string, as in *s/2008/2009/g*.) By default, sed sends the modified file to standard output, so this example uses redirection to send the output to *ca1-2009.txt*. The idea in this example is to quickly convert a file created for the year 2008 so that it can be used in 2009. If you don't specify an input filename, sed works from standard input, so it can accept the output of another command as its input.

Although it's conceptually simple, `sed` is a very complex tool; even a modest summary of its capabilities would fill a chapter. You can consult its man page for basic information; but to fully understand `sed`, you may want to consult a book on the subject, such as Dale Dougherty and Arnold Robbins's *sed & awk, 2nd Edition* (O'Reilly, 1997).



Certain `sed` commands, including the substitution command, are also used in `Vi`, which is described more fully in Chapter 5, “Bootling Linux and Editing Files.”

Summary

The command line is the key to Linux. Even if you prefer GUI tools to text-mode tools, understanding text-mode commands is necessary to fully manage Linux. This task begins with the shell, which accepts commands you type and displays the results of those commands. In addition, shells support linking programs together via pipes and redirecting programs' input and output. These features enable you to perform complex tasks using simple tools by having each program perform its own small part of the task. This technique is frequently used with Linux text filters, which manipulate text files in various ways—sorting text by fields, merging multiple files, and so on.

Exam Essentials

Summarize features that Linux shells offer to speed up command entry. The command history often enables you to retrieve an earlier command that's similar or identical to the one you want to enter. Tab completion reduces typing effort by letting the shell finish long command names or filenames. Command-line editing lets you edit a retrieved command or change a typo before committing the command.

Describe the purpose of the `man` command. The `man` command displays the manual page for the keyword (command, filename, system call, or other feature) that you type. This documentation provides succinct summary information that's useful as a reference to learn about exact command options or features.

Explain the purpose of environment variables. Environment variables store small pieces of data—program options, information about the computer, and so on. This information can be read by programs and used to modify program behavior in a way that's appropriate for the current environment.

Describe the difference between standard output and standard error. Standard output carries normal program output, whereas standard error carries high-priority output, such as error messages. The two can be redirected independently of one another.

Explain the purpose of pipes. Pipes tie programs together by feeding the standard output from the first program into the second program's standard input. They can be used to link together a series of simple programs to perform more complex tasks than any one of the programs could manage.

Summarize the structure of regular expressions. Regular expressions are strings that describe other strings. They can contain normal alphanumeric characters, which match the exact same characters, as well as several special symbols and symbol sets that match multiple different characters. The combination is a powerful pattern-matching tool used by many Linux programs.

Review Questions

1. You type a command into `bash` and pass a long filename to it, but after you enter the command, you receive a `File not found` error message because of a typo in the filename. How might you proceed?
 - A. Retype the command, and be sure you type the filename correctly, letter by letter.
 - B. Retype the command, but press the `Tab` key after typing a few letters of the long filename to ensure that the filename is entered correctly.
 - C. Press the `Up` arrow key, and use `bash`'s editing features to correct the typo.
 - D. Any of the above.
2. Which of the following commands is implemented as an internal command in `bash`?
 - A. `cat`
 - B. `echo`
 - C. `tee`
 - D. `sed`
3. You type `echo $PROC`, and the computer replies `Go away`. What does this mean?
 - A. No currently running processes are associated with your shell, so you may log out without terminating them.
 - B. The remote computer `PROC` isn't accepting connections; you should contact its administrator to correct the problem.
 - C. Your computer is handling too many processes; you must kill some of them to regain control of the computer.
 - D. You, one of your configuration files, or a program you've run has set the `$PROC` environment variable to `Go away`.
4. What does the `pwd` command accomplish?
 - A. It prints the name of the working directory.
 - B. It changes the current working directory.
 - C. It prints wide displays on narrow paper.
 - D. It parses Web page URLs for display.
5. In an `xterm` window launched from your window manager, you type `exec gedit`. What will happen when you exit from the `gedit` program?
 - A. Your shell will be a `root` shell.
 - B. The `gedit` program will terminate, but nothing else unusual will happen.
 - C. Your X session will terminate.
 - D. The `xterm` window will close.

6. What is the surest way to run a program (say, `myprog`) that's located in the current working directory?
 - A. Type `./` followed by the program name: `./myprog`.
 - B. Type the program name alone: `myprog`.
 - C. Type `run` followed by the program name: `run myprog`.
 - D. Type `/.` followed by the program name: `/.myprog`.
7. How does `man` display information by default on most Linux systems?
 - A. Using a custom X-based application
 - B. Using the Firefox Web browser
 - C. Using the `less` pager
 - D. Using the Vi editor
8. You want to store the standard output of the `ifconfig` command in a text file (`file.txt`) for future reference, and you want to wipe out any existing data in the file. How can you do so?
 - A. `ifconfig < file.txt`
 - B. `ifconfig >> file.txt`
 - C. `ifconfig > file.txt`
 - D. `ifconfig | file.txt`
9. What is the effect of the following command?
`$ myprog &> input.txt`
 - A. Standard error to `myprog` is taken from `input.txt`.
 - B. Standard input to `myprog` is taken from `input.txt`.
 - C. Standard output and standard error from `myprog` are written to `input.txt`.
 - D. All of the above.
10. How many commands can you pipe together at once?
 - A. 2
 - B. 3
 - C. 4
 - D. An arbitrary number
11. You want to run an interactive script, `gabby`, which produces a lot of output in response to the user's inputs. To facilitate future study of this script, you want to copy its output to a file. How might you do this?
 - A. `gabby > gabby-out.txt`
 - B. `gabby | tee gabby-out.txt`
 - C. `gabby < gabby-out.txt`
 - D. `gabby &> gabby-out.txt`

12. A text-mode program, `verbose`, prints a lot of spurious “error” messages to standard error. How might you get rid of those messages while still interacting with the program?
- A. `verbose | quiet`
 - B. `verbose &> /dev/null`
 - C. `verbose 2> /dev/null`
 - D. `verbose > junk.txt`
13. How do the `>` and `>>` redirection operators differ?
- A. The `>` operator creates a new file or overwrites an existing one; the `>>` operator creates a new file or appends to an existing one.
 - B. The `>` operator creates a new file or overwrites an existing one; the `>>` operator appends to an existing file or issues an error message if the specified file doesn’t exist.
 - C. The `>` operator redirects standard output; the `>>` operator redirects standard error.
 - D. The `>` operator redirects standard output; the `>>` operator redirects standard input.
14. What program would you use to display the end of a configuration file?
- A. `uniq`
 - B. `cut`
 - C. `tail`
 - D. `wc`
15. What is the effect of the following command?
- ```
$ pr report.txt | lpr
```
- A. The file `report.txt` is formatted for printing and sent to the `lpr` program.
  - B. The files `report.txt` and `lpr` are combined together into one file and sent to standard output.
  - C. Tabs are converted to spaces in `report.txt`, and the result is saved in `lpr`.
  - D. None of the above.
16. Which of the following commands will number the lines in `aleph.txt`? (Select all that apply.)
- A. `fmt aleph.txt`
  - B. `nl aleph.txt`
  - C. `cat -b aleph.txt`
  - D. `cat -n aleph.txt`
17. Which of the following commands will change all occurrences of `dog` in the file `animals.txt` to `mutt` in the screen display?
- A. `sed -s "dog" "mutt" animals.txt`
  - B. `grep -s "dog||mutt" animals.txt`
  - C. `sed 's/dog/mutt/g' animals.txt`
  - D. `cat animals.txt | grep -c "dog" "mutt"`

18. You've received an ASCII text file (`longlines.txt`) that uses no carriage returns within paragraphs but two carriage returns between paragraphs. The result is that your preferred text editor displays each paragraph as a very long line. How can you reformat this file so that you can more easily edit it (or a copy)?
- A. `sed 's/Ctrl-M/NL/' longlines.txt`
  - B. `fmt longlines.txt > longlines2.txt`
  - C. `cat longlines.txt > longlines2.txt`
  - D. `pr longlines.txt > longlines2.txt`
19. Which of the following commands will print lines from the file `world.txt` that contain matches to `changes` and `changed`?
- A. `grep change[ds] world.txt`
  - B. `sed change[d-s] world.txt`
  - C. `od "change'd|s'" world.txt`
  - D. `cat world.txt changes changed`
20. Which of the following regular expressions will match the strings `dig` and `dug` but not `dog`?
- A. `d.g`
  - B. `d[iu]g`
  - C. `d[i-u]g`
  - D. `di*g`

# Answers to Review Questions

1. D. Any of these approaches will work, or at least *might* work. (You might err when performing any of them.) Option B or C is likely to be the most efficient approach; with a long filename to type, option A is likely to be tedious.
2. B. The `echo` command is implemented internally to `bash`, although an external version is also available on most systems. The `cat`, `tee`, and `sed` commands are not implemented internally to `bash`, although they can be called from `bash` as external commands.
3. D. The `echo` command echoes what follows to standard output, and `$PROC` is an environment variable. Thus, `echo $PROC` displays the value of the `$PROC` environment variable, meaning that it must have been set to the specified value by you, one of your configuration files, or a program you've run. Although many environment variables are set to particular values to convey information, `$PROC` isn't a standard environment variable that might be associated with information described in options A, B, or C.
4. A. The `pwd` command prints (to standard output) the name of the current working directory. The remaining options are simply incorrect, although option B describes the `cd` command and various tools can be used to reformat wide text for display or printing in fewer columns, as in option C.
5. D. The `exec` command causes the rest of the command to replace the current shell. Thus, when you exit from `gedit` in this scenario, the result will be the same as if you'd terminated the shell, namely, the `xterm` window will close. The `exec` command doesn't raise the execution privilege, so option A is incorrect. (The `su` and `sudo` commands can raise execution privilege, though.) Because the `xterm` window closes, option B is incorrect. `X` won't ordinarily terminate when a single `xterm` does, and definitely not if that `xterm` was launched from a window manager, so option C is incorrect.
6. A. The dot (`.`) character refers to the current working directory, and the slash (`/`) is a directory separator. Thus, preceding a program name by `./` unambiguously identifies the intention to run the program that's stored in the current directory. Option B will run the first instance of the program that's found on the current path. Because paths often omit the current directory for security reasons, this option is likely to fail. The `run` command isn't a standard Linux command, so option C is unlikely to do anything, much less what the question specifies. Option D would be correct except that it reverses the order of the two characters. The effect is to attempt to run the `.myprog` file in the root (`/`) directory. This file probably doesn't exist, and even if it did, it's not the file the question specifies should be run.
7. C. By default, `man` uses the `less` pager to display information on most Linux systems. Although an X-based version of `man` does exist (`xman`), the basic `man` doesn't use a custom X-based application, nor does it use Firefox or the Vi editor.

8. C. The `>` redirection operator stores a command's standard output in a file, overwriting the contents of any existing file by the specified name. Option A specifies the standard input redirection so that `ifconfig` will take the contents of `file.txt` as input. Option B is almost correct; the `>>` redirection operator redirects standard output, as requested, but it appends data to the specified file rather than overwriting it. Option D specifies a pipe; the output of `ifconfig` is sent through the `file.txt` program, if it exists. (Chances are it doesn't, so you'd get a `command not found` error message.)
9. C. The `&>` redirection operator sends both standard output and standard error to the specified file, as option C states. (The name of the file, `input.txt`, is intentionally deceptive, but the usage is still valid.) Option A mentions standard error but describes it as if it were an input stream, which it's not; it's an output stream. Option B mentions standard input, but the `&>` operator doesn't affect standard input.
10. D. In principle, you can pipe together as many commands as you like. (In practice, of course, there will be limits based on input buffer size, memory, and so on, but these limits are far higher than the 2, 3, or 4 commands specified in options A, B, and C.)
11. B. The `tee` command sends its output both to standard output and to a named file. Thus, placing the `tee` command (with an output filename) after another command and a pipe will achieve the desired effect. Options A and D redirect `gabby`'s output to a file, which means you won't be able to see the output and interact with it. Option C sends the contents of `gabby-out.txt` to `gabby` as input, which isn't what's desired, either.
12. C. The `2>` redirection operator redirects standard error only, leaving standard output unaffected. Sending standard error to `/dev/null` gets rid of it. Option A pipes the standard output of `verbose` through the `quiet` program, which isn't a standard Linux program. Option B sends both standard output and standard error to `/dev/null`, so you won't be able to interact with the program, as the question specifies you must be able to do. Option D redirects standard output only to the `junk.txt` file, so once again, interaction will be impossible—and you'll see the unwanted error messages on the screen.
13. A. Option A correctly describes the difference between these two redirection operators. Option B is almost correct, but the `>>` operator will create a new file if one doesn't already exist. The `>>` operator does not redirect standard error (as stated in option C) or standard input (as stated in option D).
14. C. The `tail` command displays the final 10 lines of a file. (You can change the number of lines displayed with the `-n` option.) The `uniq` command removes duplicate lines from a list. The `cut` command echoes the specified characters or fields from an input text file. The `wc` command displays counts of the number of characters, words, and lines in a file.
15. A. The `pr` program takes a text file as input and adds formatting features intended for printing, such as a header and blank lines to separate pages. The command also pipes the output through `lpr` (which is a Linux printing command).

16. B, C, D. The `n1` command numbers lines, so it does this task without any special options. (Its options can fine-tune the way it numbers lines, though.) The `cat` command can also number lines via its `-b` and `-n` options; `-b` numbers non-blank lines, whereas `-n` numbers all lines (including blank lines). The `fmt` command is the only one described here that will not number the lines of the input file.
17. C. The `sed` utility can be used to “stream” text and change one value to another. In this case, the `s` option is used to replace `dog` with `mutt`. The syntax in option A is incorrect, and choices B and D are incorrect because `grep` doesn’t include the functionality needed to make the changes.
18. B. The `fmt` command performs the desired task of shortening long lines by inserting carriage returns. It sends its results to standard output, so option B uses output redirection to save the results in a new file. The `sed` command of option A won’t accomplish anything useful; it only replaces the string `Ctrl-M` with the string `NL`. Although these strings are both sometimes used as abbreviations for carriage returns or new lines, the replacement of these literal strings isn’t what’s required. Option C creates an exact copy of the original file, with the long single-line paragraphs intact. Although option D’s `pr` command is a formatting tool, it won’t reformat individual paragraphs. It will also add headers that you probably don’t want.
19. A. The `grep` utility is used to find matching text within a file and print those lines. It accepts regular expressions, which means you can place in brackets the two characters that differ in the words for which you’re looking. The syntax for `sed`, `od`, and `cat` wouldn’t perform the specified task.
20. B. The bracket expression within the `d[iu]g` regular expression means that either `i` or `u` may be the middle character; hence, this regular expression matches both `dig` and `dug` but not `dog`. Option A’s dot matches any single character, so `d.g` matches all three words. The range expression `[i-u]` matches any single character between `i` and `u`, inclusive. Because `o` falls between these two letters, option C matches all three words. Finally, `di*g` matches `dig`, `diiig`, `diiiig`, or any other word that begins with `d`, ends with `g`, and contains any number of `i` letters in-between. Thus, option D matches `dig` but not `dug` as required.

# Chapter 2

# Managing Software

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**THE FOLLOWING LINUX PROFESSIONAL INSTITUTE OBJECTIVES ARE COVERED IN THIS CHAPTER:**

- ✓ 1.102.3 Manage shared libraries (weight: 1)
- ✓ 1.102.4 Use Debian package management (weight: 3)
- ✓ 1.102.5 Use RPM and Yum package management (weight: 3)
- ✓ 1.103.5 Create, monitor, and kill processes (weight: 4)
- ✓ 1.103.6 Modify process execution priorities (weight: 2)





A Linux system is defined largely by the collection of software it contains. The Linux kernel, the libraries used by many packages, the shells used to interpret commands, the X Window System GUI, the servers, and more all make up the system's software environment. Many of the chapters of this book are devoted to configuring specific software components, but they all have something in common: tools used to install, uninstall, upgrade, and otherwise manipulate the software. Ironically, this commonality is a major source of differences between Linux systems. Two major Linux package management tools exist: RPM and Debian packages. (Several less-common package management systems also exist.) With few exceptions, each individual Linux computer uses precisely one package management system, so you'll need to know only one to administer a single system. To be truly fluent in all things Linux, though, you should be at least somewhat familiar with both of them. Thus, this chapter describes both.

This chapter also covers *libraries*—software components that can be used by many different programs. Libraries help reduce the disk space and memory requirements of complex programs, but they also require some attention; if that attention isn't given to them, they can cause problems by their absence or because of incompatibilities between their and their dependent software's versions.

Package management, and in some sense library management, relates to programs as files on your hard disk. Once run, though, programs are dynamic entities. Linux provides tools to help you manage running programs (known as *processes*)—you can learn what processes are running, change their priorities, and terminate processes you don't want running.

## Package Concepts

Before proceeding, you should understand some of the principles that underlie Linux package management tools. Any computer's software is like a house of cards: One program may rely on five other programs or libraries, each of which relies on several more, and so on. The foundation on which all these programs rely is the Linux kernel. Any of these packages can theoretically be replaced by an equivalent one; however, doing so sometimes causes problems. Worse, removing one card from the stack could cause the whole house of cards to come tumbling down.

Linux package management tools are intended to minimize such problems by tracking what software is installed. The information that the system maintains helps avoid problems in several ways:

**Packages** The most basic information that package systems maintain is information about software *packages*—that is, collections of files that are installed on the computer. Packages



are usually distributed as single files that are similar to *tarballs* (archives created with the *tar* utility and usually compressed with *gzip* or *bzip2*) or *zip* files. Once installed, most packages consist of dozens or hundreds of files, and the package system tracks them all. Packages include additional information that aids in the subsequent duties of package management systems.

**Installed file database** Package systems maintain a database of installed files. The database includes information about every file installed via the package system, the name of the package to which it belongs, and associated additional information.

**Dependencies** One of the most important types of information maintained by the package system is *dependency* information—that is, the requirements of packages for one another. For instance, if SuperProg relies on UltraLib to do its work, the package database records this information. If you attempt to install SuperProg when UltraLib isn't installed, the package system won't let you do so. Similarly, if you try to uninstall UltraLib when SuperProg is installed, the package system won't let you. (You can override these prohibitions, as described later in “Forcing the Installation.” Doing so is usually inadvisable, though.)

**Checksums** The package system maintains checksums and assorted ancillary information about files. This information can be used to verify the validity of the installed software. This feature has its limits, though; it's intended to help you spot disk errors, accidental overwriting of files, or other non-sinister problems. It's of limited use in detecting intrusions, because an intruder could use the package system to install altered system software.

**Upgrades and uninstallation** By tracking files and dependencies, package systems permit easy upgrades and uninstallation: Tell the package system to upgrade or remove a package, and it will replace or remove every file in the package. Of course, this assumes that the upgrade or uninstallation doesn't cause dependency problems; if it does, the package system will block the operation unless you override it.

**Binary package creation** Both the RPM and Debian package systems provide tools to help create binary packages (those that are installed directly) from source code. This feature is particularly helpful if you're running Linux on a peculiar CPU; you can download source code and create a binary package even if the developers didn't provide explicit support for your CPU. Creating a binary package from source has advantages over compiling software from source in more conventional ways, because you can then use the package management system to track dependencies, attend to individual files, and so on.

Both the RPM and Debian package systems provide all of these basic features, although the details of their operation differ. These two package systems are incompatible with one another in the sense that their package files and their installed file databases are different; you can't directly install an RPM package on a Debian-based system or vice versa. (Tools to convert between formats do exist, and developers are working on ways to better integrate the two package formats.)



Most distributions install just one package system. It's possible to install more than one, though, and some programs (such as `alien`) require both for full functionality. Actually *using* both systems to install software is inadvisable because their databases are separate. If you install a library using a Debian package and then try to install an RPM that relies on that library, RPM won't realize that the library is already installed and will return an error.

## Using RPM

The most popular package manager in the Linux world is the RPM Package Manager (RPM). RPM is also available on non-Linux platforms, although it sees less use outside the Linux world. The RPM system provides all the basic tools described in the preceding section, “Package Concepts,” such as a package database that allows for checking conflicts and ownership of particular files.

### RPM Distributions and Conventions

Red Hat developed RPM for its own distribution. Red Hat released the software under the General Public License (GPL), however, so others have been free to use it in their own distributions—and this is precisely what has happened. Some distributions, such as Mandriva (formerly Mandrake) and Yellow Dog, are based on Red Hat, so they use RPMs as well as many other parts of the Red Hat distribution. Others, such as SUSE, borrow less from the Red Hat template, but they do use RPMs. Of course, all Linux distributions share many common components, so even those that weren't originally based on Red Hat are very similar to it in many ways other than their use of RPM packages. On the other hand, distributions that were originally based on Red Hat have diverged from it over time. As a result, the group of RPM-using distributions shows substantial variability, but all of them are still Linux distributions that provide the same basic tools, such as the Linux kernel, common shells, an X server, and so on.



Red Hat has splintered into two distributions: Fedora is the downloadable version favored by home users, students, and businesses on a tight budget. The *Red Hat* name is now reserved for the for-pay version of the distribution, known more formally as Red Hat Enterprise Linux (RHEL).

RPM is a cross-platform tool. As noted earlier, some non-Linux Unix systems can use RPM, although most don't use it as their primary package-distribution system. RPM supports any CPU architecture. Red Hat Linux is or has been available for at least five CPUs: `x86`, `x86-64` (a.k.a. AMD64 and EM64T), `IA-64`, `Alpha`, and `SPARC`. Among the distributions

mentioned earlier, Yellow Dog is a PowerPC distribution (it runs on Apple PowerPC-based Macs and some non-Apple systems), and SuSE is available on *x86*, *x86-64*, and PowerPC systems. For the most part, source RPMs are transportable across architectures—you can use the same source RPM to build packages for *x86*, AMD64, PowerPC, Alpha, SPARC, or any other platform you like. Some programs are composed of architecture-independent scripts and so need no recompilation. There are also documentation and configuration packages that work on any CPU.

The convention for naming RPM packages is as follows:

```
packagename-a.b.c-x.arch.rpm
```

Each of the filename components has a specific meaning:

**Package name** The first component (*packagename*) is the name of the package, such as *samba* or *samba-server* for the Samba file and print server. Note that the same program may be given different package names by different distribution maintainers.

**Version number** The second component (*a.b.c*) is the package version number, such as 3.0.25b. The version number doesn't have to be three period-separated numbers, but that's the most common form. The program author assigns the version number.

**Build number** The number following the version number (*x*) is the *build number* (also known as the *release number*). This number represents minor changes made by the package maintainer, not by the program author. These changes may represent altered startup scripts or configuration files, changed file locations, added documentation, or patches appended to the original program to fix bugs or to make the program more compatible with the target Linux distribution. Many distribution maintainers add a letter code to the build number to distinguish their packages from those of others. Note that these numbers are *not* comparable across package maintainers—George's build number 5 of a package is *not* necessarily an improvement on Susan's build number 4 of the same package.

**Architecture** The final component preceding the *.rpm* extension (*arch*) is a code for the package's architecture. The *i386* architecture code is the most common; it represents a file compiled for any *x86* CPU from the 80386 onward. Some packages include optimizations for Pentiums or above (*i586* or *i686*), and non-*x86* binary packages use codes for their CPUs, such as *ppc* for PowerPC CPUs or *x86\_64* for the *x86-64* platform. Scripts, documentation, and other CPU-independent packages generally use the *noarch* architecture code. The main exception to this rule is source RPMs, which use the *src* architecture code.

As an example of RPM version numbering, the Mandriva 2008.0 distribution for *x86-64* ships with a Samba package called *samba-server-3.0.25b-4.5mdv2008.0.x86\_64.rpm*, indicating that this is build 4.5mdv2008.0 of Samba 3.0.25b, compiled with *x86-64* optimizations. These naming conventions are just that, though—conventions. It's possible to rename a package however you like, and it will still install and work. The information in the filename is retained within the package. This fact can be useful if you're ever forced to transfer RPMs using a medium that doesn't allow for long filenames. In fact, early versions of SUSE eschewed long filenames, preferring short filenames such as *samba.rpm*.

In an ideal world, any RPM package will install and run on any RPM-based distribution that uses an appropriate CPU type. Unfortunately, compatibility issues can crop up from time to time, including the following:

- Distributions may use different versions of the RPM utilities. This problem can completely prevent an RPM from one distribution from being used on another.
- An RPM package designed for one distribution may have dependencies that are unmet in another distribution. A package may require a newer version of a library than is present on the distribution you're using, for instance. This problem can usually be overcome by installing or upgrading the depended-on package, but sometimes doing so causes problems because the upgrade may break other packages. By rebuilding the package you want to install from a source RPM, you can often work around these problems, but sometimes the underlying source code also needs the upgraded libraries.
- An RPM package may be built to depend on a package of a particular name, such as `samba-client` depending on `samba-common`; but if the distribution you're using has named the package differently, the `rpm` utility will object. You can override this objection by using the `--nodeps` switch, but sometimes the package won't work once installed. Rebuilding from a source RPM may or may not fix this problem.
- Even when a dependency appears to be met, different distributions may include slightly different files in their packages. For this reason, a package meant for one distribution may not run correctly when installed on another distribution. Sometimes installing an additional package will fix this problem.
- Some programs include distribution-specific scripts or configuration files. This problem is particularly acute for servers, which may include startup scripts that go in `/etc/rc.d/init.d` or elsewhere. Overcoming this problem usually requires that you remove the offending script after installing the RPM and either start the server in some other way or write a new startup script, perhaps modeled after one that came with some other server for your distribution.

In most cases, it's best to use the RPMs intended for your distribution. RPM meta-packagers, such as the Yellow Dog Updater Modified (Yum), can simplify locating and installing packages designed for your distribution. If you're forced to go outside of your distribution's officially supported list of packages, mixing and matching RPMs from different distributions usually works reasonably well for most programs. This is particularly true if the distributions are closely related or you rebuild from a source RPM. If you have trouble with an RPM, though, you may do well to try to find an equivalent package that was built with your distribution in mind.

## The `rpm` Command Set

The main RPM utility program is known as `rpm`. Use this program to install or upgrade a package at the shell prompt. The `rpm` command has the following syntax:

```
rpm [operation][options] [package-files|package-names]
```

Table 2.1 summarizes the most common rpm operations, and Table 2.2 summarizes the most important options. Be aware, however, that rpm is a complex tool, so this listing is necessarily incomplete. For information about operations and options more obscure than those listed in Tables 2.1 and 2.2, see the man pages for rpm. Many of rpm's less-used features are devoted to the creation of RPM packages by software developers.

**TABLE 2.1** Common rpm Operations

| Operation       | Description                                                                                                            |
|-----------------|------------------------------------------------------------------------------------------------------------------------|
| -i              | Installs a package; system must <i>not</i> contain a package of the same name                                          |
| -U              | Installs a new package or upgrades an existing one                                                                     |
| -F or --freshen | Upgrades a package only if an earlier version already exists                                                           |
| -q              | Queries a package—finds if a package is installed, what files it contains, and so on                                   |
| -V or --verify  | Verifies a package—checks that its files are present and unchanged since installation                                  |
| -e              | Uninstalls a package                                                                                                   |
| -b              | Builds a binary package, given source code and configuration files; moved to the rpmbuild program with RPM version 4.2 |
| --rebuild       | Builds a binary package, given a source RPM file; moved to the rpmbuild program with RPM version 4.2                   |
| --rebuilddb     | Rebuilds the RPM database to fix errors                                                                                |

**TABLE 2.2** Common rpm Options

| Option            | Used with Operations | Description                                                                                                                                                                                                            |
|-------------------|----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| --root <i>dir</i> | Any                  | Modifies the Linux system having a root directory located at <i>dir</i> . This option can be used to maintain one Linux installation discrete from another one (say, during OS installation or emergency maintenance). |
| --force           | -i, -U, -F           | Forces installation of a package even when it means overwriting existing files or packages.                                                                                                                            |

**TABLE 2.2** Common rpm Options (*continued*)

| Option                               | Used with Operations | Description                                                                                                                                                                                           |
|--------------------------------------|----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| -h or --hash                         | -i, -U, -F           | Displays a series of hash marks (#) to indicate the progress of the operation.                                                                                                                        |
| -v                                   | -i, -U, -F           | Used in conjunction with the -h option to produce a uniform number of hash marks for each package.                                                                                                    |
| --nodeps                             | -i, -U, -F, -e       | Specifies that no dependency checks be performed. Installs or removes the package even if it relies on a package or file that's not present or is required by a package that's not being uninstalled. |
| --test                               | -i, -U, -F           | Checks for dependencies, conflicts, and other problems without actually installing the package.                                                                                                       |
| --prefix <i>path</i>                 | -i, -U, -F           | Sets the installation directory to <i>path</i> (works only for some packages).                                                                                                                        |
| -a or --all                          | -q, -V               | Queries or verifies all packages.                                                                                                                                                                     |
| -f <i>file</i> or --file <i>file</i> | -q, -V               | Queries or verifies the package that owns <i>file</i> .                                                                                                                                               |
| -p <i>package-file</i>               | -q                   | Queries the uninstalled RPM <i>package-file</i> .                                                                                                                                                     |
| -i                                   | -q                   | Displays package information, including the package maintainer, a short description, and so on.                                                                                                       |
| -R or --requires                     | -q                   | Displays the packages and files on which this one depends.                                                                                                                                            |
| -l or --list                         | -q                   | Displays the files contained in the package.                                                                                                                                                          |

To use rpm, you combine one operation with one or more options. In most cases, you include one or more package names or package filenames as well. (A package filename is a complete filename, but a package name is a shortened version. For instance, a package filename might be `samba-server-3.0.25b-4.5mdv2008.0.x86_64.rpm`, whereas the matching package name is `samba-server`.) You can issue the rpm command once for each package, or you can list multiple packages, separated by spaces, on the command line. The latter

is often preferable when you're installing or removing several packages, some of which depend on others in the group. Issuing separate commands in this situation requires that you install the depended-on package first or remove it last, whereas issuing a single command allows you to list the packages on the command line in any order.

Some operations require that you give a package filename, and others require a package name. In particular, `-i`, `-U`, `-F`, and the rebuild operations require package filenames; `-q`, `-V`, and `-e` normally take a package name, although the `-p` option can modify a query (`-q`) operation to work on a package filename.

When you're installing or upgrading a package, the `-U` operation is generally the most useful because it allows you to install the package without manually uninstalling the old one. This one-step operation is particularly helpful when packages contain many dependencies because `rpm` detects these and can perform the operation should the new package fulfill the dependencies provided by the old one.

To use `rpm` to install or upgrade a package, issue a command similar to the following:

```
rpm -Uvh samba-server-3.0.25b-4.5mdv2008.0.x86_64.rpm
```

You can also use `rpm -ivh` in place of `rpm -Uvh` if you don't already have a `samba-server` package installed.



It's possible to distribute the same program under different names. In this situation, upgrading may fail, or it may produce a duplicate installation, which can yield bizarre program-specific malfunctions. Red Hat has described a formal system for package naming to avoid such problems, but they still occur occasionally. Therefore, it's best to upgrade a package using a subsequent release provided by the same individual or organization that provided the original.

Verify that the package is installed with the `rpm -qi` command, which displays information such as when and on what computer the binary package was built. Listing 2.1 demonstrates this command. (`rpm -qi` also displays an extended plain-English summary of what the package is, which has been omitted from Listing 2.1.)

### Listing 2.1: RPM Query Output

```
$ rpm -qi samba-server
Name : samba-server Relocations: (not relocatable)
Version : 3.0.25b Vendor: Mandriva
Release : 4.5mdv2008.0 Build Date: Tue 27 May 2008 08:39:24 PM EDT
Install Date: Sat 31 May 2008 12:15:20 PM EDT Build Host: linsec.homelinux.org
Group : Networking/Other Source RPM: samba-3.0.25b-4.5mdv2008.0.src.rpm
```

```

Size : 13524400 License: GPL
Signature : DSA/SHA1, Tue 27 May 2008 09:38:42 PM EDT, ➡
Key ID 9aa8d0d022458a98
Packager : Mandriva Linux Security Team <security@mandriva.com>
URL : http://www.samba.org
Summary : Samba (SMB) server programs

```

## Extracting Data from RPMs

Occasionally you may want to extract data from RPMs without installing the package. For instance, this can be a good way to retrieve the original source code from a source RPM for compiling the software without the help of the RPM tools or to retrieve fonts or other non-program data for use on a non-RPM system.

RPM files are actually modified `cpio` archives. Thus, converting the files into `cpio` files is relatively straightforward, whereupon you can use `cpio` to retrieve the individual files. To do this job, you need to use the `rpm2cpio` program, which ships with most Linux distributions. (You can use this tool even on distributions that don't use RPM.) This program takes a single argument—the name of the RPM file—and outputs the `cpio` archive on standard output. So, if you want to create a `cpio` archive file, you must redirect the output:

```

$ rpm2cpio samba-server-3.0.25b-4.5mdv2008.0.src.rpm ➡
> samba-server-3.0.25b-4.5mdv2008.0.cpio

```



The redirection operator (`>`) is described in more detail in Chapter 1, “Exploring Linux Command-Line Tools,” as is the pipe operator (`|`), which is mentioned shortly.

You can then extract the data using `cpio`, which takes the `-i` option to extract an archive and `--make-directories` to create directories:

```

$ cpio -i --make-directories < samba-server-3.0.25b-4.5mdv2008.0.cpio

```

Alternatively, you can use a pipe to link these two commands together without creating an intermediary file:

```

$ rpm2cpio samba-server-3.0.25b-4.5mdv2008.0.src.rpm | ➡
cpio -i --make-directories

```

In either case, the result is an extraction of the files in the archive in the current directory. In the case of binary packages, this is likely to be a series of subdirectories that mimic the layout of the Linux root directory—that is, `usr`, `lib`, etc, and so on, although precisely which directories are included depends on the package. For a source package, the result of the extraction process is likely to be a source code tarball, a `.spec` file (which holds information RPM uses to build the package), and perhaps some patch files.





When you're extracting data from an RPM file using `rpm2cpio` and `cpio`, create a holding subdirectory and then extract the data into this subdirectory. This practice will ensure that you can find all the files. If you extract files in your home directory, some of them may get lost amidst your other files. If you extract files as root in the root (`/`) directory, they could conceivably overwrite files that you want to keep.

Another option for extracting data from RPMs is to use `alien`, which is described later, in “Converting Between Package Formats.” This program can convert an RPM into a Debian package or a tarball.

## Using Yum

Yum (<http://linux.duke.edu/projects/yum/>), mentioned earlier, is one of several meta-packagers—it enables you to easily install a package and all its dependencies using a single command line. When using Yum, you don't even need to locate and download the package files, because Yum does this for you by searching in one or more repositories (Internet sites that host RPM files for a particular distribution).

Yum originated with the fairly obscure Yellow Dog Linux distribution, but it's since been adopted by Red Hat, Fedora, and some other RPM-based distributions. Yum isn't used by all RPM-based distributions, though; SUSE and Mandriva, to name just two, each use their own meta-packagers. Debian-based distributions generally employ the Advanced Package Tools (APT), as described later, in “Using *apt-get*.” Nonetheless, because of the popularity of Red Hat and Fedora, knowing Yum can be valuable.

The most basic way to use Yum is with the `yum` command, which has the following syntax:

```
yum [options] [command] [package...]
```

Which options are available depend on the command you use. Table 2.3 describes common `yum` commands.

**TABLE 2.3** Common `yum` Commands

| Command                   | Description                                                                                                                                                       |
|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>install</code>      | Installs one or more packages by package name. Also installs dependencies of the specified package or packages.                                                   |
| <code>update</code>       | Updates the specified package or packages to the latest available version. If no packages are specified, <code>yum</code> updates every installed package.        |
| <code>check-update</code> | Checks to see whether updates are available. If they are, <code>yum</code> displays their names, versions, and repository area (updates or extras, for instance). |

**TABLE 2.3** Common yum Commands (*continued*)

| Command                  | Description                                                                                                                                                                                                                                                  |
|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| upgrade                  | Works like update with the <code>--obsoletes</code> flag set, which handles obsolete packages in a way that's superior when performing a distribution version upgrade.                                                                                       |
| remove or erase          | Deletes a package from the system; similar to <code>rpm -e</code> , but yum also removes depended-on packages.                                                                                                                                               |
| list                     | Displays information about a package, such as the installed version and whether an update is available.                                                                                                                                                      |
| provides or whatprovides | Displays information about packages that provide a specified program or feature. For instance, typing <code>yum provides samba</code> lists all the Samba-related packages, including every available update. Note that the output can be copious.           |
| search                   | Searches package names, summaries, packagers, and descriptions for a specified keyword. This is useful if you don't know a package's name but can think of a word that's likely to appear in one of these fields but not in these fields for other packages. |
| info                     | Displays information about a package, similar to the <code>rpm -qi</code> command.                                                                                                                                                                           |
| clean                    | Cleans up the Yum cache directory. Running this command from time to time is advisable, lest downloaded packages chew up too much disk space.                                                                                                                |
| shell                    | Enters the Yum shell mode, in which you can enter multiple Yum commands one after another.                                                                                                                                                                   |
| resolvedep               | Displays packages matching the specified dependency.                                                                                                                                                                                                         |
| localinstall             | Installs the specified local RPM files, using your Yum repositories to resolve dependencies.                                                                                                                                                                 |
| localupdate              | Updates the system using the specified local RPM files, using your Yum repositories to resolve dependencies. Packages other than those updated by local files and their dependencies are <i>not updated</i> .                                                |
| deplist                  | Displays dependencies of the specified package.                                                                                                                                                                                                              |

In most cases, using Yum is easier than using RPM directly to manage packages, because Yum finds the latest available package, downloads it, and installs any required dependencies. Yum has its limits, though; it's only as good as its repositories, so it can't install software that's not stored in those repositories.



If you use Yum to automatically upgrade all packages on your system, you're effectively giving control of your system to the distribution maintainer. Although Red Hat or other distribution maintainers are unlikely to try to break into your computer in this way, an automatic update with minimal supervision on your part could easily break something on your system, particularly if you've obtained packages from unusual sources in the past.

If you don't want to install the package, but merely want to obtain it, you can use `yumdownloader`. Type this command followed by the name of a package, and the latest version of the package will be downloaded to the current directory. This can be handy if you need to update a system that's not connected to the Internet; you can use another system that runs the same distribution to obtain the packages and then transfer them to the target system.

If you prefer to use GUI tools rather than command-line tools, you should be aware that GUI front-ends to yum exist. Examples include `yumex` and `kyum`. You can use the text-mode yum to install these front-ends, as in `yum install kyum`.

Exercise 2.1 runs you through the process of managing packages using the rpm utility.

## EXERCISE 2.1

### Managing Packages Using RPM

To manage packages using the rpm utility, follow these steps:

1. Log into the Linux system as a normal user.
2. Acquire a package to use for testing purposes. You can try using a package from your distribution that you know you haven't installed; but if you try a random package, you may find it's already installed or has unmet dependencies. This lab uses as an example the installation of `zsh-4.3.4-4mdv2008.0.x86_64.rpm`, a shell that's not installed by default on most systems, from the Mandriva 2008.0 DVD onto a Mandriva 2008.0 system. You must adjust the commands as necessary if you use another RPM file in your tests.
3. Launch an xterm from the desktop environment's menu system if you used a GUI login.
4. Acquire root privileges. You can do this by typing `su` in an xterm, by selecting Session > New Root Console from a Konsole window, or by using `sudo` (if it's configured) to run the commands in the following steps.
5. Type `rpm -q zsh` to verify that the package isn't currently installed. The system should respond with the message `package zsh is not installed`.

**EXERCISE 2.1 (continued)**

6. Type `rpm -qpi zsh-4.3.4-4mdv2008.0.x86_64.rpm`. (You'll need to add a complete path to the package file if it's not in your current directory.) The system should respond by displaying information about the package, such as the version number, the vendor, the hostname of the machine on which it was built, and a package description.
7. Type `rpm -ivh zsh-4.3.4-4mdv2008.0.x86_64.rpm`. The system should install the package and display a series of hash marks (#) as it does so.
8. Type `rpm -q zsh`. The system should respond with the complete package name, including the version and build numbers. This response verifies that the package is installed.
9. Type `zsh`. This launches a Z shell, which functions much like the more common `bash` and `tcsh` shells. You're likely to see your command prompt change slightly, but you can issue most of the same commands you can use with `bash` or `tcsh`.
10. Type `rpm -V zsh`. The system shouldn't produce any output—just a new command prompt. The `verify (-V or --verify)` command checks the package files against data stored in the database. Immediately after installation, most packages should show no deviations. (A handful of packages will be modified during installation, but `zsh` isn't one of them.)
11. Type `rpm -e zsh`. The system shouldn't produce any output—just a new command prompt. This command removes the package from the system. Note that you're removing the `zsh` package while running the `zsh` program. Linux continues to run the `zsh` program you're using, but you'll be unable to launch new instances of the program. Some programs may misbehave if you do this because files will be missing after you remove the package.
12. Type `exit` to exit `zsh` and return to your normal shell.
13. Type `rpm -q zsh`. The system should respond with a package `zsh` is not installed error because you've just uninstalled the package.
14. Type `yum install zsh`. The system should check your repositories, download `zsh`, and install it. It will ask for confirmation before beginning the download.
15. Type `rpm -q zsh`. The results should be similar to those in step 8, although the version number may differ.
16. Type `rpm -e zsh`. This step removes `zsh` from the system but produces no output, just as in step 11.

The final three steps will work only if your distribution uses Yum.

---

## RPM and Yum Configuration Files

Ordinarily, you needn't explicitly configure RPM or Yum; distributions that use RPM configure it in reasonable ways by default. Sometimes, though, you may want to tweak a few details, particularly if you routinely build source RPM packages and want to optimize the output for your system. You may also want to add a Yum repository for some unusual software you run. To do so, you typically edit an RPM or Yum configuration file.

The main RPM configuration file is `/usr/lib/rpm/rpmprc`. This file sets a variety of options, mostly related to the CPU optimizations used when compiling source packages. You shouldn't edit this file, though; instead, you should create and edit `/etc/rpmprc` (to make global changes) or `~/.rpmprc` (to make changes on a per-user basis). The main reason to create such a file is to implement architecture optimizations—for instance, to optimize your code for your CPU model by passing appropriate compiler options when you build a source RPM into a binary RPM. This is done with the `optflags` line:

```
optflags: athlon -O2 -g -march=i686
```

This line tells RPM to pass the `-O2 -g -march=i686` options to the compiler whenever building for the `athlon` platform. Although RPM can determine your system's architecture, the `optflags` line by itself isn't likely to be enough to set the correct flags. Most default `rpmprc` files include a series of `buildarchtranslate` lines that cause `rpmbuild` (or `rpm` for older versions of RPM) to use one set of optimizations for a whole family of CPUs. For `x86` systems, these lines typically look like this:

```
buildarchtranslate: athlon: i386
buildarchtranslate: i686: i386
buildarchtranslate: i586: i386
buildarchtranslate: i486: i386
buildarchtranslate: i386: i386
```

These lines tell RPM to translate the `athlon`, `i686`, `i586`, `i486`, and `i386` CPU codes to use the `i386` optimizations. This effectively defeats the purpose of any CPU-specific optimizations you create on the `optflags` line for your architecture, but it guarantees that the RPMs you build will be maximally portable. To change matters, you must alter the line for your CPU type, as returned when you type `uname -p`. For instance, on an Athlon-based system, you might enter the following line:

```
buildarchtranslate: athlon: athlon
```

Thereafter, when you rebuild a source RPM, the system will use the appropriate Athlon optimizations. The result can be a slight performance boost on your own system, but reduced portability—depending on the precise optimizations you choose, such packages may not run on non-Athlon CPUs. (Indeed, you may not even be able to install them on non-Athlon CPUs!)

Yum is configured via the `/etc/yum.conf` file, with additional configuration files in the `/etc/yum.repos.d/` directory. The `yum.conf` file holds basic options, such as the directory to which Yum downloads RPMs and where Yum logs its activities. Chances are you won't need to modify this file. The `/etc/yum.repos.d/` directory, on the other hand, potentially holds several files, each of which describes a Yum repository—that is, a site that holds RPMs that may be installed via Yum. You probably shouldn't directly edit these files; instead, if you want to add a repository, manually download the RPM that includes the repository configuration and install it using `rpm`. The next time you use Yum, it will access your new repository along with the old ones. Several Yum repositories exist, mostly for Red Hat and Fedora, such as the following:

**Livna** This repository (<http://rpm.livna.org/r1owiki/>) hosts multimedia tools, such as additional codecs and video drivers.

**KDE Red Hat** Red Hat and Fedora favor the GNU Network Object Model Environment (GNOME) desktop environment, although they ship with the K Desktop Environment (KDE). The repository at <http://kde-redhat.sourceforge.net> provides improved KDE RPMs for those who favor KDE.

**Fresh RPMs** This repository (<http://freshrpms.net>) provides additional RPMs, mostly focusing on multimedia applications and drivers.

Many additional repositories exist. Try a Web search on terms such as *yum repository*, or check the Web page of any site that hosts unusual software you want to run to see whether it provides a Yum repository. If so, it should provide an RPM or other instructions on adding its site to your Yum repository list.

## RPM Compared to Other Package Formats

RPM is a very flexible package management system. In most respects, it's comparable to Debian's package manager, and it offers many more features than tarballs do. When compared to Debian packages, the greatest strength of RPMs is probably their ubiquity. Many software packages are available in RPM form from their developers and/or from distribution maintainers.



Distribution packagers frequently modify the original programs in order to make them integrate more smoothly into the distribution as a whole. For instance, distribution-specific startup scripts may be added, program binaries may be relocated from default `/usr/local` subdirectories, and program source code may be patched to fix bugs or add features. Although these changes can be useful, you may not want them, particularly if you're using a program on a distribution other than the one for which the package was intended.

The fact that there are so many RPM-based distributions can be a boon. You may be able to use an RPM intended for one distribution on another, although as noted earlier, this isn't certain. In fact, this advantage can turn into a drawback if you try to mix and match

too much—you can wind up with a mishmash of conflicting packages that can be difficult to disentangle.



The RPMFind Web site, <http://rpmfind.net>, is an extremely useful resource when you want to find an RPM of a specific program. Another site with similar characteristics is Fresh RPMs, <http://freshrpms.net>. These sites include links to RPMs built by programs' authors, specific distributions' RPMs, and those built by third parties. Adding such sites as Yum repositories can make it even easier to use them.

Compared to tarballs, RPMs offer much more sophisticated package management tools. This can be important when you're upgrading or removing packages and also for verifying the integrity of installed packages. On the other hand, although RPMs are common in the Linux world, they're less common on other platforms. Therefore, you're more likely to find tarballs of generic Unix source code, and tarballs are preferred if you've written a program that you intend to distribute for other platforms.

## Using Debian Packages

In their overall features, Debian packages are similar to RPMs; but the details of operation for each differ, and Debian packages are used on different distributions than are RPMs. Because each system uses its own database format, RPMs and Debian packages aren't interchangeable without converting formats. Using Debian packages requires knowing how to use the `dpkg`, `dselect`, and `apt-get` commands. A few other commands can also be helpful.

### Debian Distributions and Conventions

As the name implies, Debian packages originated with the Debian distribution. Since that time, the format has been adopted by several other distributions, including Libranet, Ubuntu, and Xandros. Such distributions are derived from the original Debian, which means that packages from the original Debian are likely to work well on other Debian-based systems. Although Debian doesn't emphasize flashy GUI installation or configuration tools, its derivatives add GUI configuration tools to the base Debian system, which makes these distributions more appealing to Linux novices. The original Debian favors a system that's as bug free as possible, and it tries to adhere strictly to open-source software principles rather than invest effort in GUI configuration tools. The original Debian is unusual in that it's maintained by volunteers who are motivated by the desire to build a product they want to use rather than by a company that is motivated by profit.

Like RPM, the Debian package format is neutral with respect to both OS and CPU type. Debian packages are extremely rare outside Linux, although efforts are under way to create a Debian distribution that uses the GNU Hurd kernel rather than the Linux kernel. Such a distribution wouldn't be Linux but would closely resemble Debian GNU/Linux in operation and configuration.

The original Debian distribution has been ported to many different CPUs, including *x86*, *x86-64*, *IA-64*, *PowerPC*, *Alpha*, *680x0*, *MIPS*, and *SPARC*. The original architecture was *x86*, and subsequent ports exist at varying levels of maturity. Derivative distributions generally work only on *x86* systems, but this could change in the future.

Debian packages follow a naming convention similar to those for RPMs; but Debian packages sometimes omit codes in the filename to specify a package’s architecture, particularly on *x86* packages. When these codes are present, they may differ from RPM conventions. For instance, a filename ending in *i386.deb* indicates an *x86* binary, *powerpc.deb* is a *PowerPC* binary, and *all.deb* indicates a CPU-independent package, such as documentation or scripts. As with RPM files, this file-naming convention is only that—a convention. You can rename a file as you see fit, to either include or omit the processor code. There is no code for Debian source packages because, as described in the upcoming section “Debian Packages Compared to Other Package Formats,” Debian source packages consist of several separate files.

## The *dpkg* Command Set

Debian packages are incompatible with RPM packages, but the basic principles of operation are the same across both package types. Like RPMs, Debian packages include dependency information, and the Debian package utilities maintain a database of installed packages, files, and so on. You use the *dpkg* command to install a Debian package. This command’s syntax is similar to that of *rpm*:

```
dpkg [options] [action] [package-files|package-name]
```

The *action* is the action to be taken; common actions are summarized in Table 2.4. The options (Table 2.5) modify the behavior of the action, much like the options to *rpm*.

**TABLE 2.4** *dpkg* Primary Actions

| Action                                                 | Description                                                                                       |
|--------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| <code>-i</code> or <code>--install</code>              | Installs a package                                                                                |
| <code>--configure</code>                               | Reconfigures an installed package: runs the post-installation script to set site-specific options |
| <code>-r</code> or <code>--remove</code>               | Removes a package, but leaves configuration files intact                                          |
| <code>-P</code> or <code>--purge</code>                | Removes a package, including configuration files                                                  |
| <code>-p</code> or <code>--print-avail</code>          | Displays information about an installed package                                                   |
| <code>-I</code> or <code>--info</code>                 | Displays information about an uninstalled package file                                            |
| <code>-l pattern</code> or <code>--list pattern</code> | Lists all installed packages whose names match <i>pattern</i>                                     |



**TABLE 2.4** dpkg Primary Actions (*continued*)

| Action                                       | Description                                                                 |
|----------------------------------------------|-----------------------------------------------------------------------------|
| -L or --listfiles                            | Lists the installed files associated with a package                         |
| -S <i>pattern</i> or --search <i>pattern</i> | Locates the package(s) that own the file(s) specified by <i>pattern</i>     |
| -C or --audit                                | Searches for partially installed packages and suggests what to do with them |

**TABLE 2.5** Options for Fine-Tuning dpkg Actions

| Option                           | Used with Actions | Description                                                                                                                                                                                             |
|----------------------------------|-------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| --root= <i>dir</i>               | All               | Modifies the Linux system using a root directory located at <i>dir</i> . Can be used to maintain one Linux installation discrete from another one, say during OS installation or emergency maintenance. |
| -B or --auto-deconfigure         | -r                | Disables packages that rely on one that is being removed.                                                                                                                                               |
| --force- <i>things</i>           | Assorted          | Forces specific actions to be taken. Consult the dpkg man page for details of <i>things</i> this option does.                                                                                           |
| --ignore-depends= <i>package</i> | -i, -r            | Ignores dependency information for the specified package.                                                                                                                                               |
| --no-act                         | -i, -r            | Checks for dependencies, conflicts, and other problems without actually installing or removing the package.                                                                                             |
| --recursive                      | -i                | Installs all packages that match the package name wildcard in the specified directory and all subdirectories.                                                                                           |
| -G                               | -i                | Doesn't install the package if a newer version of the same package is already installed.                                                                                                                |
| -E or --skip-same-version        | -i                | Doesn't install the package if the same version of the package is already installed.                                                                                                                    |

As with `rpm`, `dpkg` expects a package name in some cases and a package filename in others. Specifically, `--install (-i)` and `--info (-I)` both require the package filename, but the other commands take the shorter package name.

As an example, consider the following command, which installs the `samba_3.0.26a-1ubuntu2.3_amd64.deb` package:

```
dpkg -i samba_3.0.26a-1ubuntu2.3_amd64.deb
```

If you're upgrading a package, you may need to remove an old package before installing the new one. To do this, use the `-r` option to `dpkg`, as in the following:

```
dpkg -r samba
```

To find information about an installed package, use the `-p` parameter to `dpkg`, as shown in Listing 2.2. This listing omits an extended English description of what the package does.

### Listing 2.2: `dpkg` Package Information Query Output

```
$ dpkg -p samba
Package: samba
Priority: optional
Section: net
Installed-Size: 9792
Maintainer: Ubuntu Core Developers <ubuntu-devel-discuss@lists.ubuntu.com>
Architecture: amd64
Version: 3.0.26a-1ubuntu2.3
Replaces: samba-common (<= 2.0.5a-2)
Depends: samba-common (= 3.0.26a-1ubuntu2.3), logrotate, libacl1 (>= 2.2.11-1),
libattr1 (>= 2.4.4-1), libc6 (>= 2.6-1), libcomerr2 (>= 1.33-3), libcupsys2
(>= 1.3.0), libgnutls13 (>= 1.6.3-0), libkrb53 (>= 1.6.dfsg.1), libldap2
(>= 2.1.17-1), libpam0g (>= 0.99.7.1), libpopt0 (>= 1.10), zlib1g
(>= 1:1.2.3.3.dfsg-1), debconf (>= 0.5) | debconf-2.0, libpam-runtime
(>= 0.76-13.1), libpam-modules, lsb-base (>= 3.0-6), procps, update-inetd
Recommends: smbldap-tools
Suggests: openbsd-inetd | inet-superserver
Size: 4180134
```

Debian-based systems often use a pair of somewhat higher-level utilities, `apt-get` and `dselect`, to handle package installation and removal. These utilities are described in the next couple of sections. Their interfaces can be very useful when you want to install several packages, but `dpkg` is often more convenient when you're manipulating just one or two packages. Because `dpkg` can take package filenames as input, it's also the preferred method of installing a package that you download from an unusual source or create yourself.

## Using *apt-cache*

The APT suite of tools includes a program, `apt-cache`, that's intended solely to provide information about the Debian package database (known in Debian terminology as the *package cache*). You may be interested in using several features of this tool:

**Display package information** Using the `showpkg` subcommand, as in `apt-cache showpkg samba`, displays information about the package. The information displayed is different from that returned by `dpkg`'s informational actions.

**Display package statistics** You can learn how many packages you've installed, how many dependencies are recorded, and various other statistics about the package database, by passing the `stats` subcommand, as in `apt-cache stats`.

**Find unmet dependencies** If a program is reporting missing libraries or files, typing `apt-cache unmet` may help; this function of `apt-cache` returns information about unmet dependencies, which may help you track down the source of missing-file problems.

**Display dependencies** Using the `depends` subcommand, as in `apt-cache depends samba`, shows all of the specified package's dependencies. This information can be helpful in tracking down dependency-related problems. The `rdepends` subcommand finds reverse dependencies—packages that depend on the one you specify.

**Locate all packages** The `pkgnames` subcommand displays the names of all the packages installed on the system. If you include a second parameter, as in `apt-cache pkgnames sa`, the program returns only those packages that begin with the specified string.

Several more subcommands and options exist, but these are the ones you're most likely to use. Several `apt-cache` subcommands are intended for package maintainers and debugging serious package database problems rather than day-to-day system administration. Consult the man page for `apt-cache` for more information.

## Using *apt-get*

APT, and its `apt-get` utility, is Debian's equivalent to Yum on certain RPM-based distributions. This meta-packaging tool enables you to perform easy upgrades of packages, especially if you have a fast Internet connection. Debian-based systems include a file, `/etc/apt/sources.list`, that specifies locations from which important packages can be obtained. If you installed the OS from a CD-ROM drive, this file will initially list directories on the installation CD-ROM in which packages can be found. There are also likely to be a few lines near the top, commented out with hash marks (`#`), indicating directories on an FTP site or a Web site from which you can obtain updated packages. (These lines may be uncommented if you did a network install initially.)



Although APT is most strongly associated with Debian systems, a port to RPM-based systems is also available. Check <http://apt4rpm.sourceforge.net> for information about this port.



Don't add a site to `/etc/apt/sources.list` unless you're sure it can be trusted. The `apt-get` utility does automatic and semiautomatic upgrades, so if you add a network source to `sources.list` and that source contains unreliable programs or programs with security holes, your system will become vulnerable after upgrading via `apt-get`.

The `apt-get` utility works by obtaining information about available packages from the sources listed in `/etc/apt/sources.list` and then using that information to upgrade or install packages. The syntax is similar to that of `dpkg`:

```
apt-get [options][command] [package-names]
```

Table 2.6 lists the `apt-get` commands, and Table 2.7 lists the most commonly used options. In most cases, you won't use *any* options with `apt-get`—just a single command and possibly one or more package names. One particularly common use of this utility is to keep your system up to date with any new packages. The following two commands will accomplish this goal if `/etc/apt/sources.list` includes pointers to up-to-date file archive sites:

```
apt-get update
apt-get dist-upgrade
```

**TABLE 2.6** apt-get Commands

| Command                      | Description                                                                                                                                                                                |
|------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>update</code>          | Obtains updated information about packages available from the installation sources listed in <code>/etc/apt/sources.list</code> .                                                          |
| <code>upgrade</code>         | Upgrades all installed packages to the newest versions available, based on locally stored information about available packages.                                                            |
| <code>dselect-upgrade</code> | Performs any changes in package status (installation, removal, and so on) left undone after running <code>dselect</code> .                                                                 |
| <code>dist-upgrade</code>    | Similar to <code>upgrade</code> , but performs “smart” conflict resolution to avoid upgrading a package if doing so would break a dependency.                                              |
| <code>install</code>         | Installs a package by package name (not by package filename), obtaining the package from the source that contains the most up-to-date version.                                             |
| <code>remove</code>          | Removes a specified package by package name.                                                                                                                                               |
| <code>source</code>          | Retrieves the newest available source package file by package filename using information about available packages and installation archives listed in <code>/etc/apt/sources.list</code> . |

**TABLE 2.6** apt-get Commands (*continued*)

| Command   | Description                                                                                                                                                                                                          |
|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| check     | Checks the package database for consistency and broken package installations.                                                                                                                                        |
| clean     | Performs housekeeping to help clear out information about retrieved files from the Debian package database. If you don't use dselect for package management, run this from time to time in order to save disk space. |
| autoclean | Similar to clean, but removes information only about packages that can no longer be downloaded.                                                                                                                      |

**TABLE 2.7** Most Useful apt-get Options

| Option                                                        | Used with Commands                                | Description                                                                                                               |
|---------------------------------------------------------------|---------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| -d or --download-only                                         | upgrade, dselect-upgrade, install, source         | Downloads package files but doesn't install them.                                                                         |
| -f or --fix-broken                                            | install, remove                                   | Attempts to fix a system on which dependencies are unsatisfied.                                                           |
| -m, --ignore-missing, or --fix-missing                        | upgrade, dselect-upgrade, install, remove, source | Ignores all package files that can't be retrieved (because of network errors, missing files, or the like).                |
| -q or --quiet                                                 | All                                               | Omits some progress indicator information. May be doubled (for instance, -qq) to produce still less progress information. |
| -s, --simulate, --just-print, --dry-run, --recon, or --no-act | All                                               | Performs a simulation of the action without actually modifying, installing, or removing files.                            |
| -y, --yes, or --assume-yes                                    | All                                               | Produces a "yes" response to any yes/no prompt in installation scripts.                                                   |

**TABLE 2.7** Most Useful apt-get Options (*continued*)

| Option                    | Used with Commands | Description                                                                              |
|---------------------------|--------------------|------------------------------------------------------------------------------------------|
| -b, --compile, or --build | source             | Compiles a source package after retrieving it.                                           |
| --no-upgrade              | install            | Causes apt-get to <i>not</i> upgrade a package if an older version is already installed. |



If you use APT to automatically upgrade all packages on your system, you're effectively giving control of your system to the distribution maintainer. Although Debian or other distribution maintainers are unlikely to try to break into your computer in this way, an automatic update with minimal supervision on your part could easily break something on your system, particularly if you've obtained packages from unusual sources in the past.

In Exercise 2.2, you'll familiarize yourself with the Debian package system.

## EXERCISE 2.2

### Managing Debian Packages

To manage Debian packages, follow these steps:

1. Log into the Linux system as a normal user.
2. Acquire a package to use for testing purposes. You can try using a package from your distribution that you know you haven't installed; but if you try a random package, you may find it's already installed or has unmet dependencies. This lab uses as an example the installation of `zsh_4.3.4-24ubuntu1_amd64.deb`, a shell that's not installed by default on most systems, obtained using the `-d` option to `apt-get` on an Ubuntu 8.04 system. You must adjust the commands as necessary if you use another package, distribution, or architecture in your tests.
3. Launch an `xterm` from the desktop environment's menu system if you used a GUI login.
4. Acquire root privileges. You can do this by typing `su` in an `xterm`, by selecting `Session > New Root Console` from a `Konsole` window, or by using `sudo` (if it's configured) to run the commands in the following steps.
5. Type `dpkg -L zsh` to verify that the package isn't currently installed. This command responds with a list of files associated with the package if it's installed or with an error that reads `Package `zsh' is not installed` if it's not.

**EXERCISE 2.2 (continued)**

6. Type **dpkg -I zsh\_4.3.4-24ubuntu1\_amd64.deb**. (You'll need to add a complete path to the package file if it's not in your current directory.) The system should respond by displaying information about the package, such as the version number, dependencies, the name of the package maintainer, and a package description.
  7. Type **dpkg -i zsh\_4.3.4-24ubuntu1\_amd64.deb**. The system should install the package and display a series of lines summarizing its actions as it does so.
  8. Type **dpkg -p zsh**. The system should respond with information about the package similar to that displayed in step 6.
  9. Type **zsh**. This launches a Z shell, which functions much like the more common bash and tcsh shells. You're likely to see your command prompt change slightly, but you can issue most of the same commands you can use with bash or tcsh.
  10. Type **dpkg -P zsh**. This command removes the package from the system, including configuration files. It may produce a series of warnings about non-empty directories that it couldn't remove. Note that you're removing the zsh package while running the zsh program. Linux continues to run the zsh program you're using, but you'll be unable to launch new instances of the program. Some programs may misbehave because files will be missing after you remove the package.
  11. Type **exit** to exit from zsh and return to your normal shell.
  12. Type **dpkg -L zsh**. The system should respond with a Package `zsh' is not installed error because you've just uninstalled it.
  13. Type **apt-get install zsh** to install zsh using the APT system. Depending on your configuration, the system may download the package from an Internet site or ask you to insert a CD-ROM. If it asks for a CD-ROM, insert it and press the Enter key. The system should install the package.
  14. Type **dpkg -p zsh**. The system should respond with information about the package similar to that displayed in step 6 or 8.
  15. Type **dpkg -P zsh**. This command removes the package from the system, as described in step 10.
- 

## Using *dselect*, *aptitude*, and *Synaptic*

The *dselect* program is a high-level package browser. Using it, you can select packages to install on your system from the APT archives defined in `/etc/apt/sources.list`, review the packages that are already installed on your system, uninstall packages, and upgrade packages. Overall, *dselect* is a powerful tool, but it can be intimidating to the uninitiated because it presents a lot of options that aren't obvious, using a text-mode interactive user interface.

Although `dselect` supports a few command-line options, they're mostly obscure or minor (such as options to set the color scheme). Consult `dselect`'s man page for details. To use the program, type `dselect`. The result is the `dselect` main menu, as shown running in a KDE Konsole window in Figure 2.1.

**FIGURE 2.1** The `dselect` utility provides access to APT features using a menu system.

```

root@teela.rodsbooks.com: /root - Shell - Konsole
Session Edit View Bookmarks Settings Help
Debian 'dselect' package handling frontend.
* 0. [A]ccess Choose the access method to use.
 1. [U]pdate Update list of available packages, if possible.
 2. [S]elect Request which packages you want on your system.
 3. [I]nstall Install and upgrade wanted packages.
 4. [C]onfig Configure any packages that are unconfigured.
 5. [R]emove Remove unwanted software.
 6. [Q]uit Quit dselect.

Move around with ^P and ^N, cursor keys, initial letters, or digits;
Press <enter> to confirm selection. ^L redraws screen.

Version 1.10.26 (powerpc).
Copyright (C) 1994-1996 Ian Jackson.
Copyright (C) 2000,2001 Wichert Akkerman.
This is free software; see the GNU General Public Licence version 2
or later for copying conditions. There is NO warranty. See
dselect --licence for details.

```

Another text-based Debian package manager is `aptitude`. In interactive mode, `aptitude` is similar to `dselect` in a rough way, but `aptitude` adds menus accessed by pressing `Ctrl+T` and rearranges some features. You can also pass various commands to `aptitude` on the command line, as in `aptitude search samba`, which searches for packages related to Samba. Features accessible from the command line (or the interactive interface) include the following:

**Update package lists** You can update package lists from the APT repositories by typing `aptitude update`.

**Install software** The `install` command-line option installs a named package. This command has several variant names and syntaxes that modify its action. For instance, typing `aptitude install zsh` installs the `zsh` package, but typing `aptitude install zsh-` and `aptitude remove zsh` both uninstall `zsh`.

**Upgrade software** The `full-upgrade` and `safe-upgrade` options both upgrade all installed packages. The `safe-upgrade` option is conservative about removing packages or installing new ones and so may fail; `full-upgrade` is less conservative about these actions and so is more likely to complete its tasks, but it may break software in the process.

**Search for packages** The `search` option, noted earlier, searches the database for packages matching the specified name. The result is a list of packages, one per line, with summary codes for each package's install status, its name, and a brief description.



**Clean up the database** The `autoclean` option removes already downloaded packages that are no longer available, and `clean` removes all downloaded packages.

**Obtain help** Typing `aptitude help` results in a complete list of options.

Broadly speaking, `aptitude` combines the interactive features of `dselect` with the command-line options of `apt-get`. All three programs provide similar functionality, so you can use whichever one you prefer.

A tool that's similar to `dselect` and `aptitude` in some ways is Synaptic, but Synaptic is a fully GUI X-based program and as such is easier to use. Overall, `dselect`, `aptitude`, and Synaptic are useful tools, particularly if you need to locate software but don't know its exact name—the ability to browse and search the available packages can be a great boon. Unfortunately, the huge package list can be intimidating.

## Reconfiguring Packages

Debian packages often provide more extensive initial setup options than do their RPM counterparts. Frequently, the install script included in the package asks a handful of questions, such as asking for the name of an outgoing mail-relay system for a mail server program. These questions help the system set up a standardized configuration that's nonetheless been customized for your system.

In the course of your system administration, you may alter the configuration files for a package. If you do this and find you've made a mess of things, you may want to revert to the initial standard configuration. To do so, you can use the `dpkg-reconfigure` program, which runs the initial configuration script for the package you specify:

```
dpkg-reconfigure samba
```

This command reconfigures the `samba` package, asking the package's initial installation questions and restarting the Samba daemons. Once this is done, the package should be in something closer to its initial state.

## Debian Packages Compared to Other Package Formats

The overall functionality of Debian packages is similar to that of RPMs, although there are differences. Debian source packages aren't single files; they're groups of files—the original source tarball, a patch file that's used to modify the source code (including a file that controls the building of a Debian package), and a `.dsc` file that contains a digital “signature” to help verify the authenticity of the collection. The Debian package tools can combine these and compile the package to create a Debian binary package. This structure makes Debian source packages slightly less convenient to transport because you must move at least two files (the tarball and patch file; the `.dsc` file is optional) rather than just one. Debian source packages also support just one patch file, whereas RPM source packages may contain multiple patch files. Although you can certainly combine multiple patch files into one, doing so makes it less clear where a patch comes from, thus making it harder to back out of any given change.

These source package differences are mostly of interest to software developers. As a system administrator or end user, you need not normally be concerned with them unless you must recompile a package from a source form—and even then, the differences between the formats need not be overwhelming. The exact commands and features used by each system differ, but they accomplish similar overall goals.

Because all distributions that use Debian packages are derived from Debian, they tend to be more compatible with one another (in terms of their packages) than RPM-based distributions are. In particular, Debian has defined details of its system startup scripts and many other features to help Debian packages install and run on any Debian-based system. This helps Debian-based systems avoid the sorts of incompatibilities in startup scripts that can cause problems using one distribution’s RPMs on another distribution. Of course, some future distribution could violate Debian’s guidelines for these matters, so this advantage isn’t guaranteed to hold over time.

As a practical matter, it can be harder to locate Debian packages than RPM packages for some exotic programs. Debian maintains a good collection at <http://www.debian.org/distrib/packages>, and some program authors make Debian packages available as well. If you can find an RPM but not a Debian package, you may be able to convert the RPM to Debian format using a program called `alien`, as described shortly in “Converting Between Package Formats.” If all else fails, you can use a tarball, but you’ll lose the advantages of the Debian package database.

## Configuring Debian Package Tools

With the exception of the APT sources list mentioned earlier, Debian package tools don’t usually require configuration. Debian installs reasonable defaults (as do its derivative distributions). On rare occasions, though, you may want to adjust some of these defaults. Doing so requires that you know where to look for them.

The main configuration file for `dpkg` is `/etc/dpkg/dpkg.cfg` or `~/dpkg.cfg`. This file contains `dpkg` options, as summarized in Table 2.5, but without the leading dashes. For instance, to have `dpkg` always perform a test run rather than actually install a package, you’d create a `dpkg.cfg` file that contains one line:

```
no-act
```

For APT, the main configuration file you’re likely to modify is `/etc/apt/sources.list`, which is described earlier, in “Using *apt-get*.” Beyond this file is `/etc/apt/apt.conf`, which controls APT and `dselect` options. As with `dpkg.cfg`, chances are you won’t need to modify `apt.conf`. If you do need to make changes, the format is more complex and is modeled after those of the Internet Software Consortium’s (ISC’s) Dynamic Host Configuration Protocol (DHCP) and Berkeley Internet Name Domain (BIND) servers’ configuration files. Options are grouped together by open and close curly braces (`{ }`):

```
APT
{
```

```
Get
{
 Download-Only "true";
};
};
```

These lines are equivalent to permanently setting the `--download-only` option described in Table 2.7. You can, of course, set many more options. For details, consult `apt.conf`'s man page. You may also want to review the sample configuration file, `/usr/share/doc/apt/examples/apt.conf`. (The working `/etc/apt/apt.conf` file is typically extremely simple and therefore not very helpful as an example.)

You should be aware that Debian's package tools rely on various files in the `/var/lib/dpkg` directory tree. These files maintain lists of available packages, lists of installed packages, and so on. In other words, this directory tree is effectively the Debian installed file database. As such, you should be sure to back up this directory when you perform system backups and be careful about modifying its contents.

## Converting Between Package Formats

Sometimes you're presented with a package file in one format, but you want to use another format. This is particularly common when you use a Debian-based distribution and can only find tarballs or RPM files of a package. When this happens, you can keep looking for a package file in the appropriate format, install the tools for the foreign format, create a package from a source tarball using the standard RPM or Debian tools, or convert between package formats with a utility like `alien`.

This section focuses on this last option. The `alien` program comes with Debian and a few other distributions but may not be installed by default. If it's not installed on your system, install it by typing `apt-get install alien` on a system that uses APT, or use the RPM Find or Debian package Web site to locate it. This program can convert between RPM packages, Debian packages, Stampede packages (used by Stampede Linux), and tarballs.

You need to be aware of some caveats. For one thing, `alien` requires that you have appropriate package manager software installed—for instance, both RPM and Debian to convert between these formats. The `alien` utility doesn't always convert all dependency information completely correctly. When converting from a tarball, `alien` copies the files directly as they had been in the tarball, so `alien` works only if the original tarball has files that should be installed off the root (`/`) directory of the system.



Although `alien` requires both RPM and Debian package systems to be installed to convert between these formats, `alien` doesn't use the database features of these packages unless you use the `--install` option. The presence of a foreign package manager isn't a problem as long as you don't use it to install software that might duplicate or conflict with software installed with your primary package manager.

The basic syntax of `alien` is as follows:

```
alien [options] file[...]
```

The most important options are `--to-deb`, `--to-rpm`, `--to-slp`, and `--to-tgz`, which convert to Debian, RPM, Stampede, and tarball format, respectively. (If you omit the destination format, `alien` assumes you want a Debian package.) The `--install` option installs the converted package and removes the converted file. Consult the `alien` man page for additional options.

For instance, suppose you have a Debian package called `someprogram-1.2.3-4_i386.deb`, and you want to create an RPM from it. You can issue the following command to create an RPM called `someprogram-1.2.3-5.i386.rpm`:

```
alien --to-rpm someprogram-1.2.3-4_i386.deb
```

If you use a Debian-based system and want to install a tarball but keep a record of the files it contains in your Debian package database, you can do so with the following command:

```
alien --install binary-tarball.tar.gz
```

It's important to remember that converting a tarball converts the files in the directory structure of the original tarball using the system's root directory as the base. Therefore, you may need to unpack the tarball, juggle files around, and repack it to get the desired results *prior to* installing the tarball with `alien`. For instance, suppose you've got a binary tarball that creates a directory called `program-files`, with `bin`, `man`, and `lib` directories under this. The intent may have been to unpack the tarball in `/usr` or `/usr/local` and create links for critical files. To convert this tarball to an RPM, you can issue the following commands:

```
tar xvfz program.tar.gz
mv program-files usr
tar cvfz program.tgz usr
rm -r usr
alien --to-rpm program.tgz
```

By renaming the `program-files` directory to `usr` and creating a new tarball, you've created a tarball that, when converted to RPM format, will have files in the locations you want—`/usr/bin`, `/usr/man`, and `/usr/lib`. You might need to perform more extensive modifications, depending on the contents of the original tarball.

## Package Dependencies and Conflicts

Although package installation often proceeds smoothly, sometimes it doesn't. The usual sources of problems relate to unsatisfied dependencies or conflicts between packages. The RPM and Debian package management systems are intended to help you locate and resolve such problems, but on occasion (particularly when mixing packages from different vendors), they can actually cause problems. In either event, it pays to recognize these errors and know how to resolve them.



If you use a meta-packager, such as Yum or APT, for all your package management, you're much less likely to run into problems with package dependencies and conflicts. These problems are most likely to arise when you install lone packages, especially those from unusual sources.

## Real and Imagined Package Dependency Problems

Package dependencies and conflicts can arise for a variety of reasons, including the following:

**Missing libraries or support programs** One of the most common dependency problems is caused by a missing support package. For instance, all KDE programs rely on Qt, a widget set that provides assorted GUI tools. If Qt isn't installed, you won't be able to install any KDE packages using RPMs or Debian packages. Libraries—support code that can be used by many different programs as if it were part of the program itself—are particularly common sources of problems in this respect.

**Incompatible libraries or support programs** Even if a library or support program is installed on your system, it may be the wrong version. For instance, if a program requires Qt 3.3, the presence of Qt 2.2 won't do much good. Fortunately, Linux library-naming conventions enable you to install multiple versions of a library in case you have programs with competing requirements.

**Duplicate files or features** Conflicts arise when one package includes files that are already installed and that belong to another package. Occasionally, broad features can conflict as well, as in two Web server packages. Feature conflicts are usually accompanied by name conflicts. Conflicts are most common when mixing packages intended for different distributions, because distributions may split files across packages in different ways.

**Mismatched names** RPM and Debian package management systems give names to their packages. These names don't always match across distributions. For this reason, if one package checks for another package by name, the first package may not install on another distribution, even if the appropriate package is installed, because that target package has a different name.

Some of these problems are very real and serious. Missing libraries, for instance, must be installed. (Sometimes, though, a missing library isn't quite as missing as it seems, as described in the upcoming section "Forcing the Installation.") Others, like mismatched package names, are artifacts of the packaging system. Unfortunately, it's not always easy to tell into which category a conflict fits. When using a package management system, you may be able to use the error message returned by the package system, along with your own experience with and knowledge of specific packages, to make a judgment. For instance, if RPM reports that you're missing a slew of libraries with which you're unfamiliar, you'll probably have to track down at least one package—unless you know you've installed the libraries in some other way, in which case you may want to force the installation.

## Workarounds to Package Dependency Problems

When you encounter an unmet package dependency or conflict, what can you do about it? There are several approaches to these problems. Some of these approaches work well in some situations but not others, so you should review the possibilities carefully. The options include forcing the installation, modifying your system to meet the dependency, rebuilding the problem package from source code, and finding another version of the problem package.

### Forcing the Installation

One approach is to ignore the issue. Although this sounds risky, it's appropriate in some cases involving failed RPM or Debian dependencies. For instance, if the dependency is on a package that you installed by compiling the source code yourself, you can safely ignore the dependency. When using `rpm`, you can tell the program to ignore failed dependencies by using the `--nodeps` parameter:

```
rpm -i apackage.rpm --nodeps
```

You can force installation over some other errors, such as conflicts with existing packages, by using the `--force` parameter:

```
rpm -i apackage.rpm --force
```



Do *not* use `--nodeps` or `--force` as a matter of course. Ignoring the dependency checks can lead you into trouble, so you should use these options only when you need to do so. In the case of conflicts, the error messages you get when you first try to install without `--force` will tell you which packages' files you'll be replacing, so be sure you back them up or are prepared to reinstall the package in case of trouble.

If you're using `dpkg`, you can use the `--ignore-depends=package`, `--force-depends`, and `--force-conflicts` parameters to overcome dependency and conflict problems in Debian-based systems. Because there's less deviation in package names and requirements among Debian-based systems, these options are less often needed on such systems.

### Upgrading or Replacing the Depended-On Package

Officially, the proper way to overcome a package dependency problem is to install, upgrade, or replace the depended-upon package. If a program requires, say, Qt 3.3 or greater, you should upgrade an older version (such as 3.2) to 3.3. To perform such an upgrade, you'll need to track down and install the appropriate package. This usually isn't too difficult if the new package you want comes from a Linux distribution, and especially if you use a meta-packager such as Yum or APT; the appropriate depended-on package should come with the same distribution.

One problem with this approach is that packages intended for different distributions sometimes have differing requirements. If you run Distribution A and install a package that

was built for Distribution B, the package will express dependencies in terms of Distribution B's files and versions. The appropriate versions may not be available in a form intended for Distribution A; and by installing Distribution B's versions, you can sometimes cause conflicts with other Distribution A packages. Even if you install the upgraded package and it works, you may run into problems in the future when it comes time to install some other program or upgrade the distribution as a whole—the upgrade installer may not recognize Distribution B's package or may not be able to upgrade to its own newer version.

## Rebuilding the Problem Package

Some dependencies result from the libraries and other support utilities installed on the computer that compiled the package, not from requirements in the underlying source code. If the software is recompiled on a system that has different packages, the dependencies will change. Therefore, rebuilding a package from source code can overcome at least some dependencies.

If you use an RPM-based system, the command to rebuild a package is straightforward: You call `rpmbuild` (or `rpm` with old versions of RPM) with the name of the source package and use `--rebuild`, as follows:

```
rpmbuild --rebuild packagename-version.src.rpm
```

Of course, to do this you must have the source RPM for the package. This can usually be obtained from the same location as the binary RPM. When you execute this command, `rpmbuild` extracts the source code and executes whatever commands are required to build a new package—or sometimes several new packages. (One source RPM can build multiple binary RPMs.) The compilation process can take anywhere from a few seconds to several hours, depending on the size of the package and the speed of your computer. The result should be one or more new binary RPMs in `/usr/src/distname/RPMS/arch`, where *distname* is a distribution-specific name (such as `redhat` on Red Hat or `packages` on SuSE) and *arch* is your CPU architecture (such as `i386` or `i586` for x86 or `ppc` for PowerPC). You can move these RPMs to any convenient location and install them just as you would any others.



Source packages are also available for Debian systems, but aside from sites devoted to Debian and related distributions, Debian source packages are rare. The sites that do have these packages provide them in forms that typically install easily on appropriate Debian or related systems. For this reason, it's less likely that you'll rebuild a Debian package from source.

## Locating Another Version of the Problem Package

Frequently, the simplest way to fix a dependency problem or package conflict is to use a different version of the package you want to install. This could be a newer or older official version (4.2.3 rather than 4.4.7, say), or it might be the same official version but built for your distribution rather than for another distribution. Sites like RPM Find (<http://www.rpmfind.net>)

and Debian's package listing (<http://www.debian.org/distrib/packages>) can be very useful in tracking down alternative versions of a package. Your own distribution's Web site or FTP site can also be a good place to locate packages.



If the package you're trying to install requires newer libraries than you've got and you don't want to upgrade those libraries, an older version of the package may work with your existing libraries. Before doing so, though, you should check to be sure that the newer version of the program doesn't fix security bugs. If it does, you should find another way to install the package.

The main problem with locating another version of the package is that sometimes you really need the version that's not installing correctly. It may have features you need, or it may fix important bugs. On occasion, other versions may not be available, or you may be unable to locate another version of the package in your preferred package format.

## Startup Script Problems

One particularly common problem when trying to install servers from one distribution in another is getting SysV startup scripts working. Although most major Linux distributions use SysV startup scripts, these scripts aren't always transportable across distributions. Different distributions frequently implement support routines in unique ways, so these scripts may be incompatible. The result is that the server you installed may not start up, even if the links to the startup scripts are correct. Possible workarounds include modifying the startup script that came with the server, building a new script based on another one from your distribution, and starting the server through a local startup script like `/etc/rc.d/rc.local` or `/etc/rc.d/boot.local`. Chapter 5, "Booting Linux and Editing Files," describes startup scripts in more detail.



Startup script problems affect only servers and other programs that are started automatically when the computer boots; they don't affect typical user applications or libraries.

## Managing Shared Libraries

Most Linux software relies heavily on *shared libraries*. The preceding sections have described some of the problems that can arise in managing shared library packages—for example, if a library isn't installed or is the wrong version, you may have problems installing a package. Library management goes beyond merely configuring them, though. To understand this, you must first understand a few library principles. You can then move on to setting the library path and using commands that manage libraries.



## Library Principles

The idea behind a library is to simplify programmers' lives by providing commonly used program fragments. For instance, one of the most important libraries is the *C library* (*libc*), which provides many of the higher-level features associated with the C programming language. Another common type of library is associated with GUIs. These libraries are often called *widget sets* because they provide the on-screen *widgets* used by programs—buttons, scroll bars, menu bars, and so on. The GIMP Tool Kit (GTK+) and Qt are the most popular Linux widget sets, and both ship largely as libraries. Libraries are chosen by programmers, not by users; you usually can't easily substitute one library for another. (The main exceptions are minor version upgrades.)



Linux uses the *GNU C library* (*glibc*) version of the C library. Package-manager dependencies and other library references are to *glibc* specifically. As of *glibc* 2.3.4, for historical reasons the main *glibc* file is usually called `/lib/libc.so.6`, but this file is sometimes a symbolic link to a file of another name, such as `/lib/libc-2.3.4.so`.

In principle, the routines in a library can be linked into a program's main file, just like all the object code files created by the compiler. This approach, however, has certain problems:

- The resulting program file is huge. This means it takes up a lot of disk space, and it consumes a lot of RAM when loaded.
- If multiple programs use the library, as is common, the program-size issue is multiplied several times.
- The program can't take advantage of improvements in the library without recompiling (or at least relinking) the program.

For these reasons, most programs use their libraries as shared libraries (a.k.a. *dynamic libraries*). In this form, the main program executable omits most of the library routines. Instead, the executable includes references to shared library files, which can then be loaded along with the main program file. This approach helps keep program file size down, enables sharing of the memory consumed by libraries across programs, and enables programs to take advantage of improvements in libraries by upgrading the library.



Linux shared libraries are similar to the dynamic link libraries (DLLs) of Windows. Windows DLLs are usually identified by `.DLL` filename extensions; but in Linux, shared libraries usually have a `.so` or `.so.version` extension, where *version* is a version number. (`.so` stands for *shared object*.) Linux *static libraries* (used by linkers for inclusion in programs when dynamic libraries aren't to be used) have `.a` filename extensions.

On the downside, shared libraries can degrade program load time slightly if the library isn't already in use by another program, and they can create software management complications:

- Shared library changes can be incompatible with some or all programs that use the library. Linux uses library numbering schemes to enable you to keep multiple versions of a library installed at once. Upgrades that shouldn't cause problems can overwrite older versions, whereas major upgrades get installed side-by-side with their older counterparts. This approach minimizes the chance of problems, but sometimes changes that *shouldn't* cause problems *do* cause them.
- Programs must be able to locate shared libraries. This task requires adjusting configuration files and environment variables. If it's done wrong, or if a program overrides the defaults and looks in the wrong place, the result is usually that the program won't run at all.
- The number of libraries for Linux has risen dramatically over time. When they're used in shared form, the result can be a tangled mess of package dependencies, particularly if you use programs that rely on many or obscure libraries. In most cases, this issue boils down to a package problem that can be handled by your package management tools.
- If an important shared library becomes inaccessible because it was accidentally overwritten, due to a disk error or for any other reason, the result can be severe system problems. In a worst-case scenario, the system might not even boot.

In most cases, these drawbacks are manageable and are much less important than the problems associated with using static libraries. Thus, dynamic libraries are very popular.



Static libraries are sometimes used by developers who create programs using particularly odd, outdated, or otherwise exotic libraries. This enables them to distribute their binary packages without requiring users to obtain and install their oddball libraries. Likewise, static libraries are sometimes used on small emergency systems, which don't have enough programs installed to make the advantages of shared libraries worth pursuing.

## Locating Library Files

The major administrative challenge of handling shared libraries involves enabling programs to locate those shared libraries. Binary program files can point to libraries either by name alone (as in `libc.so.6`) or by providing a complete path (as in `/lib/libc.so.6`). In the first case, you must configure a *library path*—a set of directories in which programs should search for libraries. This can be done both through a global configuration file and through an environment variable. If a static path to a library is wrong, you must find a way to correct the problem. In all of these cases, after making a change, you may need to use a special command to get the system to recognize the change, as described later in “Library Management Commands.”

## Setting the Path Systemwide

The first way to set the library path is to edit the `/etc/ld.so.conf` file. This file consists of a series of lines, each of which lists one directory in which shared library files may be found. Typically, this file lists between half a dozen and a couple dozen directories. Some distributions have an additional type of line in this file. These lines begin with the `include` directive; they list files that are to be included as if they were part of the main file. For instance, Ubuntu 8.04's `ld.so.conf` begins with this line:

```
include /etc/ld.so.conf.d/*.conf
```

This line tells the system to load all the files in `/etc/ld.so.conf.d` whose names end in `.conf` as if they were part of the main `/etc/ld.so.conf` file. This mechanism enables package maintainers to add their unique library directories to the search list by placing a `.conf` file in the appropriate directory.

Some distributions, such as Gentoo, use a mechanism with a similar goal but different details. With these distributions, the `env-update` utility reads files in `/etc/env.d` to create the final form of several `/etc` configuration files, including `/etc/ld.so.conf`. In particular, the `LDPATH` variables in these files are read, and their values make up the lines in `ld.so.conf`. Thus, to change `ld.so.conf` in Gentoo or other distributions that use this mechanism, you should add or edit files in `/etc/env.d` and then type **env-update** to do the job.

Generally speaking, there's seldom a need to change the library path system-wide. Library package files usually install themselves in directories that are already on the path or add their paths automatically. The main reason to make such changes would be if you installed a library package, or a program that creates its own libraries, in an unusual location via a mechanism other than your distribution's main package utility. For instance, you might compile a library from source code and then need to update your library path in this way.

After you change your library path, you must use `ldconfig` to have your programs use the new path, as described later in “Library Management Commands.”



In addition to the directories specified in `/etc/ld.so.conf`, Linux refers to the trusted library directories, `/lib` and `/usr/lib`. These directories are always on the library path, even if they aren't listed in `ld.so.conf`.

## Temporarily Changing the Path

Sometimes, changing the path permanently and globally is unnecessary and even inappropriate. For instance, you might want to test the effect of a new library before using it for all your programs. To do so, you could install the shared libraries in an unusual location and then set the `LD_LIBRARY_PATH` environment variable. This environment variable specifies additional directories the system is to search for libraries.



Chapter 9, “Writing Scripts, Configuring E-Mail, and Using Databases,” describes environment variables in more detail.

To set the `LD_LIBRARY_PATH` environment variable using the bash shell, you can type a command like this:

```
$ export LD_LIBRARY_PATH=/usr/local/testlib:/opt/newlib
```

This line adds two directories, `/usr/local/testlib` and `/opt/newlib`, to the search path. You can specify as few or as many directories as you like, separated by colons. These directories are added to the *start* of the search path, which means they take precedence over other directories. This fact is handy when you’re testing replacement libraries, but it can cause problems if users manage to set this environment variable inappropriately.

You can set this environment variable permanently in a user’s shell startup script files, as described in Chapter 9. Doing so means the user will *always* use the specified library paths in addition to the normal system paths. In principle, you could set the `LD_LIBRARY_PATH` globally; however, using `/etc/ld.so.conf` is the preferred method of effecting global changes to the library path.

Unlike other library path changes, this one doesn’t require that you run `ldconfig` for it to take effect.

## Correcting Problems

Library path problems usually manifest as a program’s inability to locate a library. If you launch the program from a shell, you’ll see an error message like this:

```
$ gimp
gimp: error while loading shared libraries: libXinerama.so.1: cannot
open shared object file: No such file or directory
```

This message indicates that the system couldn’t find the `libXinerama.so.1` library file. The usual cause of such problems is that the library isn’t installed, so you should look for it using commands such as `find` (described in Chapter 4, “Managing Files”). If the file isn’t installed, try to track down the package to which it should belong (a Web search can work wonders in this task) and install it.

If, on the other hand, the library file *is* available, you may need to add its directory globally or to `LD_LIBRARY_PATH`. Sometimes the library’s path is hard-coded in the program’s binary file. (You can discover this using `ldd`, as described shortly in “Library Management Commands.”) When this happens, you may need to create a symbolic link from the location of the library on your system to the location the program expects. A similar problem can occur when the program expects a library to have one name but the library has another name on your system. For instance, the program may link to `biglib.so.5`, but your system has `biglib.so.5.2` installed. Minor version-number changes like this are usually inconsequential, so creating a symbolic link will correct the problem:

```
ln -s biglib.so.5.2 biglib.so.5
```

You must type this command as root in the directory in which the library resides. You must then run `ldconfig`, as described in the next section.

## Library Management Commands

Linux provides a pair of commands that you're likely to use for library management. The `ldd` program displays a program's shared library dependencies—that is, the shared libraries that a program uses. The `ldconfig` program updates caches and links used by the system for locating libraries—that is, it reads `/etc/ld.so.conf` and implements any changes in that file or in the directories to which it refers. Both of these tools are invaluable in managing libraries.

### Displaying Shared Library Dependencies

If you run into programs that won't launch because of missing libraries, the first step is to check which libraries the program file uses. You can do this with the `ldd` command:

```
$ ldd /bin/ls
 librt.so.1 => /lib/librt.so.1 (0x0000002a9566c000)
 libncurses.so.5 => /lib/libncurses.so.5 (0x0000002a95784000)
 libacl.so.1 => /lib/libacl.so.1 (0x0000002a958ea000)
 libc.so.6 => /lib/libc.so.6 (0x0000002a959f1000)
 libpthread.so.0 => /lib/libpthread.so.0 (0x0000002a95c17000)
 /lib64/ld-linux-x86-64.so.2 (0x0000002a95556000)
 libattr.so.1 => /lib/libattr.so.1 (0x0000002a95dad000)
```

Each line of output begins with a library name, such as `librt.so.1` or `libncurses.so.5`. If the library name doesn't contain a complete path, `ldd` attempts to find the true library and displays the complete path following the `=>` symbol, as in `/lib/librt.so.1` or `/lib/libncurses.so.5`. You needn't be concerned about the long hexadecimal number following the complete path to the library file. The preceding example shows one library (`/lib64/ld-linux-x86-64.so.2`) that's referred to with a complete path in the executable file. It lacks the initial directory-less library name and `=>` symbol.

The `ldd` command accepts a few options. The most notable of these is probably `-v`, which displays a long list of version information following the main entry. This information may be helpful in tracking down which version of a library a program is using, in case you have multiple versions installed.

Keep in mind that libraries can themselves depend on other libraries. Thus, you can use `ldd` to discover what libraries are used by a library. Because of this potential for a dependency chain, it's possible that a program will fail to run even though all its libraries are present. When using `ldd` to track down problems, be sure to check the needs of all the libraries of the program, and all the libraries used by the first tier of libraries, and so on, until you've exhausted the chain.

The `ldd` utility can be run by ordinary users, as well as by `root`. You must run it as `root` if you can't read the program file as an ordinary user.

## Reloading the Library Cache

Linux (or, more precisely, the `ld.so` and `ld-linux.so` programs, which manage the loading of libraries) doesn't read `/etc/ld.so.conf` every time a program runs. Instead, the system relies on a cached list of directories and the files they contain, stored in binary format in `/etc/ld.so.cache`. This list is maintained in a format that's much more efficient than a plain-text list of files and directories. The drawback is that you must reload that cache every time you add or remove libraries. These additions and removals include both changing the contents of the library directories and adding or removing library directories.

The tool to do this job is called `ldconfig`. Ordinarily, it's called without any options:

### # `ldconfig`

This program does, though, take options to modify its behavior:

**Display verbose information** Ordinarily, `ldconfig` doesn't display any information as it works. The `-v` option causes the program to summarize the directories and files it's registering as it goes about its business.

**Don't rebuild the cache** The `-N` option causes `ldconfig` to *not* perform its primary duty of updating the library cache. It will, though, update symbolic links to libraries, which is a secondary duty of this program.

**Process only specified directories** The `-n` option causes `ldconfig` to update the links contained in the directories specified on the command line. The system won't examine the directories specified in `/etc/ld.so.conf` or the trusted directories (`/lib` and `/usr/lib`).

**Don't update links** The `-X` option is the opposite of `-N`; it causes `ldconfig` to update the cache but not manage links.

**Use a new configuration file** You can change the configuration file from `/etc/ld.so.conf` by using the `-f conffile` option, where *conffile* is the file you want to use.

**Use a new cache file** You can change the cache file that `ldconfig` creates by passing the `-C cachefile` option, where *cachefile* is the file you want to use.

**Use a new root** The `-r dir` option tells `ldconfig` to treat *dir* as if it were the root (`/`) directory. This option is helpful when you're recovering a badly corrupted system or installing a new OS.

**Display current information** The `-p` option causes `ldconfig` to display the current cache—all the library directories and the libraries they contain.

Both RPM and Debian library packages typically run `ldconfig` automatically after installing or removing the package. The same thing happens as part of the installation process for many packages compiled from source. Thus, you may well be running `ldconfig` more than you realize in the process of software management. You may need to run the program yourself if you manually modify your library configuration in any way.

# Managing Processes

When you type a command name, that program is run, and a *process* is created for it. Knowing how to manage these processes is critical to using Linux. Key details in this task include identifying processes, manipulating foreground and background processes, killing processes, and adjusting process priorities.

## Understanding the Kernel: The First Process

The Linux kernel is at the heart of every Linux system. Although you can't manage the kernel process in quite the way you can manage other processes, short of rebooting the computer, you can learn about it. To do so, you can use the `uname` command, which takes several options to display information:

**Node name** The `-n` or `--nodename` option displays the system's node name—that is, its network hostname.

**Kernel name** The `-s` or `--kernel-name` option displays the kernel name, which is normally `Linux` on a Linux system.

**Kernel version** You can find the kernel version with the `-v` or `--kernel-version` option. Ordinarily, this holds the kernel build date and time, not an actual version number.

**Kernel release** The actual kernel version number can be found via the `-r` or `--kernel-release` option.

**Machine** The `-m` or `--machine` option returns information about your machine. This is likely to be a CPU code, such as `i686` or `x86_64`.

**Processor** Using the `-p` or `--processor` option may return information about your CPU, such as the manufacturer, model, and clock speed; in practice, it returns `unknown` on many systems.

**Hardware platform** Hardware platform information is theoretically returned by the `-i` or `--hardware-platform` option, but this option often returns `unknown`.

**OS name** The `-o` or `--operating-system` option returns the OS name—normally `GNU/Linux` for a Linux system.

**Print all information** The `-a` or `--all` option returns all available information.

In practice, you're most likely to use `uname -a` at the command line to learn some of the basics about your kernel and system. The other options are most useful in multi-platform scripts, which can use these options to quickly obtain critical information to help them adjust their actions for the system on which they're running.

## Examining Process Lists

One of the most important tools in process management is `ps`. This program displays processes' status (hence the name, `ps`). It sports many helpful options, and it's useful in

monitoring what’s happening on a system. This can be particularly critical when the computer isn’t working as it should be—for instance, if it’s unusually slow. The `ps` program supports an unusual number of options, but just a few of them will take you a long way. Likewise, interpreting `ps` output can be tricky because so many options modify the program’s output. Some `ps`-like programs, most notably `top`, also deserve attention.

## Using Useful `ps` Options

The official syntax for `ps` is fairly simple:

```
ps [options]
```

This simplicity of form hides considerable complexity because `ps` supports three different *types* of options, as well as many options within each type. The three types of options are as follows:

**Unix98 options** These single-character options may be grouped together and are preceded by a single dash (-).

**BSD options** These single-character options may be grouped together and must *not* be preceded by a dash.

**GNU long options** These multi-character options are never grouped together. They’re preceded by two dashes (--).

Options that may be grouped together may be clustered without spaces between them. For instance, rather than typing `ps -a -f`, you can type `ps -af`. The reason for so much complexity is that the `ps` utility has historically varied a lot from one Unix OS to another. The version of `ps` that ships with major Linux distributions attempts to implement most features from all these different `ps` versions, so it supports many different personalities. In fact, you can change some of its default behaviors by setting the `PS_PERSONALITY` environment variable to `posix`, `old`, `linux`, `bsd`, `sun`, `digital`, or various others. The rest of this section describes the default `ps` behavior on most Linux systems.

Some of the more useful `ps` features include the following:

**Display help** The `--help` option presents a summary of some of the more common `ps` options.

**Display all processes** By default, `ps` displays only processes that were run from its own terminal (`xterm`, text-mode login, or remote login). The `-A` and `-e` options cause it to display all the processes on the system, and `x` displays all processes owned by the user who gives the command. The `x` option also increases the amount of information that’s displayed about each process.

**Display one user’s processes** You can display processes owned by a given user with the `-u user`, `U user`, and `--User user` options. The *user* variable may be a username or a user ID.

**Display extra information** The `-f`, `-l`, `j`, `l`, `u`, and `v` options all expand the information provided in the `ps` output. Most `ps` output formats include one line per process, but `ps` can display enough information that it’s impossible to fit it all on one 80-character line. Therefore, these options provide various mixes of information.



**Display process hierarchy** The `-H`, `-f`, and `--forest` options group processes and use indentation to show the hierarchy of relationships between processes. These options are useful if you're trying to trace the parentage of a process.

**Display wide output** The `ps` command output can be more than 80 columns wide. Normally, `ps` truncates its output so that it will fit on your screen or `xterm`. The `-w` and `w` options tell `ps` not to do this, which can be useful if you direct the output to a file, as in `ps w > ps.txt`. You can then examine the output file in a text editor that supports wide lines.

You can combine these `ps` options in many ways to produce the output you want. You'll probably need to experiment to learn which options produce the desired results because each option modifies the output in some way. Even those that would seem to influence just the selection of processes to list sometimes modify the information that's provided about each process.

## Interpreting `ps` Output

Listings 2.3 and 2.4 show a couple of examples of `ps` in action. Listing 2.3 shows `ps -u rodsmith --forest`, and Listing 2.4 shows `ps u U rodsmith`.

**Listing 2.4:** Output of `ps -u rodsmith --forest`

```
$ ps -u rodsmith --forest
 PID TTY TIME CMD
 2451 pts/3 00:00:00 bash
 2551 pts/3 00:00:00 ps
 2496 ? 00:00:00 kvt
 2498 pts/1 00:00:00 bash
 2505 pts/1 00:00:00 _ nedit
 2506 ? 00:00:00 _ csh
 2544 ? 00:00:00 _ xeyes
19221 ? 00:00:01 dfm
```

**Listing 2.5:** Output of `ps u U rodsmith`

```
$ ps u U rodsmith
USER PID %CPU %MEM VSZ RSS TTY STAT START TIME COMMAND
rodsmith 19221 0.0 1.5 4484 1984 ? S May07 0:01 dfm
rodsmith 2451 0.0 0.8 1856 1048 pts/3 S 16:13 0:00 -bash
rodsmith 2496 0.2 3.2 6232 4124 ? S 16:17 0:00 /opt/kd
rodsmith 2498 0.0 0.8 1860 1044 pts/1 S 16:17 0:00 bash
rodsmith 2505 0.1 2.6 4784 3332 pts/1 S 16:17 0:00 nedit
rodsmith 2506 0.0 0.7 2124 1012 ? S 16:17 0:00 /bin/cs
rodsmith 2544 0.0 1.0 2576 1360 ? S 16:17 0:00 xeyes
rodsmith 2556 0.0 0.7 2588 916 pts/3 R 16:18 0:00 ps u U
```

The output produced by `ps` normally begins with a heading line, which displays the meaning of each column. Important information that may be displayed (and labeled) includes the following:

**Username** This is the name of the user who runs the programs. Listings 1.4 and 1.5 restricted this output to one user to limit the size of the listings.

**Process ID** The process ID (PID) is a number that's associated with the process. This item is particularly important because you need it to modify or kill the process, as described later in this chapter.

**Parent process ID** The parent process ID (PPID) identifies the process's parent. (Neither Listing 2.4 nor Listing 2.5 shows the PPID.)

**TTY** The teletype (TTY) is a code used to identify a terminal. As illustrated by Listings 1.4 and 1.5, not all processes have TTY numbers—X programs and daemons, for instance, don't. Text-mode programs do have these numbers, which point to a console, `xterm`, or remote login session.

**CPU time** The `TIME` and `%CPU` headings are two measures of CPU time used. The first indicates the total amount of CPU time consumed, and the second represents the percentage of CPU time the process is using when `ps` executes. Both can help you spot runaway processes—those that are consuming too much CPU time. Unfortunately, what constitutes “too much” varies from one program to another, so it's impossible to give a simple rule to help you spot a runaway process.

**CPU priority** As described shortly, in “Managing Process Priorities,” it's possible to give different processes different priorities for CPU time. The `NI` column, if present (it's not in the preceding examples) lists these priority codes. The default value is 0. Positive values represent *reduced* priority, whereas negative values represent *increased* priority.

**Memory use** Various headings indicate memory use—for instance, `RSS` is resident set size (the memory used by the program and its data) and `%MEM` is the percentage of memory the program is using. Some output formats also include a `SHARE` column, which is memory that's shared with other processes (such as shared libraries). As with CPU-use measures, these columns can help point you to the sources of difficulties; but because legitimate memory needs of programs vary so much, it's impossible to give a simple criterion for when a problem exists.

**Command** The final column in most listings is the command used to launch the process. This is truncated in Listing 2.5 because this format lists the complete command, but so much other information appears that the complete command won't usually fit on one line. (This is where the wide-column options can come in handy.)

As you can see, a lot of information can be gleaned from a `ps` listing—or perhaps that should be the plural *listings*, because no single format includes all of the available information. For the most part, the PID, username, and command are the most important pieces of information. In some cases, though, you may need specific other components. If your system's memory or CPU use has skyrocketed, for instance, you'll want to pay attention to the memory or CPU use column.



It's often necessary to find specific processes. You might want to find the PID associated with a particular command in order to kill it, for instance. This information can be gleaned by piping the `ps` output through `grep`, as in `ps ax | grep bash` to find all the instances of `bash`.

Although you may need a wide screen or `xterm` to view the output, you may find `ps -A --forest` to be a helpful command in learning about your system. Processes that aren't linked to others were either started directly by `init` or have had their parents killed, and so they have been “adopted” by `init`. (Chapter 5 describes `init` and the boot procedure in more detail.) Most of these processes are fairly important—they're servers, login tools, and so on. Processes that hang off several others in this tree view, such as `xeyes` and `nedit` in Listing 2.4, are mostly user programs launched from shells.

### top: A Dynamic `ps` Variant

If you want to know how much CPU time various processes are consuming relative to one another, or if you want to quickly discover which processes are consuming the most CPU time, a tool called `top` is the one for the job. The `top` tool is a text-mode program, but of course it can be run in an `xterm` or similar window, as shown in Figure 2.2; there are also GUI variants, like `kpm` and `gnome-system-monitor`. By default, `top` sorts its entries by CPU use, and it updates its display every few seconds. This makes it a very good tool for spotting runaway processes on an otherwise lightly loaded system—those processes almost always appear in the first position or two, and they consume an inordinate amount of CPU time. Looking at Figure 2.2, you might think that `FahCore_65.exe` is such a process, but in fact, it's legitimately consuming a lot of CPU time. You'll need to be familiar with the purposes and normal habits of programs running on *your* system in order to make such determinations; the legitimate needs of different programs vary so much that it's impossible to give a simple rule for judging when a process is consuming too much CPU time.

**FIGURE 2.2** The `top` command shows system summary information and information about the most CPU-intensive processes on a computer.

```

top - 21:51:03 up 20 days, 11:25, 20 users, load average: 2.09, 2.10, 2.02
Tasks: 150 total, 3 running, 146 sleeping, 0 stopped, 1 zombie
Cpu(s): 2.0% us, 0.0% sy, 98.0% ni, 0.0% id, 0.0% wa, 0.0% hi, 0.0% si
Mem: 513056k total, 509992k used, 3064k free, 36588k buffers
Swap: 683888k total, 237528k used, 446360k free, 140308k cached

 PID USER PR NI VIRT RES SHR S %CPU %MEM TIME+ COMMAND
 8673 root 39 19 70648 9m 2112 R 98.2 2.0 1664:29 FahCore_65.exe
 8774 rodsmith 15 0 48080 4992 45m S 1.3 1.0 411:12.66 artsd
12292 root 15 0 156m 67m 66m S 0.3 13.4 175:55.95 X
 1 root 16 0 2476 480 2312 S 0.0 0.1 0:02.39 init
 2 root 34 19 0 0 0 S 0.0 0.0 0:00.11 ksoftirqd/0
 3 root 5 -10 0 0 0 S 0.0 0.0 0:05.84 events/0
 4 root 5 -10 0 0 0 S 0.0 0.0 0:42.30 kblockd/0
 6 root 5 -10 0 0 0 S 0.0 0.0 0:00.00 khelper
 9 root 15 0 0 0 0 S 0.0 0.0 0:00.11 khubd
 10 root 15 -10 0 0 0 S 0.0 0.0 0:00.00 aicard/0
 9 root 15 0 0 0 0 S 0.0 0.0 0:18.85 kswapd0
 99 root 25 0 0 0 0 S 0.0 0.0 0:00.00 scsi_eh_0
 104 root 15 0 0 0 0 S 0.0 0.0 0:00.00 scsi_eh_1
 106 root 16 0 0 0 0 S 0.0 0.0 0:00.00 scsi_eh_2
 107 root 15 0 0 0 0 S 0.0 0.0 0:00.00 katad-2
 137 root 16 0 0 0 0 S 0.0 0.0 0:00.00 kseriod
 178 root 5 -10 0 0 0 S 0.0 0.0 0:07.52 reiserfs/0

```

Like many Linux commands, `top` accepts several options. The most useful are listed here:

- d *delay*** This option specifies the delay between updates, which is normally 5 seconds.
- p *pid*** If you want to monitor specific processes, you can list them using this option. You'll need the PIDs, which you can obtain with `ps`, as described earlier. You can specify up to 20 PIDs by using this option multiple times, once for each PID.
- n *iter*** You can tell `top` to display a certain number of updates (*iter*) and then quit. (Normally, `top` continues updating until you terminate the program.)
- b** This option specifies batch mode, in which `top` doesn't use the normal screen-update commands. You might use this to log CPU use of targeted programs to a file, for instance.

You can do more with `top` than watch it update its display. When it's running, you can enter any of several single-letter commands, some of which prompt you for additional information. These commands include the following:

- h and ?** These keystrokes display help information
- k** You can kill a process with this command. The `top` program will ask for a PID number, and if it's able to kill the process, it will do so. (The upcoming section "Killing Processes" describes other ways to kill processes.)
- q** This option quits from `top`.
- r** You can change a process's priority with this command. You'll have to enter the PID number and a new priority value—a positive value will decrease its priority, and a negative value will increase its priority, assuming it has the default 0 priority to begin with. Only `root` may increase a process's priority. The `renice` command (described shortly, in "Managing Process Priorities") is another way to accomplish this task.
- s** This command changes the display's update rate, which you'll be asked to enter (in seconds).
- P** This command sets the display to sort by CPU usage, which is the default.
- M** You can change the display to sort by memory usage with this command.

More commands are available in `top` (both command-line options and interactive commands) than can be summarized here; consult `top`'s man page for more information.

One of the pieces of information provided by `top` is the *load average*, which is a measure of the demand for CPU time by applications. In Figure 2.2, you can see three load-average estimates on the top line; these correspond to the current load average and two previous measures. A system on which no programs are demanding CPU time has a load average of 0. A system with one program running CPU-intensive tasks has a load average of 1. Higher load averages reflect programs competing for available CPU time. You can also find the current load average via the `uptime` command, which displays the load average along with information on how long the computer has been running. The load average can be useful in detecting runaway processes. For instance, if a system normally has a load average of 0.5 but it suddenly gets stuck at a load average of 2.5, a couple of CPU-hogging processes may have *hung*—that is, become unresponsive. Hung processes sometimes needlessly consume a lot of CPU time. You can use `top` to locate these processes and, if necessary, kill them.

## **jobs: Processes Associated with Your Session**

The `jobs` command displays minimal information about the processes associated with the current session. In practice, `jobs` is usually of limited value, but it does have a few uses. One of these is to provide job ID numbers. These numbers are conceptually similar to PID numbers, but they're not the same. Jobs are numbered starting from 1 for each session, and in most cases, a single shell has only a few associated jobs. The job ID numbers are used by a handful of utilities in place of PIDs, so you may need this information.

A second use of `jobs` is to ensure that all your programs have terminated prior to logging out. Under some circumstances, logging out of a remote login session can cause the client program to freeze up if you've left programs running. A quick check with `jobs` will inform you of any forgotten processes and enable you to shut them down.

## **Understanding Foreground and Background Processes**

One of the most basic process-management tasks is to control whether a process is running in the foreground or the background—that is, whether it's monopolizing the use of the terminal from which it was launched. Normally, when you launch a program, it takes over the terminal, preventing you from doing other work in that terminal. (Some programs, though, release the terminal. This is most common for servers and some GUI programs.)

If a program is running but you decide you want to use that terminal for something else, pressing `Ctrl+Z` normally pauses the program and gives you control of the terminal. (An important point is that this procedure suspends the program, so if it's performing real work, that work stops!) This can be handy if, say, you're running a text editor in a text-mode login, and you want to check a filename so you can mention it in the file you're editing. You press `Ctrl+Z` and type `!s` to get the file listing. To get back to the text editor, you then type `fg`, which restores the text editor to the foreground of your terminal. If you've suspended several processes, you add a job number, as in `fg 2` to restore job 2. You can obtain a list of jobs associated with a terminal by typing `jobs`, which displays the jobs and their job numbers.

A variant on `fg` is `bg`. Whereas `fg` restores a job to the foreground, `bg` restores a job to running status, but in the background. You can use this command if the process you're running is performing a CPU-intensive task that requires no human interaction but you want to use the terminal in the meantime. Another use of `bg` is in a GUI environment—after launching a GUI program from an `xterm` or similar window, that shell is tied up servicing the GUI program, which probably doesn't really need the shell. Pressing `Ctrl+Z` in the `xterm` window will enable you to type shell commands again, but the GUI program will be frozen. To unfreeze the GUI program, type `bg` in the shell, which enables the GUI program to run in the background while the shell continues to process your commands.

As an alternative to launching a program, using `Ctrl+Z`, and typing `bg` to run a program in the background, you can append an ampersand (`&`) to the command when launching the program. For instance, rather than edit a file with the `NEdit` GUI editor by typing `nedit myfile.txt`, you can type `nedit myfile.txt &`. This command launches the `nedit` program in the background from the start, leaving you able to control your `xterm` window for other tasks.

## Managing Process Priorities

Sometimes, you may want to prioritize your programs' CPU use. For instance, you may be running a program that's very CPU-intensive but that will take a long time to finish its work, and you don't want that program to interfere with others that are of a more interactive nature. Alternatively, on a heavily loaded computer, you may have a job that's more important than others that are running, so you may want to give it a priority boost. In either case, the usual method of accomplishing this goal is through the `nice` and `renice` commands. You can use `nice` to launch a program with a specified priority or use `renice` to alter the priority of a running program.

You can assign a priority to `nice` in any of three ways: by specifying the priority preceded by a dash (this works well for positive priorities but makes them look like negative priorities), by specifying the priority after a `-n` parameter, or by specifying the priority after an `--adjustment=` parameter. In all cases, these parameters are followed by the name of the program you want to run:

```
nice [argument] [command [command-arguments]]
```

For instance, the following three commands are all equivalent:

```
$ nice -12 number-crunch data.txt
$ nice -n 12 number-crunch data.txt
$ nice --adjustment=12 number-crunch data.txt
```

All three of these commands run the `number-crunch` program at priority 12 and pass it the `data.txt` file. If you omit the adjustment value, `nice` uses 10 as a default. The range of possible values is `-20` to `19`, with negative values having the highest priority. Only `root` may launch a program with increased priority (that is, give a negative priority value), but any user may use `nice` to launch a program with low priority. The default priority for a program run without `nice` is `0`.

If you've found that a running process is consuming too much CPU time or is being swamped by other programs and so should be given more CPU time, you can use the `renice` program to alter its priority without disrupting the program's operation. The syntax for `renice` is as follows:

```
renice priority [[-p] pids] [[-g] pgrps] [[-u] users]
```

You must specify the *priority*, which takes the same values this variable takes with `nice`. In addition, you must specify one or more PIDs (*pids*), one or more group IDs (*pgrps*), or one or more usernames (*users*). In the latter two cases, `renice` changes the priority of all programs that match the specified criterion—but only `root` may use `renice` in this way. Also, only `root` may increase a process's priority. If you give a numeric value without a `-p`, `-g`, or `-u` option, `renice` assumes the value is a PID. You may mix and match these methods of specification. For instance, you might enter the following command:

```
renice 7 16580 -u pdavison tbaker
```

This command sets the priority to 7 for PID 16580 and for all processes owned by `pdavison` and `tbaker`.

## Killing Processes

Sometimes, reducing a process's priority isn't a strong enough action. A program may have become totally unresponsive, or you may want to terminate a process that shouldn't be running. In these cases, the `kill` command is the tool to use. This program sends a *signal* (a method that Linux uses to communicate with processes) to a process. The signal is usually sent by the kernel, the user, or the program itself to terminate the process. Linux supports many numbered signals, each of which is associated with a specific name. You can see them all by typing `kill -l`. If you don't use `-l`, the syntax for `kill` is as follows:

```
kill -s signal pid
```



Although Linux includes a `kill` program, many shells, including `bash` and `csh`, include built-in `kill` equivalents that work in much the same way as the external program. If you want to be sure you're using the external program, type its complete path, as in `/bin/kill`.

The `-s signal` parameter sends the specified signal to the process. You can specify the signal using either a number (such as 9) or a name (such as `SIGKILL`). The signals you're most likely to use are 1 (`SIGHUP`, which terminates interactive programs and causes many daemons to reread their configuration files), 9 (`SIGKILL`, which causes the process to exit without performing routine shutdown tasks), and 15 (`SIGTERM`, which causes the process to exit but allows it to close open files and so on). If you don't specify a signal, the default is 15 (`SIGTERM`). You can also use the shortened form `-signal`. If you do this and use a signal name, you should omit the `SIG` portion of the name—for instance, use `KILL` rather than `SIGKILL`. The `pid` option is, of course, the PID for the process you want to kill. You can obtain this number from `ps` or `top`.



The `kill` program will kill only those processes owned by the user who runs `kill`. The exception is if that user is `root`; the superuser may kill any user's processes.



### Real World Scenario

#### Running Programs Persistently

Signals can be passed to programs by the kernel even if you don't use the `kill` command. For instance, when you log out of a session, the programs you started from that session are sent the `SIGHUP` signal, which causes them to terminate. If you want to run a program that will continue running even when you log out, you can launch it with the `nohup` program:

```
$ nohup program options
```

This command causes the program to ignore the `SIGHUP` signal. It can be handy if you want to launch certain small servers that may legitimately be run as ordinary users.



A variant on `kill` is `killall`, which has the following form:

```
killall [options] [--] name [...]
```

This command kills a process based on its name rather than its PID number. For instance, `killall vi` kills all the running processes called `vi`. You may specify a signal in the shortened form (*-signal*) or by preceding the signal number with `-s` or `--signal`. As with `kill`, the default is 15 (SIGTERM). One potentially important option to `killall` is `-i`, which causes it to ask for confirmation before sending the signal to each process. You might use it like this:

```
$ killall -i vi
Kill vi(13211) ? (y/n) y
Kill vi(13217) ? (y/n) n
```

In this example, two instances of the Vi editor were running, but only one should have been killed. As a general rule, if you run `killall` as root, you should use the `-i` parameter; if you don't, it's all too likely that you'll kill processes that you shouldn't, particularly if the computer is being used by many people at once.



Some versions of Unix provide a `killall` command that works very differently from Linux's `killall`. This alternate `killall` kills all the processes started by the user who runs the command. This is a potentially much more destructive command, so if you ever find yourself on a non-Linux system, *do not* use `killall` until you've discovered what that system's `killall` does (say, by reading the `killall` man page).

## Summary

Linux provides numerous tools to help you manage software. Most distributions are built around the RPM or Debian package systems, both of which enable installation, upgrade, and removal of software using a centralized package database to avoid conflicts and other problems that are common when no central package database exists. You can perform basic operations on individual files or, with the help of extra tools such as Yum and APT, keep your system synchronized with the outside world, automatically or semi-automatically updating all your software to the latest versions.

No matter how you install your software, you may need to manage shared libraries. These software components are necessary building blocks of large modern programs, and in the best of all possible worlds they operate entirely transparently. Sometimes, though, shared libraries need to be upgraded or the system configuration changed so that programs



can find the libraries. When this happens, knowing about critical configuration files and commands can help you work around any difficulties.

Beyond managing packages and libraries, Linux software management involves manipulating processes. Knowing how to manipulate foreground and background processes, adjust process priorities, and kill stray processes can help you keep your Linux system working well.

## Exam Essentials

**Identify critical features of RPM and Debian package formats.** RPM and Debian packages store all files for a given package in a single file that also includes information about what other packages the software depends on. These systems maintain a database of installed packages and their associated files and dependencies.

**Describe the tools used for managing RPMs.** The `rpm` program is the main tool for installing, upgrading, and uninstalling RPMs. This program accepts operations and options that tell it precisely what to do. The Yum utility, and particularly its `yum` command, enables installation of a package and all its dependencies via the Internet, rather than from local package files.

**Describe the tools used for managing Debian packages.** The `dpkg` program installs or uninstalls a single package or a group of packages you specify. The `apt-get` utility retrieves programs from installation media or from the Internet for installation and can automatically upgrade your entire system. The `dselect` program serves as a menu-driven interface to `apt-get`, enabling you to select programs you want to install from a text-mode menu.

**Summarize tools for extracting files and converting between package formats.** The `rpm2cpio` program can convert an RPM file to a `cpio` archive, enabling users of non-RPM systems to access files in an RPM. The `alien` utility can convert in any direction between Debian packages, RPMs, Stampede packages, and tarballs. This enables the use of packages intended for one system on another.

**Summarize the reasons for using shared libraries.** Shared libraries keep disk space and memory requirements manageable by placing code that's needed by many programs in separate files from the programs that use it, enabling one copy to be used multiple times. More generally, libraries enable programmers to use basic “building blocks” that others have written without having to constantly reinvent code.

**Describe methods available to change the library path.** The library path can be changed system-wide by editing the `/etc/ld.so.conf` file and then typing `ldconfig`. For temporary or per-user changes, directories may be added to the path by placing them in the `LD_LIBRARY_PATH` environment variable.

**Explain the difference between foreground and background processes.** Foreground processes have control of the current terminal or text-mode window (such as an `xterm`). Background processes don't have exclusive control of a terminal or text-mode window but are still running.

**Describe how to limit the CPU time used by a process.** You can launch a program with `nice` or use `renice` to alter its priority in obtaining CPU time. If a process is truly out of control, you can terminate it with the `kill` command.

# Review Questions

1. Which of the following is *not* an advantage of a source package over a binary package?
  - A. A single source package can be used on multiple CPU architectures.
  - B. By recompiling a source package, you can sometimes work around library incompatibilities.
  - C. You can modify the code in a source package, altering the behavior of a program.
  - D. Source packages can be installed more quickly than binary packages can.
2. Which is true of using both RPM and Debian package management systems on one computer?
  - A. It's generally inadvisable because the two systems don't share installed-file database information.
  - B. It's impossible because their installed-file databases conflict with one another.
  - C. It causes no problems if you install important libraries once in each format.
  - D. It's a common practice on Red Hat and Debian systems.
3. Which of the following statements is true about binary RPM packages that are built for a particular distribution?
  - A. They can often be used on another RPM-based distribution for the same CPU architecture, but this isn't guaranteed.
  - B. They may be used in another RPM-based distribution only when you set the `--convert-distrib` parameter to `rpm`.
  - C. They may be used in another RPM-based distribution only after you convert the package with `alien`.
  - D. They can be recompiled for an RPM-based distribution running on another type of CPU.
4. An administrator types the following command on an RPM-based Linux distribution:  

```
rpm -ivh megaprog.rpm
```

What is the effect of this command?

- A. The `megaprog` package, if it's installed, is uninstalled from the computer.
- B. The `megaprog.rpm` package, if it exists, is valid, and isn't already installed, is installed on the system.
- C. The `megaprog.rpm` source RPM package is compiled into a binary RPM for the computer.
- D. Nothing; `megaprog.rpm` isn't a valid RPM filename, so `rpm` will refuse to operate on this file.

5. Which of the following commands will extract the contents of the `myfonts.rpm` file into the current directory?
- A. `rpm2cpio myfonts.rpm | cpio -i --make-directories`
  - B. `rpm2cpio myfonts.rpm > make-directories`
  - C. `rpm -e myfonts.rpm`
  - D. `alien --to-extract myfonts.rpm`
6. To use `dpkg` to remove a package called `theprogram`, including its configuration files, which of the following commands would you issue?
- A. `dpkg -P theprogram`
  - B. `dpkg -p theprogram`
  - C. `dpkg -r theprogram`
  - D. `dpkg -r theprogram-1.2.3-4.deb`
7. Which of the following describes a difference between `apt-get` and `dpkg`?
- A. `apt-get` provides a GUI interface to Debian package management; `dpkg` doesn't.
  - B. `apt-get` can install tarballs in addition to Debian packages; `dpkg` can't.
  - C. `apt-get` can automatically retrieve and update programs from Internet sites; `dpkg` can't.
  - D. `apt-get` is provided only with the original Debian distribution, but `dpkg` comes with Debian and its derivatives.
8. What command would you type to obtain a list of all installed packages on a Debian system?
- A. `apt-cache pkgnames`
  - B. `apt-cache showpkg`
  - C. `dpkg -r allpkgs`
  - D. `dpkg -i`
9. As root, you type `apt-get update` on a Debian system. What should be the effect of this command?
- A. None; `update` is an invalid option to `apt-get`.
  - B. The APT utilities deliver information about the latest updates you've made to the APT Internet repositories, enabling you to share your changes with others.
  - C. The APT utilities download all available upgrades for your installed programs and install them on your system.
  - D. The APT utilities retrieve information about the latest packages available so that you may install them with subsequent `apt-get` commands.
10. Which of the following commands would you type to update the `unzip` program on a Fedora system to the latest version? (Select all that apply.)
- A. `yum update unzip`
  - B. `yum upgrade unzip`
  - C. `yum -u unzip`
  - D. `yum -U unzip`

11. How should you configure a system that uses Yum to access an additional Yum software repository?
  - A. Edit the `/etc/apt/sources.list` file to include the repository site's URL, as detailed on the repository's Web site.
  - B. Download a package from the repository site and install it with RPM, or place a configuration file from the repository site in the `/etc/yum.repos.d` directory.
  - C. Use the `add-repository` subcommand to `yum` or the Add Repository option in the File menu in `yumex`, passing it the URL of the repository.
  - D. Edit the `/etc/yum.conf` file, locate the `[repos]` section, and add the URL to the repository after the existing repository URLs.
12. What is the preferred method of adding a directory to the library path for all users?
  - A. Modify the `LD_LIBRARY_PATH` environment variable in a global shell script.
  - B. Add the directory to the `/etc/ld.so.conf` file, and then type `ldconfig`.
  - C. Type `ldconfig /new/dir`, where `/new/dir` is the directory you want to add.
  - D. Create a symbolic link from that directory to one that's already on the library path.
13. You prefer the look of GTK+ widgets to Qt widgets, so you want to substitute the GTK+ libraries for the Qt libraries on your system. How would you do this?
  - A. You must type `ldconfig --makesubs=qt,gtk`. This command substitutes the GTK+ libraries for the Qt libraries at load time.
  - B. You must uninstall the Qt library packages and re-install the GTK+ packages with the `--substitute=qt` option to `rpm` or the `--replace=qt` option to `dpkg`.
  - C. You must note the filenames of the Qt libraries, uninstall the packages, and create symbolic links from the Qt libraries to the GTK+ libraries.
  - D. You can't easily do this; libraries can't be arbitrarily exchanged for one another. You would need to rewrite all the Qt-using programs to use GTK+.
14. A user types `kill -9 11287` at a bash prompt. What is the probable intent, assuming the user typed the correct command?
  - A. To cut off a network connection using TCP port 11287
  - B. To display the number of processes that have been killed with signal 11287 in the last nine days
  - C. To cause a server with process ID 11287 to reload its configuration file
  - D. To terminate a misbehaving or hung program with process ID 11287
15. What programs might you use to learn what your system's load average is? (Select all that apply.)
  - A. `ld`
  - B. `load`
  - C. `top`
  - D. `uptime`

16. Which of the following commands creates a display of processes, showing the parent/child relationships through links between their names?
- A. **ps --forest**
  - B. **ps aux**
  - C. **ps -e**
  - D. All of the above
17. You use **top** to examine the CPU time being consumed by various processes on your system. You discover that one process, **dfcomp**, is consuming more than 90 percent of your system's CPU time. What can you conclude?
- A. Very little; **dfcomp** could be legitimately consuming that much CPU time or it could be an unauthorized or malfunctioning program.
  - B. No program should consume 90 percent of available CPU time; **dfcomp** is clearly malfunctioning and should be terminated.
  - C. This is normal; **dfcomp** is the kernel's main scheduling process, and it consumes any unused CPU time.
  - D. This behavior is normal *if* your CPU is less powerful than a 2.5GHz EM64T Pentium; but on newer systems, no program should consume 90 percent of CPU time.
18. You type **jobs** at a **bash** command prompt and receive a new command prompt with no intervening output. What can you conclude?
- A. The total CPU time used by your processes is negligible (below 0.1).
  - B. No processes are running under your username except the shell you're using.
  - C. The **jobs** shell is installed and working correctly on the system.
  - D. No background processes are running that were launched from the shell you're using.
19. Which two of the following commands are equivalent to one another? (Select two.)
- A. **nice --value 10 crunch**
  - B. **nice -n -10 crunch**
  - C. **nice -10 crunch**
  - D. **nice crunch**
20. Which of the following are restrictions on ordinary users' abilities to run **renice**? (Select all that apply.)
- A. Users may not modify the priorities of processes that are already running.
  - B. Users may not modify the priorities of other users' processes.
  - C. Users may not decrease the priority (that is, increase the priority value) of their own processes.
  - D. Users may not increase the priority (that is, decrease the priority value) of their own processes.

# Answers to Review Questions

1. D. Because they must be compiled prior to installation, source packages require *more* time to install than binary packages do, contrary to option D's assertion. The other options all describe advantages of source packages over binary packages.
2. A. Package management systems don't share information, but neither do their databases actively conflict. Installing the same libraries using both systems would almost guarantee that the files served by both systems would conflict with one another. Actively using both RPM and Debian packages isn't common on any distribution, although it's possible with all of them.
3. A. RPMs are usually portable across distributions, but occasionally they contain incompatibilities. There is no `--convert-distrib` parameter to `rpm`, nor is `alien` used to convert from RPM format to RPM format. Binary packages can't be rebuilt for another CPU architecture, but source packages may be rebuilt for any supported architecture provided the source code doesn't rely on any CPU-specific features.
4. B. The `-i` operation installs software, so option B is correct. (The `-v` and `-h` options cause a status display of the progress of the operation, which wasn't mentioned in the option.) Uninstallation is performed by the `-e` operation, and rebuilding source RPMs is done by the `--rebuild` operation (to either `rpm` or `rpmbuild`, depending on the RPM version). Although the filename `megaproj.rpm` is missing several conventional RPM filename components, the `rpm` utility doesn't use the filename as a package validity check, so option D is incorrect.
5. A. The `rpm2cpio` program extracts data from an RPM file and converts it into a `cpio` archive that's sent to standard output. Piping the results through `cpio` and using the `-i` and `--make-directories` options, as in option A, will extract those files to the current directory. Option B creates a `cpio` file called `make-directories` that contains the files from the RPM package. Option C will uninstall the package called `myfonts.rpm` (but not the `myfonts` package). The `alien` utility has no `--to-extract` target, so option D is invalid.
6. A. An uppercase `-P` invokes the purge operation, which completely removes a package and its configuration files. The lowercase `-p` causes `dpkg` to print information about the package's contents. The `-r` parameter removes a package but leaves configuration files behind. The final variant (option D) also specifies a complete filename, which isn't used for removing a package—you should specify only the shorter package name.
7. C. You can specify Debian package archive sites in `/etc/apt/sources.list`, and then you can type `apt-get update` and `apt-get upgrade` to quickly update a Debian system to the latest packages. GUI package management tools for Debian and related distributions exist, but they aren't `apt-get`. The `alien` program can convert an RPM file and install the converted package on a Debian system; `dpkg` and `apt-get` both come with all Debian-based distributions.

8. A. The `apt-cache` subcommand `pkgnames` displays the names of all installed packages or, if a further string is used, of all installed packages whose names begin with that string, making option A correct. The `showpkg` subcommand to `apt-cache` displays information about a named package; when used without a package name, as in option B, it displays no data. The `dpkg -r` action removes a package, so option C would remove the package called `allpkgs` if it were installed. The `dpkg -i` action installs a package, so option D is incorrect—and that option doesn't list a package name, which the `-i` action requires.
9. D. The `update` option to `apt-get` causes retrieval of new information, as described in option D. This option is perfectly valid, contrary to option A's assertion. The `apt-get` program doesn't permit you to upload information to the Internet repositories, so option B is incorrect. Option C describes the effect of the `upgrade` or `dist-upgrade` options, not the `update` option.
10. A, B. The `yum` utility's `update` and `upgrade` options are nearly identical in effect, and either can be used to upgrade an individual package, such as `unzip`. The primary command options to `yum` don't use dashes, so `-u` and `-U` are both incorrect.
11. B. Yum uses files in the `/etc/yum.repos.d` directory to locate its repositories, so you can add to the repository list by adding files to this subdirectory, as option B specifies, typically either by installing an RPM or by adding a file manually. Option A describes a method of adding a repository to a computer that uses APT, not Yum. Option C's `add-repository` subcommand is fictitious. Although the `/etc/yum.conf` file described in option D is real, it doesn't store repository data.
12. B. The `/etc/ld.so.conf` file holds the global library path, so editing it is the preferred approach. You must then type `ldconfig` to have the system update its library path cache. Although you can add a directory to the library path by altering the `LD_LIBRARY_PATH` environment variable globally, this approach isn't the preferred one. Option C simply won't work. Option D also won't work, although linking individual library files would work. This method isn't the preferred one for adding a whole directory, though.
13. D. Libraries are selected by programmers, not by users or system administrators. If you don't like the widgets provided by one library, you have few options. (Many widget sets do provide a great deal of configurability, though, so you may be able to work around the problem in other ways.) Options A and B describe fictitious options to `ldconfig`, `rpm`, and `dpkg`. Option C wouldn't work; Qt-using programs would crash when they found GTK+ libraries in place of the Qt libraries they were expecting.
14. D. The `kill` program accepts various signals in numeric or named form (9 in this example) along with a process ID number (11287 in this example). Signal 9 corresponds to `SIGKILL`, which is an extreme way to kill processes that have run out of control. Although you might use `kill` to kill network processes, you can't pass `kill` a TCP port number and expect it to work. The program also won't display information about the number of processes that have been killed. To do as option C suggests, you'd need to tell `kill` to pass `SIGHUP` (signal 1), so the command would be `kill -1 11287`.



15. C, D. The `top` utility displays a dynamic list of processes ordered according to their CPU use along with additional system information, including load averages. If you want only the load average at a specific moment, `uptime` may be better because it presents less extraneous information—it shows the current time, the time since the system was booted, the number of active users, and the load averages. The `ld` command has nothing to do with displaying load averages (it's a programming tool that links together program modules into an executable program). There is no standard Linux program called `load`.
16. A. The `--forest` option to `ps` shows parent/child relationships by creating visual links between process names in the `ps` output. (Listing 2.4 shows this effect.) Options B and C are both valid `ps` commands, but neither creates the specified effect.
17. A. CPU-intensive programs routinely consume 90 percent or more of available CPU time, but not all systems run such programs. Furthermore, some types of program bugs can create such CPU loads. Thus, you must investigate the matter more. What is `dfcomp`? Is it designed as a CPU-intensive program? Is it consuming this much CPU time consistently, or was this a brief burst of activity?
18. D. The `jobs` command summarizes processes that were launched from your current shell. When no such processes are running, `jobs` returns nothing, so option D is correct. The `jobs` command doesn't check or summarize CPU load, so option A is incorrect. The `jobs` command also doesn't check for processes run from shells other than the current one, so option B is incorrect (processes running under your username could have been launched from another shell or from a GUI environment). There is no standard `jobs` shell in Linux, so option C is incorrect.
19. C, D. The `nice` command launches a program (`crunch` in this example) with increased or decreased priority. The default priority when none is specified is 10, and the `nice -10 crunch` command also sets the priority to 10, so options C and D are equivalent. Option A isn't a valid `nice` command because `nice` has no `--value` option. Option B is a valid `nice` command, but it sets the priority to `-10` rather than 10.
20. B, D. Linux insulates users' actions from one another, and this rule applies to `renice`; only `root` may modify the priority of other users' processes. Similarly, only `root` may increase the priority of a process, in order to prevent users from setting their processes to maximum priority, thus stealing CPU time from others. Option A correctly describes `nice`, but not `renice`; the whole point of `renice` is to be able to change the priorities of existing processes. Option C also describes an action that `renice` permits.



# Chapter 3

# Configuring Hardware

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**THE FOLLOWING LINUX PROFESSIONAL INSTITUTE OBJECTIVES ARE COVERED IN THIS CHAPTER:**

- ✓ 1.101.1 Determine and configure hardware settings (weight: 2)
- ✓ 1.102.1 Design hard disk layout (weight: 2)
- ✓ 1.104.1 Create partitions and filesystems (weight: 2)
- ✓ 1.104.2 Maintain the integrity of filesystems (weight: 2)
- ✓ 1.104.3 Control mounting and unmounting of filesystems (weight: 3)





All OSs run atop hardware, and this hardware influences how the OSs run. Most obviously, hardware can be fast or slow, reliable or unreliable. Somewhat more subtly, OSs provide various means of configuring and accessing the hardware—partitioning hard disks and reading data from *Universal Serial Bus* (USB) devices, for instance. You must understand at least the basics of how Linux interacts with its hardware environment in order to effectively administer a Linux system, so this chapter presents this information.

This chapter begins with a look at the BIOS, which is the lowest-level software that runs on a computer. The BIOS starts the boot process and configures certain hardware devices. This chapter then moves on to expansion cards and USB devices.

This chapter concludes with an examination of disk hardware and the filesystems it contains—disk interface standards, disk partitioning, how to track disk usage, how to tune filesystems for optimal performance, how to check filesystems' internal consistency, and how to repair simple filesystem defects. Assuming a filesystem is in good shape, you must be able to mount it to be able to use it, so that topic is also covered here. (One disk topic, boot managers, is covered in Chapter 5, “Booting Linux and Editing Files.”)

## Configuring the BIOS and Core Hardware

All computers ship with a set of core hardware—most obviously, a *central processing unit* (CPU), which does the bulk of the computational work, and *random access memory* (RAM), which holds data. Many additional basic features help glue everything together, and some of these can be configured both inside and outside of Linux. At the heart of much of this hardware is the *Basic Input/Output System* (BIOS), which provides configuration tools and initiates the OS booting process. You can use the BIOS to enable and disable key hardware components, but once Linux is booted, you may need to manage this hardware using Linux utilities. Key components managed by the BIOS (and, once it's booted, Linux) include interrupts, I/O addresses, DMA addresses, the real-time clock, and *Advanced Technology Attachment* (ATA) hard disk interfaces.

### Understanding the Role of the BIOS

The BIOS is the firmware that initiates the process of booting an operating system on a computer. It resides on the motherboard in ROM, typically in an *electronically erasable programmable read-only memory* (EEPROM), a.k.a. flash memory. When you turn on a computer, the BIOS performs a *power-on self-test* (POST), initializes hardware to a known

operational state, loads the boot loader from the boot device (typically the first hard disk), and passes control to the boot loader, which in turn loads the OS.

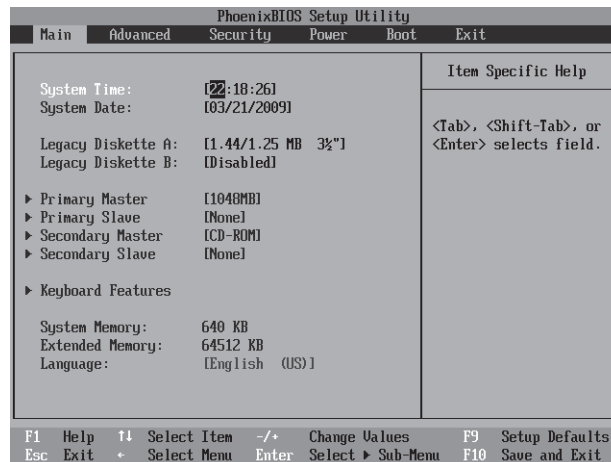
Historically, a further purpose of the BIOS was to provide fundamental input/output (I/O) services to the operating system and application programs, insulating them from hardware changes. Although the Linux kernel uses the BIOS to collect information about the hardware, once Linux is running, it doesn't use BIOS services for I/O. Having said that, Linux system administrators require a basic understanding of the BIOS because of the key role it plays in configuring hardware and in booting.



The BIOS as described here is used on most x86 *and* x86-64 computers; however, some computers use radically different software in place of the PC BIOS. Apple computers, for instance, use either OpenFirmware (for PowerPC systems) or the Extensible Firmware Interface (EFI; for Intel-based Macs). A few other computers use EFI, as well. Although OpenFirmware, EFI, and other firmware programs differ from the traditional (some now say “legacy”) x86 BIOS, these systems all perform similar tasks. If you must administer a non-BIOS system, you should take some time to research the details of how its low-level firmware operates; however, this won't greatly affect how Linux treats the hardware at the level of day-to-day system administration.

Although BIOS implementations vary from manufacturer to manufacturer, most provide an interactive facility to configure them. Typically, you enter this setup tool by pressing the Delete, F1, or F2 key early in the boot sequence. (Consult your motherboard manual or look for on-screen prompts for details.) Figure 3.1 shows a typical BIOS setup main screen. You can use the arrow keys, the Enter key, and so on to move around the BIOS options and adjust them. Computers usually come delivered with reasonable BIOS defaults, but you may need to adjust them if you add new hardware or if a standard piece of hardware is causing problems.

**FIGURE 3.1** The BIOS setup screen provides features related to low-level hardware configuration.



One key ability of the BIOS is enabling or disabling on-board hardware. Modern motherboards provide a wide range of hardware devices, including hard disk controllers, RS-232 serial ports, parallel ports, USB ports, Ethernet ports, audio hardware, and even video hardware. Usually, having this hardware available is beneficial, but sometimes it's not. The hardware may be inadequate, so you'll want to replace it with a more capable plug-in card; or you may not need it. In such cases, you can disable the device in the BIOS. Doing so keeps the device from consuming the hardware resources that are described shortly, reducing the odds of an unused device interfering with the hardware you do use.

Precisely how to disable hardware in the BIOS varies from one computer to another. You should peruse the available menus to find mention of the hardware you want to disable. Menus entitled Integrated Peripherals or Advanced are particularly likely to hold these features. Once you've spotted the options, follow the on-screen prompts for hints at how to proceed; for instance, Figure 3.1 shows an Item Specific Help area on the right side of the screen. Information about keys to press to perform various actions appears here. Once you're finished, follow the on-screen menus and prompts to save your changes and exit. When you do so, the computer will reboot.

Once Linux boots, it uses its own drivers to access the computer's hardware. Understanding the hardware resources that Linux uses will help you determine when you may want to shut down, boot into the BIOS, and disable particular hardware devices at such a low level.



## Real World Scenario

### Booting Without a Keyboard

Most PCs have keyboards attached to them; however, many Linux computers function as servers, which don't require keyboards for day-to-day operation. In such cases, you may want to detach the keyboard to reduce clutter and eliminate the risk of accidental key-presses causing problems.

Unfortunately, many computers complain and refuse to boot if you unplug the keyboard and attempt to boot the computer. To disable this warning, look for a BIOS option called Halt On or something similar. This option tells the BIOS under what circumstances it should refuse to boot. You should find an option to disable the keyboard check. Once you select this option, you should be able to shut down, detach the keyboard, and boot normally. Of course, you'll need to be able to access the computer via a network connection or in some other way to administer it, so be sure this is configured before you remove the keyboard!

## IRQs

An *interrupt request* (IRQ), or interrupt, is a signal sent to the CPU instructing it to suspend its current activity and to handle some external event such as keyboard input. On the x86 platform, IRQs are numbered from 0 to 15. More modern computers, including x86-64 systems, provide more than these 16 interrupts. Some interrupts are reserved for specific purposes, such as the keyboard and the real-time clock; others have common uses (and are sometimes overused) but may be reassigned; and some are left available for extra devices that may be added to the system. Table 3.1 lists the IRQs and their common purposes in the x86 system. (On x86-64 systems, IRQs are typically assigned as in Table 3.1, but additional hardware may be assigned to higher IRQs.)

**TABLE 3.1** IRQs and Their Common Uses

| IRQ | Typical Use                                           | Notes                                                                                                                                            |
|-----|-------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| 0   | System timer                                          | Reserved for internal use.                                                                                                                       |
| 1   | Keyboard                                              | Reserved for keyboard use only.                                                                                                                  |
| 2   | Cascade for IRQs 8–15                                 | The original x86 IRQ-handling circuit can manage just 8 IRQs; 2 are tied together to handle 16 IRQs, but IRQ 2 must be used to handle IRQs 8–15. |
| 3   | Second RS-232 serial port (COM2: in Windows)          | May also be shared by a fourth RS-232 serial port.                                                                                               |
| 4   | First RS-232 serial port (COM1: in Windows)           | May also be shared by a third RS-232 serial port.                                                                                                |
| 5   | Sound card or second parallel port (LPT2: in Windows) |                                                                                                                                                  |
| 6   | Floppy disk controller                                | Reserved for the first floppy disk controller.                                                                                                   |
| 7   | First parallel port (LPT1: in Windows)                |                                                                                                                                                  |
| 8   | Real-time clock                                       | Reserved for system clock use only.                                                                                                              |
| 9   | Open interrupt                                        |                                                                                                                                                  |
| 10  | Open interrupt                                        |                                                                                                                                                  |
| 11  | Open interrupt                                        |                                                                                                                                                  |

**TABLE 3.1** IRQs and Their Common Uses (*continued*)

| IRQ | Typical Use              | Notes                                                                                            |
|-----|--------------------------|--------------------------------------------------------------------------------------------------|
| 12  | PS/2 mouse               |                                                                                                  |
| 13  | Math coprocessor         | Reserved for internal use.                                                                       |
| 14  | Primary ATA controller   | The controller for ATA devices such as hard drives; typically /dev/hda and /dev/hdb under Linux. |
| 15  | Secondary ATA controller | The controller for more ATA devices; typically /dev/hdc and /dev/hdd under Linux.                |

The original *Industry Standard Architecture* (ISA) bus design makes sharing an interrupt between two devices tricky. Ideally, every ISA device should have its own IRQ. The more recent *Peripheral Component Interconnect* (PCI) bus makes sharing interrupts a bit easier, so PCI devices frequently end up sharing an IRQ. The ISA bus has become rare on computers made since 2001 or so, but it's common on older computers. Even some computers that lack physical ISA slots may use ISA internally to manage some devices, such as RS-232 serial ports and parallel ports.



IRQ 5 is a common source of interrupt conflicts because it's the default value for sound cards as well as for second parallel ports.

Once a Linux system is running, you can explore what IRQs are being used for various purposes by examining the contents of the /proc/interrupts file. A common way to do this is with the use of the cat command:

```
$ cat /proc/interrupts
```

```

CPU0
0: 42 IO-APIC-edge timer
1: 444882 IO-APIC-edge i8042
4: 12 IO-APIC-edge
6: 69 IO-APIC-edge floppy
8: 0 IO-APIC-edge rtc
9: 0 IO-APIC-fasteoi acpi
14: 3010291 IO-APIC-edge ide0
15: 11156960 IO-APIC-edge ide1
16: 125264892 IO-APIC-fasteoi eth0
17: 0 IO-APIC-fasteoi cx88[0], cx88[0]
20: 3598946 IO-APIC-fasteoi sata_via
```



```

21: 4566307 IO-APIC-fasteoi uhci_hcd:usb1, uhci_hcd:usb2, ehci_hcd:usb3
22: 430444 IO-APIC-fasteoi VIA8237
NMI: 0 Non-maskable interrupts
LOC: 168759611 Local timer interrupts
TRM: 0 Thermal event interrupts
THR: 0 Threshold APIC interrupts
SPU: 0 Spurious interrupts
ERR: 0

```



The `/proc` filesystem is a virtual filesystem—it doesn't refer to actual files on a hard disk, but to kernel data that's convenient to represent using a filesystem. The files in `/proc` provide information about the hardware, running processes, and so on. Many Linux utilities use `/proc` behind the scenes; or you can directly access these files using utilities like `cat`, which copies the data to the screen when given just one argument.

This output shows the names of the drivers that are using each IRQ. Some of these driver names are easy to interpret, such as `floppy`. Others are more puzzling, such as `cx88` (it's a driver for a video capture card). If the purpose of a driver isn't obvious, try doing a Web search on it; chances are you'll find a relevant hit fairly easily. Note that the preceding output shows interrupts numbered up to 22; this system supports more than the 16 base x86 interrupts.



The `/proc/interrupts` file lists IRQs that are in use by Linux, but Linux doesn't begin using an IRQ until the relevant driver is loaded. This may not happen until you try to use the hardware. Thus, the `/proc/interrupts` list may not show all the interrupts that are configured on your system. For instance, the preceding example shows nothing for IRQ 7, which is reserved for the parallel port, because the port hadn't been used prior to viewing the file. If the parallel port were used and `/proc/interrupts` viewed again, an entry for IRQ 7 and the `parport0` driver would appear.

If your system suffers from IRQ conflicts, you must reconfigure one or more devices to use different IRQs. This topic is described shortly, in “Configuring Expansion Cards.”

## I/O Addresses

I/O addresses (also referred to as I/O ports) are unique locations in memory that are reserved for communications between the CPU and specific physical hardware devices. Like IRQs, I/O addresses are commonly associated with specific devices and should not ordinarily be shared. Table 3.2 lists some Linux device filenames along with the equivalent names in Windows, as well as the common IRQ and I/O address settings.

**TABLE 3.2** Common Linux Devices

| Linux Device | Windows Name | Typical IRQ | I/O Address   |
|--------------|--------------|-------------|---------------|
| /dev/ttyS0   | COM1         | 4           | 0x03f8        |
| /dev/ttyS1   | COM2         | 3           | 0x02f8        |
| /dev/ttyS2   | COM3         | 4           | 0x03e8        |
| /dev/ttyS3   | COM4         | 3           | 0x02e8        |
| /dev/lp0     | LPT1         | 7           | 0x0378-0x037f |
| /dev/lp1     | LPT2         | 5           | 0x0278-0x027f |
| /dev/fd0     | A:           | 6           | 0x03f0-0x03f7 |
| /dev/fd1     | B:           | 6           | 0x0370-0x0377 |



Although the use is deprecated, older systems sometimes use `/dev/cuax` (where `x` is a number from 0 and up) to indicate an RS-232 serial device. Thus, `/dev/ttyS0` and `/dev/cua0` refer to the same physical device.

Once a Linux system is running, you can explore what I/O addresses are being used by examining the contents of the `/proc/ioports` file. A common way to do this is with the use of the `cat` command:

```
$ cat /proc/ioports
0000-001f : dma1
0020-0021 : pic1
0040-0043 : timer0
0050-0053 : timer1
0060-006f : keyboard
0070-0077 : rtc
0080-008f : dma page reg
00a0-00a1 : pic2
00c0-00df : dma2
00f0-00ff : fpu
```

This example truncates the output, which goes on for quite a way on the test system. As with IRQs, if your system suffers from I/O port conflicts, you must reconfigure one or more

devices, as described in “Configuring Expansion Cards.” In practice, such conflicts are rarer than IRQ conflicts.

## DMA Addresses

*Direct memory addressing* (DMA) is an alternative method of communication to I/O ports. Rather than have the CPU mediate the transfer of data between a device and memory, DMA permits the device to transfer data directly, without the CPU’s attention. The result can be lower CPU requirements for I/O activity, which can improve overall system performance.

To support DMA, the *x86* architecture implements several DMA channels, each of which can be used by a particular device. To learn what DMA channels are in use on your system, examine the `/proc/dma` file:

```
$ cat /proc/dma
2: floppy
4: cascade
```

This output indicates that DMA channels 2 and 4 are in use. As with IRQs and I/O ports, DMA addresses should not normally be shared. In practice, DMA address conflicts are rarer than IRQ conflicts, so chances are you won’t run into problems. If you do, consult the upcoming section “Configuring Expansion Cards.”

## Boot Disks and Geometry Settings

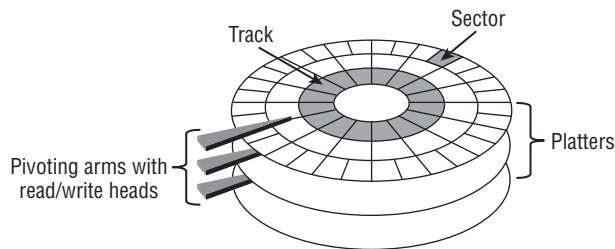
Most BIOSs allow you to choose the order of the devices from which to boot, falling back to the second entry if the first fails, the third entry if the second fails, and so on. A common order is the first floppy (known as A: in DOS and Windows), followed by the CD-ROM, followed by the first hard disk. With this configuration, the system attempts to boot from each device in turn until one works. If all the devices fail to boot, the BIOS displays an error message.

Although this is a common boot sequence, it has its problems. Specifically, if somebody accidentally leaves a floppy disk in the drive, this can prevent the system from booting. Worse, some (mostly old) viruses are transmitted by floppy disks’ boot sectors, so this method can result in viral infection. Using removable disks as the default boot media also opens the door to intruders who have physical access to the computer; they need only reboot with a bootable floppy disk or CD-ROM to gain complete control of your system. For these reasons, it’s better to make the first hard disk the only boot device. (You must change this configuration when installing Linux or using an emergency boot disk for maintenance.) Some BIOSs (most commonly on notebooks) make temporary changes easier by providing a special key to allow a one-time change to the boot sequence. On most other computers, to change the boot sequence, you must locate the appropriate BIOS option, change it, and reboot the computer. It’s usually located in an Advanced menu, so look there.

Another disk option is the one for detecting disk devices. Figure 3.1 shows three disk devices: the A: floppy disk (`/dev/fd0` under Linux), a 1048MB primary master hard disk, and a CD-ROM drive as the secondary master. In most cases, the BIOS detects and configures hard disks and CD-ROM drives correctly. You may need to tell it what sort of floppy disk you've got, though. Also, in rare circumstances, you must tell the BIOS about the hard disk's *cylinder/head/sector (CHS) geometry*.

The CHS geometry is a holdover from the early days of the *x86* architecture. Figure 3.2 shows the traditional hard disk layout, which consists of a fixed number of read/write heads that can move across the disk surfaces (or platters). As the disk spins, each head marks out a circular track on its platter; these tracks collectively make up a cylinder. Each track is broken down into a series of sectors. Thus, any sector on a hard disk can be uniquely identified by three numbers: a cylinder number, a head number, and a sector number. The *x86* BIOS was designed to use this three-number CHS identification code. One consequence of this configuration is that the BIOS must know how many cylinders, heads, and sectors the disk has. Modern hard disks relay this information to the BIOS automatically; but for compatibility with the earliest hard disks, BIOSs still enable you to set these values manually.

**FIGURE 3.2** Hard disks are built from platters, each of which is broken into tracks, which are broken into sectors.



The BIOS will detect only certain types of disks. Of particular importance, SCSI disks and (on some computers) serial ATA disks won't appear in the main BIOS disk-detection screen. These disks are handled by supplementary BIOSs associated with the controllers for these devices. Some BIOSs do provide explicit options to add SCSI devices into the boot sequence, so you can give priority to either ATA or SCSI devices. For those without these options, SCSI disks generally take second seat to ATA disks.

CHS geometry, unfortunately, has its problems. For one thing, all but the earliest hard disks use variable numbers of sectors per cylinder—modern disks squeeze more sectors onto outer tracks than inner ones, fitting more data on each disk. Thus, the CHS geometry presented to the BIOS by the hard disk is a convenient lie. Worse, because of limits on the numbers in the BIOS and in the ATA hard disk interface, plain CHS geometry tops out at 540MB, which is puny by today's standards. Various patches, such as CHS geometry

translation, can be used to expand the limit to about 8GB. Today, though, the preference is to use *logical block addressing* (LBA) mode. (Some sources use the expansion *linear block addressing* for this acronym.) In this mode, a single unique number is assigned to each sector on the disk, and the disk's firmware is smart enough to read from the correct head and cylinder when given this sector number. Modern BIOSs typically provide an option to use LBA mode, CHS translation mode, or possibly some other modes with large disks. In most cases, LBA mode is the best choice. If you must retrieve data from very old disks, though, you may need to change this option.



Because of variability in how different BIOSs handle CHS translation, moving disks between computers can result in problems because of mismatched CHS geometries claimed in disk structures and by the BIOS. Linux is usually smart enough to work around such problems, but you may see some odd error messages in disk utilities like `fdisk`. If you see messages about inconsistent CHS geometries, proceed with caution when using low-level disk utilities lest you create an inconsistent partition table that could cause problems, particularly in OSs that are less robust than Linux on this score.

## Coldplug and Hotplug Devices

Whenever you deal with hardware, you should keep in mind a distinction between two device types: *coldplug* and *hotplug*. These device types differ depending on whether they can be physically attached and detached when the computer is turned on (that is, “hot”), versus only when it's turned off (“cold”).



Coldplug devices are designed to be physically connected and disconnected only when the computer is turned off. Attempting to attach or detach such devices when the computer is running can damage the device or the computer, so do not attempt to do so.

Traditionally, components that are internal to the computer, such as the CPU, memory, PCI cards, and hard disks, have been coldplug devices. A hotplug variant of PCI, however, has been developed and is used on some systems—mainly on servers and other systems that can't afford the downtime required to install or remove a device.

Modern external devices, such as Ethernet, USB, and IEEE-1394 devices, are hotplug; you can attach and detach such devices as you see fit. These devices rely on specialized Linux software to detect the changes to the system as they're attached and detached. Several utilities help in managing hotplug devices:

**Sysfs** The *sysfs* virtual filesystem, mounted at `/sys`, exports information about devices so that user space utilities can access the information.



A *user space* program is one that runs as an ordinary program, whether it runs as an ordinary user or as root. This contrasts with *kernel space* code, which runs as part of the kernel. Typically, only the kernel (and hence kernel space code) can communicate directly with hardware. User space programs are the ultimate users of hardware, though. Traditionally, the `/dev` filesystem has provided the main means of interface between user space programs and hardware; however, the tools described here help expand on this access, particularly in ways that are useful for hotplug devices.

**HAL Daemon** The *Hardware Abstraction Layer (HAL) Daemon*, or `halld`, is a user space program that runs at all times (that is, as a daemon) that provides other user space programs with information about available hardware.

**D-Bus** The *Desktop Bus (D-Bus)* provides a further abstraction of hardware information access. Like `halld`, D-Bus runs as a daemon. D-Bus enables processes to communicate with each other as well as to register to be notified of events, both by other processes and by hardware (such as the availability of a new USB device).

**udev** Traditionally, Linux has created device nodes as conventional files in the `/dev` directory tree. The existence of hotplug devices and various other issues, however, have motivated the creation of `udev`: a virtual filesystem, mounted at `/dev`, which creates dynamic device files as drivers are loaded and unloaded. You can configure `udev` through files in `/etc/udev`, but the standard configuration is usually sufficient for common hardware.

These tools all help programs work seamlessly in a world of hotplug devices by enabling the programs to learn about hardware, including receiving notification when the hardware configuration changes.

Older external devices, such as parallel and RS-232 ports, are officially coldplug in nature. In practice, many people treat these devices as if they were hotplug, and they can usually get away with it; but there is a risk of damage, so it's safest to power down a computer before connecting or disconnecting such a device. When RS-232 or parallel port devices are hotplugged, they typically aren't registered by tools such as `udev` and `halld`. Only the ports to which these devices connect are handled by the OS; it's up to user space programs, such as terminal programs or the printing system, to know how to communicate with the external devices.

## Configuring Expansion Cards

Many hardware devices require configuration—you must set the IRQ, I/O port, and DMA addresses used by the device. (Not all devices use all three resources.) Through the mid-1990s, this process involved tedious changes to jumpers on the hardware. Today, though, you can configure most options through software.



Even devices that are built into the motherboard are configured through the same means used to configure PCI cards.

## Configuring PCI Cards

The PCI bus, which is the standard expansion bus for most internal devices, was designed with Plug-and-Play (PnP)-style configuration in mind; thus, automatic configuration of PCI devices is the rule rather than the exception. For the most part, PCI devices configure themselves automatically, and there's no need to make any changes. You can, though, tweak how PCI devices are detected in several ways:

- The Linux kernel has an option that affects how it detects PCI devices: Bus Options > PCI Access Mode. This option has four values: BIOS, which uses the BIOS to do the job; MMConfig, which uses a protocol of that name to detect PCI devices; Direct, which uses a Linux-specific direct-detection system; and Any, which tries MMConfig followed by Direct followed by BIOS detection. In most cases, Any is the most appropriate option; however, if your devices aren't being detected correctly or are being assigned resources that are causing conflicts, you may want to try experimenting with this option.
- Most BIOSs have PCI options that change the way PCI resources are allocated. Adjusting these options may help if you run into strange hardware problems with PCI devices. These options affect only the BIOS detection system, though, and so may work only if you select BIOS as the PCI-detection method in the kernel.
- Some Linux drivers support options that cause them to configure the relevant hardware to use particular resources. You should consult the drivers' documentation files for details of the options they support. You must then pass these options to the kernel using a boot loader (as described in Chapter 5) or as kernel module options.
- You can use the `setpci` utility to directly query and adjust PCI devices' configurations. This tool is most likely to be useful if you know enough about the hardware to fine-tune its low-level configuration; it's not often used to tweak the hardware's basic IRQ, I/O port, or DMA options.

In addition to the configuration options, you may want to check how PCI devices are currently configured. The `lspci` command is used for this purpose; it displays all information about the PCI busses on your system and all devices connected to those busses. This command takes several options that fine-tune its behavior. The most common of these are listed in Table 3.3.

**TABLE 3.3** Options for `lspci`

| Option          | Effect                                                                                                                                      |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| <code>-v</code> | Increases verbosity of output. This option may be doubled ( <code>-vv</code> ) or tripled ( <code>-vvv</code> ) to produce yet more output. |

**TABLE 3.3** Options for `lspci` (*continued*)

| Option                                                                              | Effect                                                                                                                                                                                                                                     |
|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>-n</code>                                                                     | Displays information in numeric codes rather than translating the codes to manufacturer and device names.                                                                                                                                  |
| <code>-nn</code>                                                                    | Displays both the manufacturer and device names and their associated numeric codes.                                                                                                                                                        |
| <code>-x</code>                                                                     | Displays the PCI configuration space for each device as a hexadecimal dump. This is an extremely advanced option. Tripling ( <code>-xxx</code> ) or quadrupling ( <code>-xxxx</code> ) this option displays information about more devices |
| <code>-b</code>                                                                     | Shows IRQ numbers and other data as seen by devices rather than as seen by the kernel.                                                                                                                                                     |
| <code>-t</code>                                                                     | Displays a tree view depicting the relationship between devices.                                                                                                                                                                           |
| <code>-s [[[[<i>domain</i>]:]<br/><i>bus</i>]:][<i>slot</i>][.<i>[func]</i>]</code> | Displays only devices that match the listed specification. This can be used to trim the results of the output.                                                                                                                             |
| <code>-d [<i>vendor</i>]:[<i>device</i>]</code>                                     | Shows data on the specified device.                                                                                                                                                                                                        |
| <code>-i <i>file</i></code>                                                         | Uses the specified file to map vendor and device IDs to names. (The default is <code>/usr/share/misc/pci.ids</code> .)                                                                                                                     |
| <code>-m</code>                                                                     | Dumps data in a machine-readable form, intended for use by scripts. A single <code>-m</code> uses a backward-compatible format, whereas doubling ( <code>-mm</code> ) uses a newer format.                                                 |
| <code>-D</code>                                                                     | Displays PCI domain numbers. These numbers normally aren't displayed.                                                                                                                                                                      |
| <code>-M</code>                                                                     | Performs a scan in bus-mapping mode, which can reveal devices hidden behind a misconfigured PCI bridge. This is an advanced option that can be used only by root.                                                                          |
| <code>--version</code>                                                              | Displays version information.                                                                                                                                                                                                              |

## Learning about Kernel Modules

Hardware in Linux is handled by kernel drivers, many of which come in the form of *kernel modules*. These are stand-alone driver files, typically stored in the `/lib/modules` directory tree, that can be loaded and unloaded to provide access to hardware. Typically, Linux loads the modules it needs when it boots, but you may need to load additional modules yourself.



You can learn about the modules that are currently loaded on your system by using `lsmod`, which takes no options and produces output like this:

```
$ lsmod
Module Size Used by
isofs 35820 0
zlib_inflate 21888 1 isofs
floppy 65200 0
nls_iso8859_1 5568 1
nls_cp437 7296 1
vfat 15680 1
fat 49536 1 vfat
sr_mod 19236 0
ide_cd 42848 0
cdrom 39080 2 sr_mod, ide_cd
```



This output has been edited for brevity. Although outputs this short are possible with certain configurations, they're rare.

The most important column in this output is the first one, labeled `Module`; this column specifies the names of all the modules that are currently loaded. You can learn more about these modules with `modinfo`, as described shortly, but sometimes their purpose is fairly obvious. For instance, the `floppy` module provides access to the floppy disk drive.

The `Used by` column of the `lsmod` output describes what's using the module. All the entries have a number, which indicates the number of other modules or processes that are using the module. For instance, in the preceding example, the `isofs` module (used to access CD-ROM filesystems) isn't currently in use, as revealed by its 0 value; but the `vfat` module (used to read VFAT hard disk partitions and floppies) is being used, as shown by its value of 1. If one of the modules is being used by another module, the using module's name appears in the `Used by` column. For instance, the `isofs` module relies on the `zlib_inflate` module, so the latter module's `Used by` column includes the `isofs` module name. This information can be useful when you're managing modules. For instance, if your system produced the preceding output, you couldn't directly remove the `zlib_inflate` module because it's being used by the `isofs` module; but you could remove the `isofs` module, and after doing so you could remove the `zlib_inflate` module. (Both modules would need to be added back to read most CD-ROMs, though.)



The `lsmod` command displays information only about kernel modules, not about drivers that are compiled directly into the Linux kernel. For this reason, a module may need to be loaded on one system but not on another to use the same hardware because the second system may compile the relevant driver directly into the kernel.

## Loading Kernel Modules

Linux enables you to load kernel modules with two programs: `insmod` and `modprobe`. The `insmod` program inserts a single module into the kernel. This process requires you to have already loaded any modules on which the module you're loading relies. The `modprobe` program, by contrast, automatically loads any depended-on modules and so is generally the preferred way to do the job.



In practice, you may not need to use `insmod` or `modprobe` to load modules because Linux can load them automatically. This ability relies on the kernel's module auto-loader feature, which must be compiled into the kernel, and on various configuration files, which are also required for `modprobe` and some other tools. Using `insmod` and `modprobe` can be useful for testing new modules or for working around problems with the auto-loader, though.

In practice, `insmod` is a fairly straightforward program to use; you type it followed by the module filename:

```
insmod /lib/modules/2.6.26/kernel/drivers/block/floppy.ko
```

This command loads the `floppy.ko` module, which you must specify by filename. Modules have module names, too, which are usually the same as the filename but without the extension, as in `floppy` for the `floppy.ko` file. Unfortunately, `insmod` requires the full module name.

You can pass additional module options to the module by adding them to the command line. Module options are highly module-specific, so you must consult the documentation for the module to learn what to pass. Examples include options to tell an RS-232 serial port driver what interrupt to use to access the hardware or to tell a video card framebuffer driver what screen resolution to use.

Some modules depend on other modules. In these cases, if you attempt to load a module that depends on others and those other modules aren't loaded, `insmod` will fail. When this happens, you must either track down and manually load the depended-on modules or use `modprobe`. In the simplest case, you can use `modprobe` much as you use `insmod`, by passing it a module name:

```
modprobe floppy
```

As with `insmod`, you can add kernel options to the end of the command line. Unlike `insmod`, you specify a module by its module name rather than its module filename when you use `modprobe`. Generally speaking, this helps make `modprobe` easier to use, as does the fact that `modprobe` automatically loads dependencies. This greater convenience means that `modprobe` relies on configuration files. It also means that you can use options (placed between the command name and the module name) to modify `modprobe`'s behavior:

**Be verbose** The `-v` or `--verbose` option tells `modprobe` to display extra information about its operations. Typically, this includes a summary of every `insmod` operation it performs.

**Change configuration files** The `modprobe` program uses a configuration file called `/etc/modprobe.conf`. You can change the file by passing a new file with the `-C filename` option, as in `modprobe -C /etc/mymodprobe.conf floppy`.

**Perform a dry run** The `-n` or `--dry-run` option causes `modprobe` to perform checks and all other operations *except* the actual module insertions. You might use this option in conjunction with `-v` to see what `modprobe` would do without loading the module. This may be helpful in debugging, particularly if inserting the module is having some detrimental effect, such as disabling disk access.

**Remove modules** The `-r` or `--remove` option reverses `modprobe`'s usual effect; it causes the program to remove the specified module and any on which it depends. (Depended-on modules are *not* removed if they're in use.)

**Force loading** The `-f` or `--force` option tells `modprobe` to force the module loading even if the kernel version doesn't match what the module expects. This action is potentially dangerous, but it's occasionally required when using third-party binary-only modules.

**Show dependencies** The `--show-depends` option shows all the modules on which the specified module depends. This option doesn't install any of the modules; it's purely informative in nature.

**Show available modules** The `-l` or `--list` option displays a list of available options whose names match the wildcard you specify. For instance, typing `modprobe -l v*` displays all modules whose names begin with `v`. If you provide no wildcard, `modprobe` displays all available modules. Like `--show-depends`, this option doesn't cause any modules to be loaded.



This list of options is incomplete. The others are relatively obscure, so you're not likely to need them often. Consult the `modprobe` man page for more information.

## Removing Kernel Modules

In most cases, you can leave modules loaded indefinitely; the only harm that a module does when it's loaded but not used is to consume a small amount of memory. (The `lsmod` program shows how much memory each module consumes.) Sometimes, though, you may want to remove a loaded module. Reasons include reclaiming that tiny amount of memory, unloading an old module so you can load an updated replacement module, and removing a module that you suspect is unreliable.

The work of unloading a kernel module is done by the `rmmod` command, which is something of the opposite of `insmod`. The `rmmod` command takes a module name as an option, though, rather than a module filename:

```
rmmod floppy
```

This example command unloads the floppy module. You can modify the behavior of `rmmmod` in various ways:

**Be verbose** Passing the `-v` or `--verbose` option causes `rmmmod` to display some extra information about what it's doing. This may be helpful if you're troubleshooting a problem.

**Force removal** The `-f` or `--force` option forces module removal even if the module is marked as being in use. Naturally, this is a very dangerous option, but it's sometimes helpful if a module is misbehaving in some way that's even more dangerous. This option has no effect unless the `CONFIG_MODULE_FORCE_UNLOAD` kernel option is enabled.

**Wait until unused** The `-w` or `--wait` option causes `rmmmod` to wait for the module to become unused, rather than return an error message, if the module is in use. Once the module is no longer being used (say, after a floppy disk is unmounted if you try to remove the floppy module), `rmmmod` unloads the module and returns. Until then, `rmmmod` doesn't return, making it look like it's not doing anything.

A few more `rmmmod` options exist; consult the `rmmmod` man page for details.

Like `insmod`, `rmmmod` operates on a single module. If you try to unload a module that's depended on by other modules or is in use, `rmmmod` will return an error message. (The `-w` option modifies this behavior, as just described.) If the module is depended on by other modules, those modules are listed, so you can decide whether to unload them. If you want to unload an entire *module stack*—that is, a module and all those upon which it depends—you can use the `modprobe` command and its `-r` option, as described earlier in “Loading Kernel Modules.”

## Configuring USB Devices

Modern computers invariably ship with USB ports, and USB is now an extremely popular (perhaps the most popular) external interface form. This fact means you must understand something about USB, including USB itself, Linux's USB drivers, and Linux's USB management tools.

### USB Basics

USB is a protocol and hardware port for transferring data to and from devices. It allows for many more (and varied) devices per interface port than either ATA or SCSI and gives better speed than RS-232 serial and parallel ports. The USB 1.0 and 1.1 specifications allow for up to 127 devices and 12Mbps of data transfer. USB 2.0 allows for much higher transfer rates—480Mbps, to be precise.



Data transfer speeds may be expressed in bits per second (bps) or multiples thereof, such as megabits per second (Mbps); or in bytes per second (B/s) or multiples thereof, such as megabytes per second (MB/s). In most cases, there are 8 bits per byte, so multiplying or dividing by eight may be necessary if you're trying to compare speeds of devices that use different measures.

USB is the preferred interface method for many external devices, including printers, scanners, mice, digital cameras, and music players. USB keyboards, Ethernet adapters, modems, speakers, hard drives, and other devices are also available, although USB has yet to dominate these areas as it has some others.

Most computers ship with four to eight USB ports. (A few years ago, two USB ports were more common.) Each port can handle one device by itself, but you can use a *USB hub* to connect several devices to each port. Thus, you can theoretically connect huge numbers of USB devices to a computer. In practice, you may run into speed problems, particularly if you're using USB 1.x for devices that tend to transfer a lot of data, such as scanners, printers, or hard drives.



If you've got an older computer that only supports USB 1.x, and you want to connect a high-speed USB 2.0 device, buy a separate USB 2.0 board. You can use this board for the USB 2.0 device and either disable the onboard USB 1.x ports or use them for slower devices.

## Linux USB Drivers

Several different USB controllers are available, with names such as UHCI, OHCI, EHCI, and R8A66597. Modern Linux distributions ship with the drivers for the common USB controllers enabled, so your USB port should be activated automatically when you boot the computer. The UHCI and OHCI controllers handle USB 1.x devices, but most other controllers can handle USB 2.0 devices. Note that these controllers merely provide a means to access the actual USB devices (mice, printers, and so on). Chances are you'll be most interested in the tools and utilities that enable you to use these devices.

You can learn a great deal about your devices by using the `lsusb` utility. A simple use of this program with no options reveals basic information about your USB devices:

### \$ `lsusb`

```
Bus 003 Device 008: ID 0686:400e Minolta Co., Ltd
Bus 003 Device 001: ID 0000:0000
Bus 002 Device 002: ID 046d:c401 Logitech, Inc. TrackMan Marble Wheel
Bus 002 Device 001: ID 0000:0000
Bus 001 Device 001: ID 0000:0000
```

In this example, three USB busses are detected (001, 002, and 003). The first bus has no devices attached, but the second and third each have one device—a Logitech TrackMan Marble Wheel trackball and a Minolta DiIMAGE Scan Elite 5400 scanner, respectively. (The scanner's name isn't fully identified by this output, except insofar as the ID number encodes this information.) You can gather additional information by using various options to `lsusb`:

**Be verbose** The `-v` option produces extended information about each product.

**Restrict bus and device number** Using the `-s [[bus]:][devnum]` option restricts output to the specified bus and device number.

**Restrict vendor and product** You can limit output to a particular vendor and product by using the `-d [vendor]:[product]` option. The *vendor* and *product* are the codes just after ID on each line of the basic `lsusb` output.

**Display device by filename** Using `-D filename` displays information about the device that's accessible via *filename*, which should be a file in the `/proc/bus/usb` directory tree. This directory provides a low-level interface to USB devices, as described shortly.

**Tree view** The `-t` option displays the device list as a tree, so that you can more easily see what devices are connected to specific controllers.

**Version** The `--version` option displays the version of the `lsusb` utility and exits.

Early Linux USB implementations required a separate driver for every USB device. Many of these drivers remain in the kernel, and some software relies on them. For instance, USB disk storage devices use USB storage drivers that interface with Linux's SCSI support, making USB hard disks, removable disks, and so on look like SCSI devices.

Linux is migrating toward a model in which a USB filesystem provides access to USB devices. This filesystem appears as part of the `/proc` virtual filesystem. In particular, USB device information is accessible from `/proc/bus/usb`. Subdirectories of `/proc/bus/usb` are given numbered names based on the USB controllers installed on the computer, as in `/proc/bus/usb/001` for the first USB controller. Software can access files in these directories to control USB devices rather than use device files in `/dev` as with most hardware devices.

## USB Manager Applications

USB can be challenging for OSs because it was designed as a hot-pluggable technology. The Linux kernel wasn't originally designed with this sort of activity in mind, so the kernel relies on external utilities to help manage matters. Two tools in particular are used for managing USB devices: `usbmgr` and `hotplug`.

The `usbmgr` package (located at <http://www.dotaster.com/~shuu/linux/usbmgr/>) is a program that runs in the background to detect changes on the USB bus. When it detects changes, it loads or unloads the kernel modules that are required to handle the devices. For instance, if you plug in a USB Zip drive, `usbmgr` will load the necessary USB and SCSI disk modules. This package uses configuration files in `/etc/usbmgr` to handle specific devices and `/etc/usbmgr/usbmgr.conf` to control the overall configuration.

With the shift from in-kernel device-specific USB drivers to the USB device filesystem (`/proc/bus/usb`), `usbmgr` has been declining in importance. In fact, it may not be installed on your system. Instead, most distributions rely on the `Hotplug` package (<http://linux-hotplug.sourceforge.net>), which relies on kernel support added with the 2.4.x kernel series. This system uses files stored in `/etc/hotplug` to control the configuration of specific USB devices. In particular, `/etc/hotplug/usb.usermap` contains a database of USB device IDs and pointers to scripts in `/etc/hotplug/usb` that are run when devices are plugged in or unplugged. These scripts might change permissions on USB device files so that ordinary users can access USB hardware, run commands to detect new USB disk devices, or otherwise prepare the system for a new (or newly removed) USB device.

# Configuring Hard Disks

Hard disks are among the most important components in your system. Three different hard disk interfaces are common on modern computers: *Parallel Advanced Technology Attachment* (PATA), a.k.a. ATA; *Serial Advanced Technology Attachment* (SATA); and *Small Computer System Interface* (SCSI). In addition, external USB and IEEE-1394 drives are available, as well as external variants of SATA and SCSI drives. Each has its own method of low-level configuration.

## Configuring PATA Disks

PATA disks once ruled the roost in the x86 PC world, but today they're fast giving way to SATA disks. Thus, you're most likely to encounter PATA disks on slightly older computers—say, from 2005 or earlier. PATA disks are still readily available, though, and PATA is still used even in some new computers, particularly for CD-ROM and DVD-ROM drives.

As the full name implies, PATA disks use a parallel interface, meaning that several bits of data are transferred over the cable at once. Thus, PATA cables are wide, supporting a total of either 40 or 80 lines, depending on the variety of PATA. You can connect up to two devices to each PATA connector on a motherboard or plug-in PATA controller, meaning that PATA cables typically have three connectors—one for the motherboard and two for disks.

PATA disks must be configured as masters or as slaves. This can be done via jumpers on the disks themselves. Typically, the master device sits at the end of the cable and the slave device resides on the middle connector. In recent years, a new configuration option has appeared on PATA disks: cable select. When set to this option, the drive attempts to configure itself automatically based on its position on the PATA cable. Thus, your easiest configuration is usually to set all PATA devices to use the cable-select option; you can then attach them to whatever position is convenient, and the drives should configure themselves.

For best performance, disks should be placed on separate controllers rather than configured as master and slave on a single controller, because each PATA controller has a limited throughput that may be exceeded by two drives. Until recently, most motherboards have included at least two controllers, so putting each drive on its own controller isn't a problem until you install more than two drives in a single computer.

All but the most ancient BIOSs auto-detect PATA devices and provide information about their capacities and model numbers in the BIOS setup utilities. Until recently, most motherboards would boot PATA drives in preference to other drives, although BIOSs have also often provided options to change this preference in favor of SCSI drives. Thus, in a mixed-drive setup, you may have to place your boot loader on a PATA drive.

In Linux, PATA disks have traditionally been identified as `/dev/hda`, `/dev/hdb`, and so on, with `/dev/hda` being the master drive on the first controller, `/dev/hdb` being the slave drive on the first controller, and so on. Thus, gaps can occur in the numbering scheme—if you've got master disks on the first and second controllers but no slave disks, your system will contain `/dev/hda` and `/dev/hdc`, but no `/dev/hdb`. Partitions are identified by numbers after the main device name, as in `/dev/hda1`, `/dev/hdb2`, and so on.

The naming rules for disks also apply to optical media, except that these media aren't typically partitioned. Most Linux distributions also create a link to your optical drive under the name `/dev/cdrom` or `/dev/dvd`. Removable PATA disks, such as Zip disks, are given identifiers as if they were fixed PATA disks, optionally including partition identifiers.

Recently, Linux drivers have appeared that treat PATA disks as if they were SCSI disks. Thus, you may find that your device filenames follow the SCSI rules rather than the PATA rules even if you have PATA disks.

## Configuring SATA Disks

SATA is a newer interface than PATA, but SATA is rapidly displacing PATA as the interface of choice. New motherboards typically host four or more SATA interfaces, often at the expense of PATA interfaces.

SATA disks connect to their motherboards or controllers on a one-to-one basis—unlike PATA, you can't connect more than one disk to a single cable. This fact simplifies configuration; there typically aren't jumpers to set, and you needn't be concerned with the position of the disk on the cable.

As the word *serial* in the expansion of SATA implies, SATA is a serial bus—only one bit of data can be transferred at a time. SATA transfers more bits per unit time on its data line, though, so SATA is faster than PATA (187–375 MB/s for SATA vs. 16–133 MB/s for PATA; but these are theoretical maximums that are unlikely to be achieved in real-world situations). Because of SATA's serial nature, SATA cables are much thinner than PATA cables.

Modern BIOSs detect SATA disks and provide information about them just as they do for PATA disks. The BIOS may provide boot order options, too. Older BIOSs are likely to be more limited. This is particularly true if your motherboard doesn't provide SATA support but you use a separate SATA controller card. You may be able to boot from an SATA disk in such cases if your controller card supports this option, or you may need to use a PATA boot disk.

Most Linux SATA drivers treat SATA disks as if they were SCSI disks, so you should read the next section, “Configuring SCSI Disks,” for information about device naming. Some older drivers treat SATA disks like PATA disks, so you may need to use PATA names.

## Configuring SCSI Disks

There are many types of SCSI definitions, which use a variety of different cables and operate at various speeds. SCSI is traditionally a parallel bus, like PATA, although the latest variant, Serial Attached SCSI (SAS), is a serial bus like SATA. SCSI has traditionally been considered a superior bus to PATA; however, the cost difference has risen dramatically over the past decade, so few people today use SCSI. You may find it on older systems or on very high-end systems.

SCSI supports up to 8 or 16 devices per bus, depending on the variety. One of these devices is the SCSI host adapter, which either is built into the motherboard or comes as a plug-in card. In practice, the number of devices you can attach to a SCSI bus is more limited because of cable-length limits, which vary from one SCSI variety to another. Each device has its own ID number, typically assigned via a jumper on the device. You must ensure that each device's ID is unique. Consult its documentation to learn how to set the ID.



SCSI hard disks aren't detected by the standard x86 BIOS. You can still boot from a SCSI hard disk *if* your SCSI host adapter has its own BIOS that supports booting. Most high-end SCSI host adapters have this support, but low-end SCSI host adapters don't have BIOSs. If you use such a host adapter, you can still attach SCSI hard disks to the adapter, and Linux can use them, but you'll need to boot from a PATA or SATA hard disk.

SCSI IDs aren't used to identify the corresponding device file on a Linux system. Hard drives follow the naming system `/dev/sdx` (where *x* is a letter from a up), SCSI tapes are named `/dev/stx` and `/dev/nstx` (where *x* is a number from 0 up), and SCSI CD-ROMs and DVD-ROMs are named `/dev/scdx` (where *x* is a number from 0 up).

SCSI device numbering (or lettering) is usually assigned in increasing order based on the SCSI ID. If you have one hard disk with a SCSI ID of 2 and another hard disk with a SCSI ID of 4, they will be assigned to `/dev/sda` and `/dev/sdb`, respectively. The real danger is if you add a third SCSI drive and give it an ID of 0, 1, or 3. This new disk will become `/dev/sda` (for an ID of 0 or 1) or `/dev/sdb` (for ID 3), bumping up one or both of the existing disks' Linux device identifiers. For this reason, it's usually best to give hard disks the lowest possible SCSI IDs so that you can add future disks using higher IDs.



The mapping of Linux device identifiers to SCSI devices depends in part on the design of the SCSI host adapter. Some host adapters result in assignment starting from SCSI ID 7 and working down to 0 rather than the reverse, with Wide SCSI device numbering continuing on from there to IDs 14 through 8.

Another complication is when you have multiple SCSI host adapters. In this case, Linux assigns device filenames to all of the disks on the first adapter followed by all those on the second adapter. Depending on where the drivers for the SCSI host adapters are found (compiled directly into the kernel or loaded as modules) and how they're loaded (for modular drivers), you may not be able to control which adapter takes precedence.



Remember that some non-SCSI devices, such as USB disk devices and SATA disks, are mapped onto the Linux SCSI subsystem. This can cause a true SCSI hard disk to be assigned a higher value than you'd expect if you use such "pseudo-SCSI" devices.

The SCSI bus is logically one-dimensional—that is, every device on the bus falls along a single line. This bus must not fork or branch in any way. Each end of the SCSI bus must be *terminated*. This refers to the presence of a special resistor pack that prevents signals from bouncing back and forth along the SCSI chain. Consult your SCSI host adapter and SCSI devices' manuals to learn how to terminate them. Remember that both ends of the SCSI chain must be terminated, but devices mid-chain must *not* be terminated. The SCSI host adapter qualifies as a device, so if it's at the end of the chain, it must be terminated.

Modern SCSI devices usually include a jumper or other setting to enable or disable termination. Older internal devices use comb-shaped resistor packs that you insert or remove to terminate the device, and older external devices use external terminators that attach to one of the

device's two SCSI connectors. (A few external SCSI devices are permanently terminated and have just one SCSI connector.)

Incorrect termination often results in bizarre SCSI problems, such as an inability to detect SCSI devices, poor performance, or unreliable operation. Similar symptoms can result from the use of poor-quality SCSI cables or cables that are too long.

## Configuring External Disks

External disks come in several varieties, the most common of which are USB, IEEE-1394, and SCSI. SCSI has long supported external disks directly, and many SCSI host adapters have both internal and external connectors. You configure external SCSI disks just like internal disks, although the physical details of setting the SCSI ID number and termination may differ; consult your devices' manuals for details.

Linux treats external USB and IEEE-1394 disks just like SCSI devices, from a software point of view. Typically, you can plug the device in, see a `/dev/sdx` device node appear, and use it as you would a SCSI disk. This is the case for both true external hard disks and media such as solid state USB pen drives.



External drives are easily removed, and this can be a great convenience; however, you should never unplug an external drive until you've unmounted the disk in Linux using the `umount` command, as described in Chapter 5. Failure to unmount a disk is likely to result in damage to the filesystem, including lost files. In addition, although USB and IEEE-1394 busses are hot-pluggable, most SCSI busses aren't, so connecting or disconnecting a SCSI device while the computer is running is dangerous. (Inserting or ejecting a removable SCSI disk, such as a Zip disk, is safe, however.)

## Designing a Hard Disk Layout

Whether your system uses PATA, SATA, or SCSI disks, you must design a disk layout for Linux. If you're using a system with Linux preinstalled, you may not need to deal with this task immediately; however, sooner or later you'll have to install Linux on a new computer or one with an existing OS or upgrade your hard disk. The next few pages describe the *x86* partitioning scheme, Linux mount points, and common choices for a Linux partitioning scheme. The upcoming section "Creating Partitions and Filesystems" covers the mechanics of creating partitions.

### Why Partition?

The first issue with partitioning is the question of why you should do it. The answer is that partitioning provides a variety of advantages, including the following:

**Multi-OS support** Partitioning enables you to keep the data for different OSs separate. In fact, many OSs can't easily co-exist on the same partition because they don't support

each other's primary filesystems. This feature is obviously important only if you want the computer to boot multiple OSs. It can still be handy to help maintain an emergency system, though—you can install a single OS twice, using the second installation as an emergency maintenance tool for the first in case problems develop.

**Filesystem choice** By partitioning your disk, you can use different *filesystems*—data structures designed to hold all the files on a partition—on each partition. Perhaps one filesystem is faster than another and so is important for time-critical or frequently accessed files, but another may provide accounting or backup features you want to use for users' data files.

**Disk space management** By partitioning your disk, you can lock certain sets of files into a fixed space. For instance, if you restrict users to storing files on one or two partitions, they can fill those partitions without causing problems on other partitions, such as system partitions. This feature can help keep your system from crashing if space runs out. On the other hand, if you get the partition sizes wrong, it can cause lesser problems much sooner than would be the case if you'd used fewer partitions.

**Disk error protection** Disks sometimes develop problems. These problems can be the result of bad hardware or of errors that creep into the filesystems. In either case, splitting a disk into partitions provides some protection against such problems. If data structures on one partition become corrupted, these errors affect only the files on that disk. This separation can therefore protect data on other partitions and simplify data recovery.

**Security** You can use different security-related mount options on different partitions. For instance, you might mount a partition that holds critical system files read-only, preventing users from writing to that partition. Linux's file security options should provide similar protection, but taking advantage of Linux filesystem mount options provides redundancy that can be helpful in case of an error in setting up file or directory permissions.

**Backup** Some backup tools work best on whole partitions. By keeping partitions small, you may be able to back up more easily than you could if your partitions were large.

In practice, most Linux computers use several partitions, although precisely how the system is partitioned varies from one system to another. (The upcoming section “Common Partitions and Filesystem Layouts” describes some possibilities.)

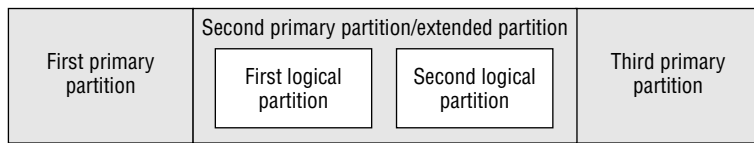
## Types of Disk Partitions

The *x86* architecture dates back to the 1980s, when a big hard disk was about 10MB in size. In such an environment, creating lots of partitions on the disk seemed pointless, so the original *x86* partitioning scheme supported just four partitions. Today, these four partitions are known as *primary partitions*. Some OSs, such as DOS and Windows, must boot from a primary partition. Linux isn't so limited, but using one or more primary partitions for some (or even all) of Linux's partition needs is common.

As hard disks grew larger and OSs more plentiful, the four-partition limit of the original *x86* partitioning scheme became a problem. To work around the issue while maintaining backward compatibility, the *x86* partitioning scheme was extended by using a single

primary partition as a placeholder for an arbitrary number of additional partitions. The placeholder partition is known as an *extended partition*, and the partitions it contains are called *logical partitions*. The *x86* partitioning system supports an arbitrary number of logical partitions, but because they're all contained within a single extended partition, the logical partitions must all be contiguous with one another. Figure 3.3 depicts this scheme, although the specific partition sizes, locations, and number of partitions are arbitrary.

**FIGURE 3.3** The *x86* partitioning system uses up to four primary partitions, one of which can be a placeholder extended partition that contains logical partitions.



Under Linux, primary and extended partitions are assigned numbers from 1 to 4, as in `/dev/hda1` or `/dev/sdb3` for the first primary partition on the first PATA disk or the third primary partition on the second SCSI disk, respectively. These numbers are fixed, and numbers can be skipped. For instance, a disk might have `/dev/hda1` and `/dev/hda3`, but not `/dev/hda2` or `/dev/hda4`.

Logical partitions are assigned numbers from 5 up, as in `/dev/hda5` or `/dev/sdb5`. These numbers are assigned sequentially, and numbers aren't ordinarily skipped; if a disk has `/dev/hda6`, then `/dev/hda5` also exists.

For the most part, Linux doesn't care whether a partition is primary or logical; you can use either partition type for just about any partition function in Linux. For booting the OS, you can use either type of partition, but if you put certain Linux files on a logical partition, you'll limit your boot loader options. (This topic is described in more detail in Chapter 5.)

In addition to the distinction between primary, extended, and logical partitions, another class of partition types is important: The *x86* partition table supports partition type codes, which are two-digit hexadecimal numbers that are assigned to specific functions. For instance, `0x06` is reserved for a certain type of File Allocation Table (FAT) partition, `0x82` denotes a Linux swap partition, and `0x83` indicates a Linux filesystem partition. Some OSs, such as DOS and Windows, rely on these type codes to determine which partitions they should try to access. DOS and Windows ignore Linux partitions because of their type codes, for instance. For the most part, though, Linux ignores partition type codes; you can try to mount any type of partition. A couple of partial exceptions to this rule exist, though:

- During installation, most Linux distributions pay attention to the partition type codes to help them guess how the system is configured. Installers and Linux disk utilities also create partitions with appropriate type codes set.
- Linux relies on the extended partition type codes (`0x05` and `0x0f`) to identify extended partitions. You can try to act directly on the extended partition using various utilities, but for the most part doing so would be a mistake.

The x86 partition table stores partition information in both CHS and LBA forms. The partition table also records the CHS geometry for the disk. If you use a disk on just one computer, no problems will result; but if you move a disk from one computer to another, the CHS geometry might change, which can result in confusion. Linux is usually pretty flexible about this and can generally cope well with such changes. Other OSs aren't always so flexible.

Although partitioning is usually considered a hard disk tool, some other disk devices can be partitioned. This practice is most common with certain types of removable disks. Because most removable disks are treated just like hard disks in Linux, you can partition them as you see fit; this practice is common with certain types of removable disks, such as Zip disks and USB pen drives. Other removable disks, such as CD-ROMs and magneto-optical (MO) disks, aren't commonly partitioned. Linux doesn't support partitioning for some types of disks, such as floppy disks. If you're in doubt about whether to partition a particular type of removable disk, try examining a working disk. As `root`, type `fdisk -l /dev/hdb` (change `hdb` to an appropriate device identifier) to examine the partition table on a disk. If this command returns partition table information, other disks of this type should probably be partitioned. The upcoming section "Partitioning a Disk" describes how to use `fdisk` in more detail.



## Real World Scenario

### Non-x86 Partitioning Systems

Most non-x86 platforms have their own partitioning systems. Most of these systems are simpler than the x86 system in that there's no distinction between primary, extended, and logical partitions. The basic principles of partitioning are the same across these platforms: The disk is split into multiple partitions for the same reasons x86 systems are partitioned, and Linux identifies the partitions in the same way (as `/dev/hda2`, for instance). Thus, at a system level, non-x86 partitions work just like x86 partitions.

To manipulate non-x86 partitions, though, you may use different tools. Sometimes these tools have the same names as the x86 tools, but their operational details may differ. One tool that's common across several platforms is GNU Parted (<http://www.gnu.org/software/parted/>), which supports x86, Macintosh, and several other types of partition tables.

Linux can handle about a dozen different partitioning schemes, although x86 distributions may not have the necessary support compiled by default. The File Systems > Partition Types kernel configuration area lists the available options, should you need to read disks created on an unusual platform.

Most computers with an x86-64 CPU use the x86 partitioning scheme; however, some x86-64 systems, including most Intel-based Macintoshes, use the Globally Unique Identifier (GUID) Partition Table (GPT) system. Linux can handle GPT partitions just fine, but if you need to manipulate GPT partition tables, you should use GNU Parted rather than `fdisk`.

## An Alternative to Partitions: LVM

An alternative to partitions for some functions is logical volume management (LVM). To use LVM, you set aside one or more partitions and assign them partition type codes of 0x8e. You then use a series of utilities, such as `pvcreate`, `vgcreate`, `lvcreate`, and `lvscan`, to manage the partitions (known as physical volumes in this scheme), to merge them into volume groups, and to create and manage logical volumes within the volume groups. Ultimately, you then access the logical volumes using names you assigned to them in the `/dev/mapper` directory, such as `/dev/mapper/myvol-home`.

LVM sounds complicated, and it is. Why would you want to use it? The biggest advantage to LVM is that it enables you to easily resize your logical volumes without worrying about the positions or sizes of surrounding partitions. In a sense, the logical volumes are like files in a regular filesystem; the filesystem (or volume group, in the case of LVM) manages the allocation of space when you resize files (or logical volumes). This can be a great boon if you're not sure of the optimum starting sizes of your partitions. You can also easily add disk space, in the form of a new physical disk, to expand the size of an existing volume group.

On the down side, LVM adds complexity, and not all Linux distributions support it out of the box. LVM can complicate disaster recovery, and if your LVM configuration spans multiple disks, a failure of one disk will put all files in your volume group at risk. It's easiest to configure a system with at least one filesystem (dedicated to `/boot`, or perhaps the root filesystem containing `/boot`) in its own conventional partition, reserving LVM for `/home`, `/usr`, and other filesystems.

Despite these drawbacks, and the fact that LVM isn't included in the LPIC objectives, you might consider investigating LVM further in some situations. It's most likely to be useful if you want to create a system with many specialized filesystems and you want to retain the option of resizing those filesystems in the future. A second situation where LVM is handy is if you need to create very large filesystems that are too large for a single physical disk to handle.

## Mount Points

Once a disk is partitioned, an OS must have some way to access the data on the partitions. In DOS and Windows, this is done by assigning a drive letter, such as C: or D:, to each partition. (DOS and Windows use partition type codes to decide which partitions get drive letters and which to ignore.) Linux, though, doesn't use drive letters; instead, Linux uses a unified directory tree. Each partition is *mounted* at a *mount point* in that tree. A mount point is a directory that's used as a way to access the filesystem on the partition, and mounting the filesystem is the process of linking the filesystem to the mount point.

For instance, suppose that a Linux system has three partitions: the root (`/`) partition, `/home`, and `/usr`. The root partition holds the basic system files, and all other partitions are accessed via directories on that filesystem. If `/home` contains users' home directories, such as `sally` and `sam`, those directories will be accessible as `/home/sally` and `/home/sam` once this partition is mounted at `/home`. If this partition were unmounted and remounted at `/users`, the same directories would become accessible as `/users/sally` and `/users/sam`.

Partitions can be mounted just about anywhere in the Linux directory tree, including on directories on the root partition as well as directories on mounted partitions. For instance, if `/home` is a separate partition, you can have a `/home/morehomes` directory that serves as a mount point for another partition.

The upcoming section “Mounting and Unmounting Filesystems” describes the commands and configuration files that are used for mounting partitions. For now, you should only be concerned with what constitutes a good filesystem layout (that is, what directories you should split off into their own partitions) and how to create these partitions.

## Common Partitions and Filesystem Layouts

So, what directories are commonly split off into separate partitions? Table 3.4 summarizes some popular choices. Note that typical sizes for many of these partitions vary greatly depending on how the system is used. Therefore, it’s impossible to make recommendations on partition size that will be universally acceptable.

**TABLE 3.4** Common Partitions and Their Uses

| Partition (Mount Point) | Typical Size                | Use                                                                                                                                                                                    |
|-------------------------|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Swap (not mounted)      | 1.5–2 times system RAM size | Serves as an adjunct to system RAM; is slow, but enables the computer to run more or larger programs.                                                                                  |
| <code>/home</code>      | 200MB–1000GB (or more)      | Holds users’ data files. Isolating it on a separate partition preserves user data during a system upgrade. Size depends on the number of users and their data storage needs.           |
| <code>/boot</code>      | 20–200MB                    | Holds critical boot files. Creating it as a separate partition lets you circumvent limitations of older BIOSs and boot loaders on hard disks over 8GB.                                 |
| <code>/usr</code>       | 500MB–10GB                  | Holds most Linux program and data files; this is sometimes the largest partition, although <code>/home</code> is larger on systems with many users or if users store large data files. |
| <code>/usr/local</code> | 100MB–3GB                   | Holds Linux program and data files that are unique to this installation, particularly those that you compile yourself.                                                                 |
| <code>/opt</code>       | 100MB–5GB                   | Holds Linux program and data files that are associated with third-party packages, especially commercial ones.                                                                          |

**TABLE 3.4** Common Partitions and Their Uses (*continued*)

| Partition (Mount Point) | Typical Size | Use                                                                                                                                                                                                                                                                                       |
|-------------------------|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| /var                    | 100MB–500GB  | Holds miscellaneous files associated with the day-to-day functioning of a computer. These files are often transient in nature. Most often split off as a separate partition when the system functions as a server that uses the /var directory for server-related files like mail queues. |
| /tmp                    | 100MB–20GB   | Holds temporary files created by ordinary users.                                                                                                                                                                                                                                          |
| /mnt                    | N/A          | Not a separate partition; rather, it or its subdirectories are used as mount points for removable media like floppies or CD-ROMs.                                                                                                                                                         |
| /media                  | N/A          | Holds subdirectories that may be used as mount points for removable media, much like /mnt or its subdirectories.                                                                                                                                                                          |

Some directories—/etc, /bin, /sbin, /lib, and /dev—should *never* be placed on separate partitions. These directories host critical system configuration files or files without which a Linux system can't function. For instance, /etc contains /etc/fstab, the file that specifies what partitions correspond to what directories, and /bin contains the mount utility that's used to mount partitions on directories.



The 2.4.x and later kernels include support for a dedicated /dev filesystem, which obviates the need for files in a disk-based /dev directory; so, in some sense, /dev can reside on a separate filesystem, although not a separate partition. The udev utility controls the /dev filesystem in recent versions of Linux.

## Creating Partitions and Filesystems

If you're installing Linux on a computer, chances are it will present you with a tool to help guide you through the partitioning process. These installation tools will create the partitions you tell them to create or create partitions sized as the distribution's maintainers believe appropriate. If you need to partition a new disk you're adding, though, or if you



want to create partitions using standard Linux tools rather than rely on your distribution's installation tools, you must know something about the Linux programs that accomplish this task. Partitioning involves two tasks: creating the partitions and preparing the partitions to be used. In Linux, these two tasks are usually accomplished using separate tools, although some tools can handle both tasks simultaneously.



## Real World Scenario

### When to Create Multiple Partitions

One problem with splitting off lots of separate partitions, particularly for new administrators, is that it can be difficult to settle on appropriate partition sizes. As noted in Table 3.4, the appropriate size of various partitions can vary substantially from one system to another. For instance, a workstation is likely to need a fairly small `/var` partition (say, 100MB), but a mail or news server may need a `/var` partition that's gigabytes in size. Guessing wrong isn't fatal, but it is annoying. You'll need to resize your partitions (which is tedious and dangerous) or set up symbolic links between partitions so that subdirectories on one partition can be stored on other partitions. LVM can simplify such after-the-fact changes, but as noted earlier, LVM adds its own complexity.

For this reason, I generally recommend that new Linux administrators try simple partition layouts first. The root (`/`) partition is required, and swap is a very good idea. Beyond this, `/boot` can be helpful on hard disks of more than 8GB with older distributions or BIOSs but is seldom needed with computers or distributions sold since 2000. An appropriate size for `/home` is often relatively easy for new administrators to guess, so splitting it off generally makes sense. Beyond this, I recommend that new administrators proceed with caution.

As you gain more experience with Linux, you may want to break off other directories into their own partitions on subsequent installations or when upgrading disk hardware. You can use the `du` command to learn how much space is used by files within any given directory.

## Partitioning a Disk

The traditional Linux tool for disk partitioning is called `fdisk`. This tool's name is short for *fixed disk*, and the name is the same as a DOS and Windows tool that accomplishes the same task. (When I mean to refer to the DOS/Windows tool, I capitalize its name, as in `FDISK`. The Linux tool's name is always entirely lowercase.) Both DOS's `FDISK` and Linux's `fdisk` are text-mode tools to accomplish similar goals, but the two are very different in operational details.

Although `fdisk` is the traditional tool, several others exist. One of these that's gaining in popularity is GNU Parted, which can both partition a disk and prepare the partitions for use

in a single operation. GNU Parted can also resize several partition types without losing data. Although this operation is risky, dynamic partition resizing can save a lot of time and effort.

## Using *fdisk*

To use Linux's *fdisk*, type the command name followed by the name of the disk device you want to partition, as in ***fdisk /dev/hda*** to partition the primary master PATA disk. The result is an *fdisk* prompt. On most modern disks, you'll also see a note telling you that the number of cylinders is greater than 1024:

```
fdisk /dev/hda
```

The number of cylinders for this disk is set to 7297.

There is nothing wrong with that, but this is larger than 1024, and could in certain setups cause problems with:

- 1) software that runs at boot time (e.g., old versions of LILO)
- 2) booting and partitioning software from other OSs  
(e.g., DOS FDISK, OS/2 FDISK)

Command (m for help):

At the Command (m for help): prompt, you can type commands to accomplish various goals:

**Display the current partition table** You may want to begin by displaying the current partition table. To do so, type **p**. If you *only* want to display the current partition table, you can type ***fdisk -l /dev/hda*** (or whatever the device identifier is) at a command prompt rather than enter *fdisk*'s interactive mode. This command displays the partition table and then exits.

**Create a partition** To create a partition, type **n**. The result is a series of prompts asking for information about the partition—whether it should be a primary, extended, or logical partition; the partition's starting cylinder; the partition's ending cylinder or size; and so on. The details of what you're asked depend in part on what's already defined. For instance, *fdisk* won't ask you if you want to create an extended partition if one already exists. One *fdisk* feature you may find odd is that it measures partition start and end points in cylinders, not megabytes. This is a holdover from the CHS measurements used by the x86 partition table. In most cases it's not a problem; you can pick the default start point and then specify the partition size in megabytes or gigabytes, and *fdisk* will compute the correct end cylinder.

**Delete a partition** To delete a partition, type **d**. The program will ask for the partition number, which you must enter.

**Change a partition's type** When you create a partition, *fdisk* assigns it a type code of 0x83, which corresponds to a Linux filesystem. If you want to create a Linux swap partition or a partition for another OS, you can type **t** to change a partition type code. The program then prompts you for a partition number and a type code.

**List partition types** Several dozen partition type codes exist, so it's easy to forget what they are. Type **l** (that's a lowercase *L*) at the main `fdisk` prompt to see a list of the most common ones. You can also get this list by typing **L** when you're prompted for the partition type when you change a partition's type code.

**Mark a partition bootable** Some OSs, such as DOS and Windows, rely on their partitions having special bootable flags in order to boot. You can set this flag by typing **a**, whereupon `fdisk` asks for the partition number.

**Get help** Type **m** or **?** to see a summary of the main `fdisk` commands.

**Exit** Linux's `fdisk` supports two exit modes. First, you can type **q** to exit the program without saving any changes; anything you do with the program is lost. This option is particularly helpful if you've made a terrible mistake. Second, typing **w** writes your changes to the disk and exits the program.

As an example, consider deleting a primary, an extended, and a logical partition on a Zip disk and creating a single new one in their place:

```
fdisk /dev/sda
```

```
Command (m for help): p
```

```
Disk /dev/sda: 100 MB, 100663296 bytes
4 heads, 48 sectors/track, 1024 cylinders
Units = cylinders of 192 * 512 = 98304 bytes
```

| Device    | Boot | Start | End  | Blocks | Id | System   |
|-----------|------|-------|------|--------|----|----------|
| /dev/sda1 |      | 1     | 510  | 48936  | 83 | Linux    |
| /dev/sda2 |      | 511   | 1024 | 49344  | 5  | Extended |
| /dev/sda5 |      | 511   | 1024 | 49320  | 83 | Linux    |

```
Command (m for help): d
Partition number (1-5): 5
```

```
Command (m for help): d
Partition number (1-5): 2
```

```
Command (m for help): d
Selected partition 1
```

```
Command (m for help): n
Command action
 e extended
 p primary partition (1-4)
```

**p**Partition number (1-4): **4**First cylinder (1-1024, default 1): **1**Last cylinder or +size or +sizeM or +sizeK (1-1024, default 1024): **1024**Command (m for help): **w**

The partition table has been altered!

Calling `ioctl()` to re-read partition table.

Syncing disks.

This process begins with a `p` command to verify that the program is operating on the correct disk. With this information in hand, the three existing partitions are deleted. Note that the first two deletions ask for a partition number, but the third doesn't, because only one partition is left. Once this is done, `n` is used to create a new primary partition. This example creates a partition numbered 4 because this is the standard for Zip disks. Once the task is complete, the `w` command is used to write the changes to disk and exit the program. The result of this sequence is a Zip disk with a single primary partition (`/dev/sda4`) marked as holding a Linux filesystem.

## Using GNU Parted

GNU Parted (<http://www.gnu.org/software/parted/>) is a cross-platform partitioning tool—you can use it with non-*x86* partition tables as well as *x86* partition tables. It also supports more features than `fdisk` and is easier to use in some ways. For instance, it measures disk space in megabytes rather than cylinders. GNU Parted also supports dynamic partition resizing for several filesystem types, which can be a great convenience. On the other hand, GNU Parted uses its own way of referring to partitions, which can be confusing. It's also more finicky about mismatched CHS geometries than is `fdisk`. Although GNU Parted isn't covered on the LPI exam, knowing a bit about it can be handy.

You start GNU Parted much as you start `fdisk`, by typing its name followed by the device you want to modify, as in `parted /dev/hda` to partition `/dev/hda`. The result is some brief introductory text followed by a `(parted)` prompt at which you type commands. Type `?` to see a list of commands, which are multi-character commands similar to Linux shell commands. For instance, `print` displays the current partition table, `mkpart` creates (makes) a partition, `rm` removes a partition, `move` moves a partition, and `resize` changes a partition's size. Some of the more advanced options work on only some filesystem types, such as Linux's native `ext2fs` and `ext3fs` and the DOS/Windows standby of FAT. (The next section describes filesystem types in more detail.)



Resizing or moving a filesystem can be dangerous. If the resizing code contains a bug or if there's a power failure during the operation, data can be lost. Thus, I strongly recommend you back up any important data before resizing or moving a partition. Also, resizing or moving your boot partition can render the system unbootable until you re-install your boot loader.

## Preparing a Partition for Use

Once a partition is created, you must prepare it for use. This process is often called “making a filesystem” or “formatting a partition.” It involves writing low-level data structures to disk. Linux can then read and modify these data structures to access and store files in the partition. You should know something about the common Linux filesystems and know how to use filesystem-creation tools to create them.



The word *formatting* is somewhat ambiguous. It can refer to either *low-level formatting*, which creates a structure of sectors and tracks on the disk media, or *high-level formatting*, which creates a filesystem. Hard disks are low-level formatted at the factory and should never need to be low-level formatted again. Floppy disks, though, can be both low- and high-level formatted. The tools described here can high-level format a floppy disk as well as a hard disk. To low-level format a floppy disk, you must use the `fdformat` command, as in `fdformat /dev/fd0`. This command cannot be used on a hard disk.

## Common Filesystem Types

Linux supports quite a few different filesystems, both Linux native and those intended for other OSs. Some of the latter barely work under Linux, and even when they do work reliably, they usually don’t support all the features that Linux expects in its native filesystems. Thus, when preparing a Linux system, you’ll use one or more of its native filesystems for most or all partitions:

**Ext2fs** The *Second Extended File System* (ext2fs or ext2) is the traditional Linux native filesystem. It was created for Linux and was the dominant Linux filesystem throughout the late 1990s. Ext2fs has a reputation as a reliable filesystem. It has since been eclipsed by other filesystems, but it still has its uses. In particular, ext2fs can be a good choice for a small /boot partition, if you choose to use one, and for small (sub-gigabyte) removable disks. On such small partitions, the size of the journal used by more advanced filesystems can be a real problem, so the non-journaling ext2fs is a better choice. (Journaling is described in more detail shortly.) The ext2 filesystem type code is ext2.

**Ext3fs** The *Third Extended File System* (ext3fs or ext3) is basically ext2fs with a journal added. The result is a filesystem that’s as reliable as ext2fs but that recovers from power outages and system crashes much more quickly. The ext3 filesystem type code is ext3.

**Ext4fs** The *Fourth Extended File System* (ext4fs or ext4) is the next-generation version of this filesystem family. It adds the ability to work with very large disks (those over 32 terabytes) or very large files (those over 2 terabytes), as well as extensions intended to improve performance. As of late 2008, ext4fs is considered experimental, but this will of course change. Its filesystem type code is ext4dev, but this will change to ext4 when the filesystem is finalized.

**ReiserFS** This filesystem was designed from scratch as a journaling filesystem for Linux and is a popular choice in this role. It’s particularly good at handling filesystems with large

numbers of small files (say, smaller than about 32KB) because ReiserFS uses various tricks to squeeze the ends of files into each other's unused spaces. This small savings can add up to a large percentage of file sizes when files are small. You can use `reiserfs` as the type code for this filesystem.



---

As of Linux kernel version 2.6.26, ReiserFS version 3.x is current. A from-scratch rewrite of ReiserFS, known as Reiser4, is being developed but has not yet been integrated into the mainstream kernel.

**JFS** IBM developed the *Journaled File System* (JFS) for its AIX OS and later re-implemented it on OS/2. The OS/2 version was subsequently donated to Linux. JFS is a technically sophisticated journaling filesystem that may be of particular interest if you're familiar with AIX or OS/2 or want an advanced filesystem to use on a dual-boot system with one of these OSs. As you might expect, this filesystem's type code is `jfs`.

**XFS** Silicon Graphics (SGI) created its *Extents File System* (XFS) for its IRIX OS and, like IBM, later donated the code to Linux. Like JFS, XFS is a very technically sophisticated filesystem. XFS has gained a reputation for robustness, speed, and flexibility on IRIX, but some of the XFS features that make it so flexible on IRIX aren't supported well under Linux. Use `xfs` as the type code for this filesystem.

In practice, most administrators choose `ext3fs` or ReiserFS as their primary filesystems; however, JFS and XFS also work well, and some administrators prefer them, particularly on large disks that store large files. Hard data on the merits and problems with each filesystem are difficult to come by, and even when they do exist, they're suspect because filesystem performance interacts with so many other factors. For instance, as just noted, ReiserFS can cram more small files into a small space than can other filesystems, but this advantage isn't very important if you'll be storing mostly larger files.



---

If you're using a non-x86 platform, be sure to check filesystem development on that platform. A filesystem may be speedy and reliable on one CPU but sluggish and unreliable on another.

In addition to these Linux-native filesystems, you may need to deal with some others from time to time, including the following:

**FAT** The *File Allocation Table* (FAT) filesystem is old and primitive—but ubiquitous. It's the only hard disk filesystem supported by DOS and Windows 9x/Me. For this reason, every major OS understands FAT, making it an excellent filesystem for exchanging data on removable disks. Two major orthogonal variants of FAT exist: It varies in the size of the FAT data structure after which the filesystem is named (12-, 16-, or 32-bit pointers), and it has variants that support long filenames. Linux automatically detects the FAT size, so you shouldn't need to worry about this. To use the original FAT filenames, which are limited to eight characters with an optional three-character extension (the so-called *8.3 filenames*),

use the Linux filesystem type code of `msdos`. To use Windows-style long filenames, use the filesystem type code of `vfat`. A Linux-only long filename system, known as `umsdos`, supports additional Linux features—enough that you can install Linux on a FAT partition, although this practice isn't recommended except for certain types of emergency disks or to try Linux on a Windows system.

**NTFS** The *New Technology File System* (NTFS) is the preferred filesystem for Windows NT/200x/XP/Vista. Unfortunately, Linux's NTFS support is rather rudimentary. As of the 2.6.x kernel series, Linux can reliably read NTFS and can overwrite existing files, but the Linux kernel can't write new files to an NTFS partition.



If you must have good NTFS read/write support for a dual-boot system, look into NTFS-3G (<http://www.ntfs-3g.org/>). This is a read/write NTFS driver that resides in user space rather than in kernel space. It's used as the default NTFS driver by some Linux distributions.

**HFS and HFS+** Apple has long used the *Hierarchical File System* (HFS) with its Mac OS, and Linux provides full read/write HFS support. This support isn't as reliable as Linux's read/write FAT support, though, so you may want to use FAT when exchanging files with Mac users. Apple has extended HFS to better support large hard disks and many Unix-like features with its HFS+ (a.k.a. Extended HFS). Linux 2.6.x adds limited HFS+ support; but this filesystem is still fairly new in the 2.6.x kernels, and write support for it is risky.

**ISO-9660** The standard filesystem for CD-ROMs has long been *ISO-9660*. This filesystem comes in several levels. Level 1 is similar to the original FAT in that it supports only 8.3 filenames. Levels 2 and 3 add support for longer 32-character filenames. Linux supports ISO-9660 using its `iso9660` filesystem type code. Linux's ISO-9660 support also works with the *Rock Ridge extensions*, which are a series of extensions to ISO-9660 to enable it to support Unix-style long filenames, permissions, symbolic links, and so on. If a disc includes Rock Ridge extensions, Linux will automatically detect and use them.

**Joliet** This filesystem is used much like Rock Ridge, as an extension to ISO-9660, but it's technically a separate filesystem. *Joliet* was created by Microsoft for use by Windows, so it emphasizes Windows filesystem features rather than Unix/Linux filesystem features. Linux supports Joliet as part of its `iso9660` driver; if a disc contains Joliet but not Rock Ridge, Linux uses the Joliet filesystem.

**UDF** The *Universal Disc Format* (UDF) is the next-generation filesystem for optical discs. It's commonly used on DVD-ROMs and recordable optical discs. Linux supports it, but read/write UDF support is still in its infancy.

As a practical matter, if you're preparing a hard disk for use with Linux, you should probably use Linux filesystems only. If you're preparing a disk that will be used for a dual-boot configuration, you may want to set aside some partitions for other filesystem types. For removable disks, you'll have to be the judge of what's most appropriate. You might use `ext2fs` for a Linux-only removable disk, `FAT` for a cross-platform disk, or `ISO-9660` (perhaps with Rock Ridge and Joliet) for a CD-R or recordable DVD.



ISO-9660 and other optical disc filesystems are created with special tools intended for this purpose. Specifically, `mkisofs` creates an ISO-9660 filesystem (optionally with Rock Ridge, Joliet, HFS, and UDF components added), while `cdrecord` writes this image to a blank CD-R.

## Creating a Filesystem

Most filesystems, including all Linux-native filesystems, have Linux tools that can create the filesystem on a partition. Typically, these tools have filenames of the form `mkfs.fstype`, where *fstype* is the filesystem type code. These tools can also be called from a front-end tool called `mkfs`; you pass the filesystem type code to `mkfs` using its `-t` option:

```
mkfs -t ext3 /dev/hda6
```



For `ext2` and `ext3` filesystems, the `mke2fs` program is often used instead of `mkfs`. The `mke2fs` program is just another name for `mkfs.ext2`.

This command creates an `ext3` filesystem on `/dev/hda6`. Depending on the filesystem, the speed of the disk, and the size of the partition, this process can take anywhere from a fraction of a second to a few seconds. Most filesystem-build tools support additional options, some of which can greatly increase the time required to build a filesystem. In particular, the `-c` option is supported by several filesystems. This option causes the tool to perform a bad-block check—every sector in the partition is checked to be sure it can reliably hold data. If it can't, the sector is marked as bad and isn't used.



If you perform a bad-block check and find that some sectors are bad, chances are the entire hard disk doesn't have long to live. Sometimes this sort of problem can result from other issues, though, such as bad cables or SCSI termination problems.

Of the common Linux filesystems, `ext2fs` and `ext3fs` provide the most options in their `mkfs` tools. (In fact, these tools are one and the same; the program simply creates a filesystem with a journal when it's called as `mkfs.ext3` or when `mkfs` is called with `-t ext3`.) You can type `man mkfs.ext2` to learn about these options, most of which deal with obscure and unimportant features. One obscure option that does deserve mention is `-m percent`, which sets the reserved-space percentage. The idea is that you don't want the disk to completely fill up with user files; if the disk starts getting close to full, Linux should report that the disk *is* full before it really is, at least for ordinary users. This gives the root user the ability to log in and create new files, if necessary, to help recover the system.

The `ext2fs/ext3fs` reserved-space percentage defaults to 5 percent, which translates to quite a lot of space on large disks. You may want to reduce this value (say, by passing `-m 2` to reduce it to 2 percent) on your root (`/`) filesystem and perhaps even lower (1 percent or 0 percent) on some, such as `/home`. Setting `-m 0` also makes sense on removable disks,



which aren't likely to be critical for system recovery and are probably a bit cramped to begin with.

In addition to providing filesystem-creation tools for Linux-native filesystems, Linux distributions usually provide such tools for various non-Linux filesystems. The most important of these may be for FAT. The main tool for this task is called `mkdosfs`, but it's often linked to the `mkfs.msdos` and `mkfs.vfat` names, as well. This program can automatically adjust the size of the FAT data structure to 12 or 16 bits depending on the device size. You can override this option with the `-F fat-size` option, where *fat-size* is the FAT size in bits—12, 16, or 32. In fact, this option is *required* if you want to create a FAT-32 partition, which is a practical necessity for any partition over 2GB in size and is usually desirable for partitions over 512MB in size. No special options are required to create a FAT filesystem that can handle Windows-style (VFAT) long filenames; these are created by the OS.

In Exercise 3.1, you'll practice creating filesystems using `mkfs` and related utilities.

## EXERCISE 3.1

### Creating Filesystems

Try creating some filesystems on a spare partition or a removable disk. Even a floppy disk will do, although you won't be able to create journaling filesystems on a floppy disk. The following steps assume you're using a Zip disk, `/dev/sda4`; change the device specification as necessary. *Be sure to use an empty partition!* Accidentally entering the wrong device filename could wipe out your entire system!

This exercise uses a few commands that are described in more detail later in this chapter. To create some filesystems, follow these steps:

1. Log in as root.
2. Use `fdisk` to verify the partitions on your target disk by typing `fdisk -l /dev/sda`. You should see a list of partitions, including the one you'll use for your tests.
3. Verify that your test partition is *not* currently mounted. Type `df` to see the currently mounted partitions and verify that `/dev/sda4` is not among them.
4. Type `mkfs -t ext2 /dev/sda4`. You should see several lines of status information appear.
5. Type `mount /dev/sda4 /mnt` to mount the new filesystem to `/mnt`. (You may use another mount point, if you like.)
6. Type `df /mnt` to see basic accounting information for the filesystem. On a 100MB Zip disk, you should see that 95,171 blocks are present, 13 blocks are used, and 90,244 blocks are available. The difference between the present and available blocks is caused by the 5 percent reserved space.
7. Type `umount /mnt` to unmount the filesystem.
8. Type `mkfs -t ext2 -m 0` to create a new ext2 filesystem on the device, but without any reserved space.

**EXERCISE 3.1 (continued)**

9. Repeat steps 5–7. Note that the available space has increased (to 95,158 blocks on a Zip disk). The available space plus the used space should now equal the total blocks.
10. Repeat steps 4–7, but use a filesystem type code of ext3 to create a journaling filesystem. (This won't be possible if you use a floppy disk.) Note how much space is consumed by the journal.
11. Repeat steps 4–7, but use another filesystem, such as JFS or ReiserFS. Note how the filesystem-creation tools differ in the information they present and in their stated amounts of available space.

Be aware that, because of differences in how filesystems store files and allocate space, a greater amount of available space when a filesystem is created may not translate into a greater capacity to store files.

---

## Creating Swap Space

Some partitions don't hold files. Most notably, Linux can use a *swap partition*, which is a partition that Linux treats as an extension of memory. (Linux can also use a *swap file*, which is a file that works in the same way. Both are examples of *swap space*.) Linux uses the partition type code of 0x82 to identify swap space, but as with other partitions, this code is mostly a convenience to keep other OSs from trying to access Linux swap partitions; Linux uses `/etc/fstab` to define which partitions to use as swap space, as described in Chapter 4, "Managing Files."



Solaris for x86 also uses a partition type code of 0x82, but in Solaris, this code refers to a Solaris partition. If you dual-boot between Solaris and Linux, this double meaning of the 0x82 partition type code can cause confusion. This is particularly true when installing the OSs. You may need to use Linux's `fdisk` to temporarily change the partition type codes to keep Linux from trying to use a Solaris partition as swap space or to keep Solaris from trying to interpret Linux swap space as a data partition.

Although swap space doesn't hold a filesystem *per se* and isn't mounted in the way that filesystem partitions are mounted, swap space does require preparation similar to that for creation of a filesystem. This task is accomplished with the `mkswap` command, which you can generally use by passing it nothing but the device identifier:

```
mkswap /dev/hda7
```

This example turns `/dev/hda7` into swap space. To use the swap space, you must activate it with the `swapon` command:

```
swapon /dev/hda7
```

To permanently activate swap space, you must create an entry for it in `/etc/fstab`, as described in Chapter 4.

## Maintaining Filesystem Health

Filesystems can become “sick” in a variety of ways. They can become overloaded with too much data, they can be tuned inappropriately for your system, or they can become corrupted because of buggy drivers, buggy utilities, or hardware errors. Fortunately, Linux provides a variety of utilities that can help you keep an eye on the status of your filesystems, tune their performance, and fix them.



Many of Linux’s filesystem maintenance tools should be run when the filesystem is not mounted. Changes made by maintenance utilities while the filesystem is mounted can confuse the kernel’s filesystem drivers, resulting in data corruption. In the following pages, I mention when utilities can and can’t be used with mounted filesystems.

### Tuning Filesystems

Filesystems are basically just big data structures—they’re a means of storing data on disk in an indexed method that makes it easy to locate the data at a later time. Like all data structures, filesystems include design compromises. For instance, a design feature may enable you to store more small files on disk but might chew up disk space, thus reducing the total capacity available for storage of larger files. In many cases, you have no choice concerning these compromises, but some filesystems include tools that enable you to set filesystem options that affect performance. This is particularly true of `ext2fs` and the related `ext3fs` and `ext4fs`. Three tools are particularly important for tuning these filesystems: `dumpe2fs`, `tune2fs`, and `debugfs`. The first of these tools provides information about the filesystem, and the other two enable you to change tuning options.

### Obtaining Filesystem Information

You can learn a lot about your `ext2` or `ext3` filesystem with the `dumpe2fs` command. This command’s syntax is fairly straightforward:

```
dumpe2fs [options] device
```

The *device* is the filesystem device file, such as `/dev/hda2` or `/dev/sdb7`. This command accepts several *options*, most of which are rather obscure. The most important option is

probably `-h`, which causes the utility to omit information about group descriptors. (This information is helpful in very advanced filesystem debugging but not for basic filesystem tuning.) For information about additional options, consult the man page for `dumpe2fs`.

Unless you're a filesystem expert and need to debug a corrupted filesystem, you're most likely to want to use `dumpe2fs` with the `-h` option. The result is about three dozen lines of output, each specifying a particular filesystem option, like these:

```
Last mounted on: <not available>
Filesystem features: has_journal filetype sparse_super
Filesystem state: clean
Inode count: 657312
Block count: 1313305
Last checked: Thu Jul 3 12:32:23 2008
Check interval: 15552000 (6 months)
```

Some of these options' meanings are fairly self-explanatory; for instance, the filesystem was last checked (with `fsck`, described in "Checking Filesystems") on July 3. Other options aren't so obvious; for instance, the `Inode count` line may be puzzling. (It's a count of the number of *inodes* supported by the filesystem. Each inode contains information for one file, so the number of inodes effectively limits the number of files you can store.)

The next two sections describe some of the options you may want to change. For now, you should know that you can retrieve information about how your filesystems are currently configured using `dumpe2fs`. You can then use this information when modifying the configuration; if your current settings seem reasonable, you can leave them alone, but if they seem ill adapted to your configuration, you can change them.

Unlike many low-level disk utilities, you can safely run `dumpe2fs` on a filesystem that's currently mounted. This can be handy when you're studying your configuration to decide what to modify.

Most other filesystems lack an equivalent to `dumpe2fs`, but XFS provides something with at least some surface similarities: `xfs_info`. To invoke it, pass the command the name of the partition that holds the filesystem you want to check:

```
xfs_info /dev/sda7
meta-data=/dev/sda7 isize=256 agcount=88, agsize=1032192 blks
 = sectsz=512 attr=0
data = bsize=4096 blocks=89915392, imaxpct=25
 = sunit=0 swidth=0 blks, unwritten=1
naming =version 2 bsize=4096
log =internal bsize=4096 blocks=8064, version=1
 = sectsz=512 sunit=0 blks
realtime =none extsz=65536 blocks=0, rtextents=0
```

Instead of the partition name, you can pass the mount point, such as `/home` or `/usr/local`. Unlike most filesystem tools, `xfs_info` requires that the filesystem be mounted. The information returned by `xfs_info` is fairly technical, mostly related to block sizes, sector sizes, and so on.

Another XFS tool is `xfs_metadump`. This program copies the filesystem’s metadata (filenames, file sizes, and so on) to a file. For instance, `xfs_metadump /dev/sda7 ~/dump-file` copies the metadata to `~/dump-file`. This command doesn’t copy actual file contents and so isn’t useful as a backup tool. Instead, it’s intended as a debugging tool; if the filesystem is behaving strangely, you can use this command and send the resulting file to XFS developers for study.

## Adjusting Tunable Filesystem Parameters

The `tune2fs` program enables you to change many of the filesystem parameters that are reported by `dumpe2fs`. This program’s syntax is fairly simple, but it hides a great deal of complexity:

```
tune2fs [options] device
```

The complexity arises because of the large number of *options* that the program accepts. Each feature that `tune2fs` enables you to adjust requires its own option:

**Adjust the maximum mount count** `Ext2fs` and `ext3fs` require a periodic disk check with `fsck`. This check is designed to prevent errors from creeping onto the disk undetected. You can adjust the maximum number of times the disk may be mounted without a check with the `-c mounts` option, where *mounts* is the number of mounts. You can trick the system into thinking the filesystem has been mounted a certain number of times with the `-C mounts` option; this sets the mount counter to *mounts*.

**Adjust the time between checks** Periodic disk checks are required based on time as well as the number of mounts. You can set the time between checks with the `-i interval` option, where *interval* is the maximum time between checks. Normally, *interval* is a number with the character *d*, *w*, or *m* appended, to specify days, weeks, or months, respectively.

**Add a journal** The `-j` option adds a journal to the filesystem, effectively converting an `ext2` filesystem into an `ext3` filesystem. Journal management is described in more detail shortly, in “Maintaining a Journal.”

**Set the reserved blocks** The `-m percent` option sets the percentage of disk space that’s reserved for use by `root`. The default value is 5, but this is excessive on multi-gigabyte hard disks, so you may want to reduce it. You may want to set it to 0 on removable disks intended to store user files. You can also set the reserved space in blocks, rather than as a percentage of disk space, with the `-r blocks` option.

The options described here are the ones that are most likely to be useful. Several other options are available; consult `tune2fs`’s man page for details.

As with most low-level disk utilities, you shouldn’t use `tune2fs` to adjust a mounted filesystem. If you want to adjust a key mounted filesystem, such as your root (`/`) filesystem,

you may need to boot up an emergency disk system, such as the CD-ROM-based Knoppix (<http://www.knoppix.org>). Many distributions' install discs can be used in this capacity, as well.

If you use XFS, the `xfs_admin` command is the rough equivalent of `tune2fs`. Some options you may want to adjust include the following:

**Use version 2 journal format** The `-j` option enables version 2 log (journal) format, which can improve performance in some situations.

**Obtain the filesystem label and UUID** You can use the `-l` and `-u` options to obtain the filesystem's label (name) and *universally unique identifier* (UUID), respectively. The name is seldom used in Linux but can be used in some cases. The UUID is a long code that is increasingly used by distributions to specify a filesystem to be mounted, as described later, in "Permanently Mounting Filesystems."

**Set the filesystem label and UUID** You can change the filesystem's label or UUID by using the `-L label` or `-U uuid` option, respectively. The label is at most 12 characters in length. You'll normally use the `-U` option to set the UUID to a known value (such as the UUID the partition used prior to it being reformatted); or you can use `generate` as the `uuid` value to have `xfs_admin` create a new UUID. You should *not* set the UUID to a value that's in use on another partition!

In use, `xfs_admin` might look something like this:

```
xfs_admin -L av_data /dev/sda7
writing all SBs
new label = "av_data"
```

This example sets the name of the filesystem on `/dev/sda7` to `av_data`. As with `tune2fs`, `xfs_admin` should only be used on unmounted filesystems.

## Interactively Debugging a Filesystem

In addition to reviewing and changing filesystem flags with `dumpe2fs` and `tune2fs`, you can interactively modify a filesystem's features using `debugfs`. This program provides the abilities of `dumpe2fs`, `tune2fs`, and many of Linux's normal file-manipulation tools all rolled into one. To use the program, type its name followed by the device filename corresponding to the filesystem you want to manipulate. You'll then see the `debugfs` prompt:

```
debugfs /dev/hda11
debugfs:
```

You can type commands at this prompt to achieve specific goals:

**Display filesystem superblock information** The `show_super_stats` or `stats` command produces superblock information, similar to what `dumpe2fs` displays.

**Display inode information** You can display the inode data on a file or directory by typing `stat filename`, where `filename` is the name of the file.

**Undelete a file** You can use `debugfs` to undelete a file by typing `undelete inode name`, where *inode* is the inode number of the deleted file and *name* is the filename you want to give to it. (You can use `undel` in place of `undelete` if you like.) This facility is of limited utility because you must know the inode number associated with the deleted file. You can obtain a list of deleted inodes by typing `lsdel` or `list_deleted_inodes`, but the list may not provide enough clues to let you zero in on the file you want to recover.

**Extract a file** You can extract a file from the filesystem by typing `write internal-file external-file`, where *internal-file* is the name of a file in the filesystem you're manipulating and *external-file* is a filename on your main Linux system. This facility can be handy if a filesystem is badly damaged and you want to extract a critical file without mounting the filesystem.

**Manipulate files** Most of the commands described in Chapter 4 work within `debugfs`. You can change your directory with `cd`, create links with `ln`, remove a file with `rm`, and so on.

**Obtain help** Typing `list_requests`, `lr`, `help`, or `?` produces a summary of available commands.

**Exit** Typing `quit` exits from the program.

This summary just scratches the surface of `debugfs`'s capabilities. In the hands of an expert, this program can help rescue a badly damaged filesystem or at least extract critical data from it. To learn more, consult the program's man page.



Although `debugfs` is a useful tool, it's potentially dangerous. Don't use it on a mounted filesystem, don't use it unless you have to, and be very careful when using it. If in doubt, leave the adjustments to the experts. Be aware that the LPI exam does cover `debugfs`, though.

The closest XFS equivalent to `debugfs` is called `xfs_db`. Like `debugfs`, `xfs_db` provides an interactive tool to access and manipulate a filesystem; but `xfs_db` provides fewer tools that are amenable to novice or intermediate use. Instead, `xfs_db` is a tool for XFS experts.

## Maintaining a Journal

Ext2fs is a traditional filesystem. Although it's a good performer, it suffers from a major limitation: After a power failure, a system crash, or another uncontrolled shutdown, the filesystem could be in an inconsistent state. The only way to safely mount the filesystem so that you're sure its data structures are valid is to perform a full disk check on it, as described in "Checking Filesystems." This task is usually handled automatically when the system boots, but it takes time—probably several minutes, or perhaps more than an hour on a large filesystem or if the computer has many smaller filesystems.

The solution to this problem is to change to a *journaling filesystem*. Such a filesystem maintains a *journal*, which is a data structure that describes pending operations. Prior to writing data to the disk's main data structures, Linux describes what it's about to do in

the journal. When the operations are complete, their entries are removed from the journal. Thus, at any given moment the journal should contain a list of disk structures that *might* be undergoing modification. The result is that, in the event of a crash or power failure, the system can examine the journal and check only those data structures described in it. If inconsistencies are found, the system can roll back the changes, returning the disk to a consistent state without checking every data structure in the filesystem. This greatly speeds the disk-check process after power failures and system crashes. Today, journaling filesystems are the standard for most Linux disk partitions. Very small partitions (such as a separate /boot partition, if you use one) and small removable disks (such as Zip disks) often lack journals, though.

Four journaling filesystems are common on Linux: ext3fs, ReiserFS, XFS, and JFS. Of these, the last three require little in the way of journal configuration. Ext3fs is a bit different; it's basically just ext2fs with a journal added. This fact means you can add a journal to an ext2 filesystem, converting it into an ext3 filesystem. This is what the `-j` option to `tune2fs` does, as described earlier in “Adjusting Tunable Filesystem Parameters.”



Although using `tune2fs` on a mounted filesystem is generally inadvisable, it's safe to use its `-j` option on a mounted filesystem. The result is a file called `.journal` that holds the journal. If you add a journal to an unmounted filesystem, the journal file will be invisible.

Adding a journal alone won't do much good, though. In order to use a journal, you must mount the filesystem with the correct filesystem type code—`ext3` rather than `ext2`. (The upcoming section “Mounting and Unmounting Filesystems” describes how to do this.)

The journal, like other filesystem features, has its own set of parameters. You can set these with the `-J` option to `tune2fs`. In particular, the `size=journal-size` and `device=external-journal` sub-options enable you to set the journal's size and the device on which it's stored. By default, the system creates a journal that's the right size for the filesystem and stores it on the filesystem itself.

## Checking Filesystems

Tuning a filesystem is a task you're likely to perform every once in a while—say, when making major changes to an installation. Another task is much more common: checking a filesystem for errors. Bugs, power failures, and mechanical problems can all cause the data structures on a filesystem to become corrupted. The results are sometimes subtle, but if they're left unchecked, they can cause severe data loss. For this reason, Linux includes tools for verifying a filesystem's integrity and for correcting any problems that may exist. The main tool you'll use for this purpose is called `fsck`. This program is actually a front end to other tools, such as `e2fsck` (a.k.a. `fsck.ext2` and `fsck.ext3`) or XFS's `xfs_check` and `xfs_repair`. The syntax for `fsck` is as follows:

```
fsck [-sACVRTNP] [-t fstype] [--] [fsck-options] filesystems
```





The LPI objectives emphasize `e2fsck` rather than `fsck`, but because `fsck` is the more general tool that's useful on more filesystems, it's the form described in more detail in this book.

The more common parameters to `fsck` enable you to perform useful actions:

**Check all files** The `-A` option causes `fsck` to check all the filesystems marked to be checked in `/etc/fstab`. This option is normally used in system startup scripts.

**Indicate progress** The `-C` option displays a text-mode progress indicator of the check process. Most filesystem check programs don't support this feature, but `e2fsck` does.

**Show verbose output** The `-V` option produces verbose output of the check process.

**No action** The `-N` option tells `fsck` to display what it would normally do without actually doing it.

**Set the filesystem type** Normally, `fsck` determines the filesystem type automatically. You can force the type with the `-t fstype` flag, though. Used in conjunction with `-A`, this causes the program to check only the specified filesystem types, even if others are marked to be checked. If *fstype* is prefixed with `no`, then all filesystems *except* the specified type are checked.

**Filesystem-specific options** Filesystem check programs for specific filesystems often have their own options. The `fsck` command passes options it doesn't understand, or those that follow a double dash (`--`), to the underlying check program. Common options include `-a` or `-p` (perform an automatic check), `-r` (perform an interactive check), and `-f` (force a full filesystem check even if the filesystem initially appears to be clean).

**Filesystem list** The final parameter is usually the name of the filesystem or filesystems being checked, such as `/dev/sda6`.

Normally, you run `fsck` with only the filesystem device name, as in `fsck /dev/sda6`. You can add options as needed, however. Check `fsck`'s man page for less common options.



Run `fsck` *only* on filesystems that are not currently mounted or that are mounted in read-only mode. Changes written to disk during normal read/write operations can confuse `fsck` and result in filesystem corruption.

Linux runs `fsck` automatically at startup on partitions that are marked for this in `/etc/fstab`, as described later in “Permanently Mounting Filesystems.” The normal behavior of `e2fsck` causes it to perform just a quick cursory examination of a partition if it's been unmounted cleanly. The result is that the Linux boot process isn't delayed because of a filesystem check unless the system wasn't shut down properly. This rule has a couple of exceptions, though: `e2fsck` forces a check if the disk has gone longer than a certain amount of time without checks (normally six months) or if the filesystem has been mounted more than a certain number of times since the last check (normally 20). You can change these options

using `tune2fs`, as described earlier in “Adjusting Tunable Filesystem Parameters.” Therefore, you’ll occasionally see automatic filesystem checks of `ext2fs` and `ext3fs` partitions even if the system was shut down correctly.

Journaling filesystems do away with filesystem checks at system startup even if the system wasn’t shut down correctly. Nonetheless, these filesystems still require check programs to correct problems introduced by undetected write failures, bugs, hardware problems, and the like. If you encounter odd behavior with a journaling filesystem, you might consider unmounting it and performing a filesystem check—but be sure to read the documentation first. Some Linux distributions do odd things with some journaling filesystem check programs. For instance, Mandriva uses a symbolic link from `/sbin/fsck.reiserfs` to `/bin/true`. This configuration speeds system boot times should ReiserFS partitions be marked for automatic checks, but it can be confusing if you need to manually check the filesystem. If this is the case, run `/sbin/reiserfsck` to do the job. Similarly, `/sbin/fsck.xfs` is usually nothing but a script that advises the user to run `xfs_check` or `xfs_repair`.

## Monitoring Disk Use

One common problem with disks is that they can fill up. To avoid this problem, you need tools to tell you how much space your files are consuming. This is the task of the `df` and `du` programs, which summarize disk use on a partition-by-partition and directory-by-directory basis, respectively.

### Monitoring Disk Use by Partition

The `df` command’s syntax is as follows:

```
df [options] [files]
```

In the simplest case, you can type the command name to see a summary of disk space used on all of a system’s partitions:

```
$ df
Filesystem 1K-blocks Used Available Use% Mounted on
/dev/sdb10 5859784 4449900 1409884 76% /
/dev/sdb12 2086264 991468 1094796 48% /opt
/dev/hda13 2541468 320928 2220540 13% /usr/local
/dev/hda9 15361340 10174596 5186744 67% /home
/dev/hda10 22699288 13663408 7882820 64% /other/emu
/dev/hda6 101089 22613 74301 24% /boot
/dev/sdb5 1953216 1018752 934464 53% /other/shared
none 256528 0 256528 0% /dev/shm
speaker:/home 6297248 3845900 2451348 62% /speaker/home
/win/music 17156608 8100864 9055744 48% /win/mp3s
```

This output shows the device file associated with the filesystem, the total amount of space on the filesystem, the used space on the filesystem, the free space on the filesystem, the percentage of space that's used, and the mount point. Typically, when used space climbs above about 80 percent, you should consider cleaning up the partition. The appropriate ceiling varies from one system and partition to another, though. The risk is greatest on partitions that hold files that change frequently—particularly if large files are likely to be created on a partition, even if only temporarily.

You can fine-tune the effects of `df` by passing it several options. Each option modifies the `df` output in a specific way:

**Include all filesystems** The `-a` or `--all` option includes pseudo filesystems with a size of 0 in the output. These filesystems may include `/proc`, `/sys`, `/proc/bus/usb`, and others.

**Use scaled units** The `-h` or `--human-readable` option causes `df` to scale and label its units; for instance, instead of reporting a partition as having 5859784 blocks, it reports the size as 5.6G (for 5.6GB). The `-H` and `--si` options have a similar effect, but they use power-of-10 (1,000, 1,000,000, and so on) units rather than power-of-2 (1,024, 1,048,576, and so on) units. The `-k` (`--kilobytes`) and `-m` (`--megabytes`) options force output in their respective units.

**Summarize inodes** By default, `df` summarizes available and used disk space. You can instead receive a report on available and used inodes by passing the `-i` or `--inodes` option. This information can be helpful if a partition has very many small files, which can deplete available inodes sooner than they deplete available disk space.



The `-i` option works well for ext2, ext3, XFS, and some other filesystems that create a fixed number of inodes when the filesystem is created. Other filesystems, such as ReiserFS, create inodes dynamically, rendering the `-i` option meaningless.

**Local filesystems only** The `-l` or `--local` option causes `df` to omit network filesystems. This can speed up operation.

**Display filesystem type** The `-T` or `--print-type` option adds the filesystem type to the information `df` displays.

**Limit by filesystem type** The `-t fstype` or `--type=fstype` option displays only information about filesystems of the specified type. The `-x fstype` or `--exclude-type=fstype` option has the opposite effect; it excludes filesystems of the specified type from the report.

This list is incomplete; consult `df`'s man page for details about more options. In addition to these options, you can specify one or more *files* to `df`. When you do this, the program restricts its report to the filesystem on which the specified file or directory exists. For instance, to learn about the disk space used on the `/home` partition, you could type `df /home`. Alternatively, you can give a device filename, as in `df /dev/hda9`.

## Monitoring Disk Use by Directory

The `df` command is helpful for finding out which partitions are in danger of becoming overloaded; but once you've obtained this information, you may need to fine-tune the diagnosis and track down the directories and files that are chewing up disk space. The tool for this task is `du`, which has a syntax similar to that of `df`:

```
du [options] [directories]
```

This command searches directories you specify and reports how much disk space each is consuming. This search is recursive, so you can learn how much space the directory and all its subdirectories consume. The result can be a very long listing if you specify directories with many files, but several options can reduce the size of this output. Others can perform helpful tasks as well:

**Summarize files as well as directories** Ordinarily, `du` reports on the space used by the files in directories but not the space used by individual files. Passing the `-a` or `--all` option causes `du` to report on individual files as well.

**Compute a grand total** Adding the `-c` or `--total` option causes `du` to add a grand total to the end of its output.

**Use scaled units** The `-h` or `--human-readable` option causes `du` to scale and label its units; for instance, instead of reporting the total disk space used as 5859784 blocks, it reports the size as 5.6G (for 5.6GB). The `-H` and `--si` options have a similar effect, but they use power-of-10 (1,000, 1,000,000, and so on) units rather than power-of-2 (1,024, 1,048,576, and so on) units. The `-k` (`--kilobytes`) and `-m` (`--megabytes`) options force output in their respective units.

**Count hard links** Ordinarily, `du` counts files that appear multiple times as hard links only once. This reflects true disk space used, but sometimes you may want to count each link independently (for instance, if you're creating a CD-R and the file will be stored once for each link). To do so, include the `-l` (that's a lowercase *L*) or `--count-links` option. (Links are described in more detail in Chapter 4.)

**Limit depth** The `--max-depth=n` option limits the report to *n* levels. (The subdirectories' contents are counted even if they aren't reported.)

**Summarize** If you don't want a line of output for each subdirectory in the tree, pass the `-s` or `--summarize` option, which limits the report to those files and directories you specify on the command line. This option is equivalent to `--max=depth=0`.

**Limit to one filesystem** The `-x` or `--one-file-system` option limits the report to the current filesystem. If another filesystem is mounted within the tree you want summarized, its contents aren't included in the report.

This list is incomplete; you should consult `du`'s man page for information about additional options.

As an example of `du` in action, consider using it to discover which of your users is consuming the most disk space in `/home`. Chances are you're not concerned with the details of which subdirectories within each home directory are using the space, so you'll pass the `-s` option to the program:

```
du -s /home/*
12 /home/ellen
35304 /home/freddie
1760 /home/jennie
12078 /home/jjones
0 /home/lost+found
10110324 /home/mspiggy
```

In this example, the wildcard character (`*`) stands for all the directories in `/home`, thus producing summaries for all these subdirectories. (For more on this topic, consult Chapter 4.) Clearly, `mspiggy` (or whoever owns the `/home/mspiggy` directory) is the biggest disk space user—or at least, that directory's contents are consuming the most space. You could investigate further, say by typing `du -s /home/mspiggy/*` to learn where the disk space is being used within the `/home/mspiggy` directory. In the case of user files, if this space consumption is a problem, you may want to contact this user instead of trying to clean it up yourself.



Many types of files shouldn't simply be deleted. For instance, most program files should be removed via the system's package management system, if you decide to remove them. (This topic is covered in Chapter 2, "Managing Software.") If you're not sure what a file is or how it should be removed, don't delete it—try a Web search, type `man filename`, or otherwise research it to figure out what it is.

## Mounting and Unmounting Filesystems

Maintaining filesystems is necessary, but the whole reason filesystems exist is to store files—in other words, to be useful. Under Linux, filesystems are most often used by being *mounted*—that is, associated with a directory. This task can be accomplished on a one-time basis by using tools such as `mount` (and then unmounted with `umount`) or persistently across reboots by editing the `/etc/fstab` file.

### Temporarily Mounting or Unmounting Filesystems

Linux provides the `mount` command to mount a filesystem to a mount point. The `umount` command reverses this process. (Yes, `umount` is spelled correctly; it's missing the first `n`.) In

practice, using these commands isn't usually too difficult, but they support a large number of options.

## Syntax and Parameters for *mount*

The syntax for *mount* is as follows:

```
mount [-alrsvw] [-t fstype] [-o options] [device] [mountpoint]
```

Common parameters for *mount* support a number of features:

**Mount all filesystems** The *-a* parameter causes *mount* to mount all the filesystems listed in the */etc/fstab* file, which specifies the most-used partitions and devices. The upcoming section “Permanently Mounting Filesystems” describes this file’s format.

**Mount read-only** The *-r* parameter causes Linux to mount the filesystem read-only, even if it’s normally a read/write filesystem.

**Show verbose output** As with many commands, *-v* produces verbose output—the program provides comments on operations as they occur.

**Mount read/write** The *-w* parameter causes Linux to attempt to mount the filesystem for both read and write operations. This is the default for most filesystems, but some experimental drivers default to read-only operation. The *-o rw* option has the same effect.

**Specify the filesystem type** Use the *-t *fstype** parameter to specify the filesystem type. Common filesystem types are *ext2* (for *ext2fs*), *ext3* (for *ext3fs*), *ext4dev* (for *ext4fs* development code; this will change to *ext4* once *ext4fs* is finalized), *reiserfs* (for ReiserFS), *jfs* (for JFS), *xf*s (for XFS), *vfat* (for FAT with VFAT long filenames), *msdos* (for FAT using only short DOS filenames), *iso9660* (for CD-ROM filesystems), *udf* (for DVD and some CD-ROM filesystems), *nfs* (for NFS network mounts), *smbfs* (for SMB/CIFS network shares), and *cifs* (a newer driver for SMB/CIFS network shares). Linux supports many others. If this parameter is omitted, Linux will attempt to auto-detect the filesystem type.



Linux requires support in the kernel or as a kernel module to mount a filesystem of a given type. If this support is missing, Linux will refuse to mount the filesystem in question.

**Mount by label or UUID** The *-L *label** and *-U *uuid** options tell *mount* to mount the filesystem with the specified label or UUID, respectively.

**Additional options** You can add many options using the *-o* parameter. Many of these are filesystem specific.

**Device** The *device* is the device filename associated with the partition or disk device, such as */dev/hda4*, */dev/fd0*, or */dev/cdrom*. This parameter is usually required, but it may be omitted under some circumstances, as described shortly.

**Mount point** The *mountpoint* is the directory to which the device’s contents should be attached. As with *device*, it’s usually required, but it may be omitted under some circumstances.

The preceding list of `mount` parameters isn’t comprehensive; consult the `mount` man page for some of the more obscure options. The most common applications of `mount` use few parameters because Linux generally does a good job of detecting the filesystem type and the default parameters work reasonably well. For instance, consider this example:

```
mount /dev/sdb7 /mnt/shared
```

This command mounts the contents of `/dev/sdb7` on `/mnt/shared`, auto-detecting the filesystem type and using the default options. Ordinarily, only root may issue a `mount` command; however, if `/etc/fstab` specifies the `user`, `users`, or `owner` option, an ordinary user may mount a filesystem using a simplified syntax in which only the device *or* mount point is specified, but not both. For instance, a user may type `mount /mnt/cdrom` to mount a CD-ROM if `/etc/fstab` specifies `/mnt/cdrom` as its mount point and uses the `user`, `users`, or `owner` option.



Most Linux distributions ship with auto-mounter support, which causes the OS to automatically mount removable media when they’re inserted. In GUI environments, a file browser may also open on the inserted disk. In order to eject the disk, the user will need to unmount the filesystem by using `umount`, as described shortly, or by selecting an option in the desktop environment.

When Linux mounts a filesystem, it ordinarily records this fact in `/etc/mtab`. This file has a format similar to that of `/etc/fstab` and is stored in `/etc`, but it’s not a configuration file that you should edit. You might examine this file to determine what filesystems are mounted, though. (The `df` command, described in more detail in “Monitoring Disk Use by Partition,” is another way to learn what filesystems are mounted.)

## Options for *mount*

When you do need to use special parameters (via `-o` or in `/etc/fstab`), it’s usually to add filesystem-specific options. Table 3.5 summarizes the most important filesystem options. Some of these are meaningful only in the `/etc/fstab` file.

**TABLE 3.5** Important Filesystem Options for the `mount` Command

| Option                | Supported Filesystems | Description                                                                                                                                                            |
|-----------------------|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>defaults</code> | All                   | Causes the default options for this filesystem to be used. It’s used primarily in the <code>/etc/fstab</code> file to ensure that the file includes an options column. |

**TABLE 3.5** Important Filesystem Options for the mount Command (*continued*)

| Option         | Supported Filesystems | Description                                                                                                                                                                                                                                                                                                                                                                                                              |
|----------------|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| loop           | All                   | Causes the loopback device for this mount to be used. Allows you to mount a file as if it were a disk partition. For instance, <b>mount -t vfat -o loop image.img /mnt/image</b> mounts the file <code>image.img</code> as if it were a disk.                                                                                                                                                                            |
| auto or noauto | All                   | Mounts or doesn't mount the filesystem at boot time or when root issues the <b>mount -a</b> command. The default is <code>auto</code> , but <code>noauto</code> is appropriate for removable media. Used in <code>/etc/fstab</code> .                                                                                                                                                                                    |
| user or nouser | All                   | Allows or disallows ordinary users to mount the filesystem. The default is <code>nouser</code> , but <code>user</code> is often appropriate for removable media. Used in <code>/etc/fstab</code> . When included in this file, user allows users to type <b>mount /mountpoint</b> (where <code>/mountpoint</code> is the assigned mount point) to mount a disk. Only the user who mounted the filesystem may unmount it. |
| users          | All                   | Similar to <code>user</code> , except that any user may unmount a filesystem once it's been mounted.                                                                                                                                                                                                                                                                                                                     |
| owner          | All                   | Similar to <code>user</code> , except that the user must own the device file. Some distributions, such as Red Hat, assign ownership of some device files (such as <code>/dev/fd0</code> for the floppy disk) to the console user, so this can be a helpful option.                                                                                                                                                       |
| remount        | All                   | Changes one or more mount options without explicitly unmounting a partition. To use this option, you issue a <code>mount</code> command on an already-mounted filesystem but with <code>remount</code> along with any options you want to change. This feature can be used to enable or disable write access to a partition, for example.                                                                                |
| ro             | All                   | Specifies a read-only mount of the filesystem. This is the default for filesystems that include no write access and for some with particularly unreliable write support.                                                                                                                                                                                                                                                 |



**TABLE 3.5** Important Filesystem Options for the mount Command (*continued*)

| Option                   | Supported Filesystems                                                                         | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|--------------------------|-----------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>rw</code>          | All read/write filesystems                                                                    | Specifies a read/write mount of the filesystem. This is the default for most read/write filesystems.                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <code>uid=value</code>   | Most filesystems that don't support Unix-style permissions, such as vfat, hpfs, ntfs, and hfs | Sets the owner of all files. For instance, <code>uid=500</code> sets the owner to whoever has Linux user ID 500. (Check Linux user IDs in the <code>/etc/passwd</code> file.)                                                                                                                                                                                                                                                                                                                                                                                           |
| <code>gid=value</code>   | Most filesystems that don't support Unix-style permissions, such as vfat, hpfs, ntfs, and hfs | Works like <code>uid=value</code> , but sets the group of all files on the filesystem. You can find group IDs in the <code>/etc/group</code> file.                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <code>umask=value</code> | Most filesystems that don't support Unix-style permissions, such as vfat, hpfs, ntfs, and hfs | Sets the umask for the permissions on files. <i>value</i> is interpreted in binary as bits to be removed from permissions on files. For instance, <code>umask=027</code> yields permissions of 750, or <code>-rwxr-x---</code> . Used in conjunction with <code>uid=value</code> and <code>gid=value</code> , this option lets you control who can access files on FAT, HPFS, and many other foreign filesystems.                                                                                                                                                       |
| <code>dmask=value</code> | Most filesystems that don't support Unix-style permissions, such as vfat, hpfs, ntfs, and hfs | Similar to <code>umask</code> , but sets the umask for directories only, not for files.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <code>fmask=value</code> | Most filesystems that don't support Unix-style permissions, such as vfat, hpfs, ntfs, and hfs | Similar to <code>umask</code> , but sets the umask for files only, not for directories.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <code>conv=code</code>   | Most filesystems used on Microsoft and Apple OSs: msdos, umsdos, vfat, hpfs, and hfs          | If <i>code</i> is <code>b</code> or <code>binary</code> , Linux doesn't modify the files' contents. If <i>code</i> is <code>t</code> or <code>text</code> , Linux auto-converts files between Linux-style and DOS- or Macintosh-style end-of-line characters. If <i>code</i> is <code>a</code> or <code>auto</code> , Linux applies the conversion unless the file is a known binary file format. It's usually best to leave this at its default value of <code>binary</code> because file conversions can cause serious problems for some applications and file types. |

**TABLE 3.5** Important Filesystem Options for the mount Command (*continued*)

| Option   | Supported Filesystems | Description                                          |
|----------|-----------------------|------------------------------------------------------|
| norock   | iso9660               | Disables Rock Ridge extensions for ISO-9660 CD-ROMs. |
| nojoliet | iso9660               | Disables Joliet extensions for ISO-9660 CD-ROMs.     |

Some filesystems support additional options that aren't described here. The man page for mount covers some of these, but you may need to look at the filesystem's documentation for some filesystems and options. This documentation may appear in `/usr/src/linux/Documentation/filesystems` or `/usr/src/linux/fs/fsname`, where *fsname* is the name of the filesystem.

## Using *umount*

The *umount* command is simpler than *mount*. The basic *umount* syntax is as follows:

```
umount [-afnr] [-t fstype] [device | mountpoint]
```

Most of these parameters have meanings similar to their meanings in *mount*, but some differences deserve mention:

**Unmount all** Rather than unmount partitions listed in `/etc/fstab`, the `-a` option causes the system to attempt to unmount all the partitions listed in `/etc/mtab`, the file that holds information about mounted filesystems. On a normally running system, this operation is likely to succeed only partly because it won't be able to unmount some key filesystems, such as the root partition.

**Force unmount** You can use the `-f` option to tell Linux to force an unmount operation that might otherwise fail. This feature is sometimes helpful when unmounting NFS mounts shared by servers that have become unreachable.

**Fall back to read-only** The `-r` option tells *umount* that if it can't unmount a filesystem, it should attempt to remount it in read-only mode.

**Unmount partitions of a specific filesystem type** The `-t fstype` option tells the system to unmount only partitions of the specified type. You can list multiple filesystem types by separating them with commas.

**The device and mount point** You need to specify only the *device* or only the *mountpoint*, not both.

As with *mount*, normal users can't ordinarily use *umount*. The exception is if the partition or device is listed in `/etc/fstab` and specifies the `user`, `users`, or `owner` option, in which case normal users can unmount the device. (In the case of `user`, only the user who mounted

the partition may unmount it; in the case of `owner`, the user issuing the command must also own the device file, as with `mount`.) These options are most useful for removable-media devices.



Be cautious when removing floppy disks or unplugging USB disk-like devices (USB “pen drives” or external hard disks). Linux caches accesses to most filesystems, which means that data may not be written to the disk until some time after a write command. Because of this, it’s possible to corrupt a disk by ejecting or unplugging it, even when the drive isn’t active. You must *always* issue a `umount` command before ejecting a mounted disk. (GUI unmount tools do this behind the scenes, so using a desktop’s unmount or eject option is equivalent to using `umount`.) After issuing the `umount` command, wait for the command to return, and if the disk has activity indicators, wait for them to stop blinking to be sure Linux has finished using the device. This isn’t an issue for most internal removable media, such as DVD and Zip drives, because Linux can lock their eject mechanisms, preventing this sort of problem. Another way to write the cache to disk is to use the `sync` command; but because this command does *not* fully unmount a filesystem, it’s not a substitute for `umount`.

## Permanently Mounting Filesystems

The `/etc/fstab` file controls how Linux provides access to disk partitions and removable media devices. Linux supports a unified directory structure in which every disk device (partition or removable disk) is mounted at a particular point in the directory tree. For instance, you might access a USB pen drive at `/media/pen`. The root of this tree is accessed from `/`. Directories off this root may be other partitions or disks, or they may be ordinary directories. For instance, `/etc` should be on the same partition as `/`, but many other directories, such as `/home`, may correspond to separate partitions. The `/etc/fstab` file describes how these filesystems are laid out. (The filename `fstab` is an abbreviation for *filesystem table*.)

The `/etc/fstab` file consists of a series of lines that contain six fields each; the fields are separated by one or more spaces or tabs. A line that begins with a hash mark (`#`) is a comment and is ignored. Listing 3.1 shows a sample `/etc/fstab` file.

### Listing 3.1: Sample `/etc/fstab` File

```
#device mount point filesystem options dump fsck
/dev/hda1 / ext3 defaults 1 1
UUID=3631a288-673e-40f5-9e96-6539fec468e9 \
 /usr reiserfs defaults 0 0
LABEL=/home /home reiserfs defaults 0 0
/dev/hdb5 /windows vfat uid=500,umask=0 0 0
/dev/hdc /media/cdrom iso9660 users,noauto 0 0
```

```

/dev/sda1 /media/pen auto users,noauto 0 0
server:/home /other/home nfs users,exec 0 0
//winsrv/shr /other/win cifs users,credentials=/etc/creds 0 0
/dev/hda4 swap swap defaults 0 0

```

The meaning of each field in this file is as follows:

**Device** The first column specifies the mount device. These are usually device filenames that reference hard disks, floppy drives, and so on. Most distributions now specify partitions by their labels or UUIDs, as in the LABEL=/home and UUID=3631a288-673e-40f5-9e96-6539fec468e9 entries in Listing 3.1. When Linux encounters such an entry, it tries to find the partition whose filesystem has the specified name or UUID and mount it. This practice can help reduce problems if partition numbers change, but some filesystems lack these labels. It's also possible to list a network drive, as in server:/home, which is the /home export on the computer called server; or //winsrv/shr, which is the shr share on the Windows or Samba server called winsrv.

**Mount point** The second column specifies the mount point; in the unified Linux filesystem, this is where the partition or disk will be mounted. This should usually be an empty directory in another filesystem. The root (/) filesystem is an exception. So is swap space, which is indicated by an entry of swap.

**Filesystem type** The filesystem type code is the same as the type code used to mount a filesystem with the mount command. You can use any filesystem type code you can use directly with the mount command. A filesystem type code of auto lets the kernel auto-detect the filesystem type, which can be a convenient option for removable media devices. Auto-detection doesn't work with all filesystems, though.

**Mount options** Most filesystems support several mount options, which modify how the kernel treats the filesystem. You may specify multiple mount options, separated by commas. For instance, uid=500,umask=0 for /windows in Listing 3.1 sets the user ID (owner) of all files to 500 and sets the umask to 0. (User IDs and umasks are covered in more detail in Chapter 4.) Table 3.3 summarizes the most common mount options. Type **man mount** or consult filesystem-specific documentation to learn more.

**Backup operation** The next-to-last field contains a 1 if the dump utility should back up a partition or a 0 if it shouldn't. If you never use the dump backup program, this option is essentially meaningless. (The dump program was once a common backup tool, but its use is discouraged today.)

**Filesystem check order** At boot time, Linux uses the fsck program to check filesystem integrity. The final column specifies the order in which this check occurs. A 0 means that fsck should *not* check a filesystem. Higher numbers represent the check order. The root partition should have a value of 1, and all others that should be checked should have a value of 2. Some filesystems, such as ReiserFS, shouldn't be automatically checked and so should have values of 0.

If you add a new hard disk or have to repartition the one you've got, you'll probably need to modify `/etc/fstab`. You may also need to edit it to alter some of its options. For instance, setting the user ID or `umask` on Windows partitions mounted in Linux may be necessary to let ordinary users write to the partition.



## Real World Scenario

### Managing User-Mountable Media

You may want to give ordinary users the ability to mount certain partitions or removable media, such as floppies, CD-ROMs, and USB pen drives. To do so, create an ordinary `/etc/fstab` entry for the filesystem, but be sure to add the `user`, `users`, or `owner` option to the options column. Table 3.5 describes the differences between these three options. Listing 3.1 shows some examples of user-mountable media: `/media/cdrom`, `/media/pen`, `/other/home`, and `/other/win`. The first two of these are designed for removable media and include the `noauto` option, which prevents Linux from wasting time trying to mount them when the OS first boots. The second pair of mount points are network file shares that are mounted automatically at boot time; the `users` option on these lines enables ordinary users to unmount and then remount the filesystem, which might be handy if, say, ordinary users have the ability to shut down the server.

As with any filesystems you want to mount, you must provide mount points—that is, create empty directories—for user-mountable media. Removable media are usually mounted in subdirectories of `/mnt` or `/media`.

The `credentials` option for the `/other/win` mount point in Listing 3.1 deserves greater elaboration. Ordinarily, most SMB/CIFS shares require a username and password as a means of access control. Although you can use the `username=name` and `password=pass` options to `smbfs` or `cifs`, these options are undesirable, particularly in `/etc/fstab`, because they leave the password vulnerable to discovery—anybody who can read `/etc/fstab` can read the password. The `credentials=file` option provides an alternative—you can use it to point Linux at a file that holds the username and password. This file has labeled lines:

```
username=hschmidt
password=yiW7t9Td
```

Of course, the file you specify (`/etc/creds` in Listing 3.1) must be well protected—it must be readable only to root and perhaps to the user whose share it describes.

## Summary

Most Linux tools and procedures provide a layer around the hardware, insulating you from a need to know too many details. Nonetheless, sometimes you've got to dig in and configure hardware directly. BIOS settings can control onboard devices such as hard disk controllers and USB ports. USB and SCSI devices have their own quirks, and USB in particular is quickly evolving.

Hard disks are one class of hardware that's likely to require more attention than most. Specifically, you must know how to create partitions and prepare filesystems on those partitions. These tasks are necessary when you install Linux (although most distributions provide GUI tools to help guide you through this task during installation), when you add a hard disk, or when you reconfigure an existing system. You should also know something about boot managers. These programs help get Linux up and running when you turn on a computer's power, so they're unusually critical to Linux operation.

Filesystem management is basic to being able to administer or use a Linux system. The most basic of these basic tasks are filesystem tasks—the ability to mount filesystems, check their health, and repair ailing filesystems. Once a filesystem is mounted, you may want to periodically check to see how full it is, lest you run out of disk space.

## Exam Essentials

**Summarize BIOS essentials.** The BIOS provides two important functions: First, it configures hardware—both hardware that's built into the motherboard and hardware on many types of plug-in cards. Second, the BIOS begins the computer's boot process, passing control on to the boot loader in the MBR.

**Describe what files contain important hardware information.** There are many files under the `/proc` filesystem. Many of these files have been mentioned throughout this chapter. Familiarize yourself with these files, such as `/proc/ioports`, `/proc/interrupts`, `/proc/dma`, `/proc/bus/usb`, and others.

**Explain Linux's model for managing USB hardware.** Linux uses drivers for USB controllers. These drivers in turn are used by some device-specific drivers (for USB disk devices, for instance) and by programs that access USB hardware via entries in the `/proc/bus/usb` directory tree.

**Summarize how to obtain information about PCI and USB devices.** The `lspci` and `lsusb` programs return information about PCI and USB devices, respectively. You can learn manufacturers' names and various configuration options by using these commands.

**Identify common disk types and their features.** PATA disks were the most common type on PCs until about 2005. Since then, SATA disks, which are more easily configured, have gained substantially in popularity. SCSI disks have long been considered the top-tier disks, but their high price has kept them out of inexpensive commodity PCs.

**Describe the purpose of disk partitions.** Disk partitions break the disk into a handful of distinct parts. Each partition can be used by a different OS, can contain a different filesystem, and is isolated from other partitions. These features improve security and safety and can greatly simplify running a multi-OS system.

**Summarize important Linux disk partitions.** The most important Linux disk partition is the root (/) partition, which is at the base of the Linux directory tree. Other possible partitions include a swap partition, /home for home directories, /usr for program files, /var for transient system files, /tmp for temporary user files, /boot for the kernel and other critical boot files, and more.

**Describe commands that help you monitor disk use.** The df command provides a one-line summary of each mounted filesystem's size, available space, free space, and percentage of space used. The du command adds up the disk space used by all the files in a specified directory tree and presents a summary by directory and subdirectory.

**Summarize the tools that can help keep a filesystem healthy.** The fsck program is a front-end to filesystem-specific tools such as e2fsck and fsck.jfs. By whatever name, these programs examine a filesystem's major data structures for internal consistency and can correct minor errors.

**Explain how filesystems are mounted in Linux.** The mount command ties a filesystem to a Linux directory; once the filesystem is mounted, its files can be accessed as part of the mount directory. The /etc/fstab file describes permanent mappings of filesystems to mount points; when the system boots, it automatically mounts the described filesystems unless they use the noauto option (which is common for removable disks).

## Review Questions

1. What are common IRQs for serial ports? (Select all that apply.)
  - A. 1
  - B. 3
  - C. 4
  - D. 16
2. What tool would you use to disable a motherboard's sound hardware if you don't want to use it?
  - A. The BIOS
  - B. The `alsactl` utility
  - C. The `lsmod` command
  - D. None of the above; onboard sound devices can't be disabled
3. What is the purpose of `udev`?
  - A. To aid in the development of software
  - B. To manage the `/dev` directory tree
  - C. To load Linux device drivers
  - D. To store devices' BIOS configurations in files
4. You've just installed Linux on a new computer with a single SATA hard disk. What device identifier will refer to the disk?
  - A. `/dev/sda`
  - B. `/dev/sda` or `/dev/hda`
  - C. `/dev/hda`
  - D. `C:`
5. Which files contain essential system information such as IRQs, DMA channels, and I/O addresses? (Select all that apply.)
  - A. `/proc/ioports`
  - B. `/proc/ioaddresses`
  - C. `/proc/dma`
  - D. `/proc/interrupts`



6. Typing `fdisk -l /dev/hda` on an x86 Linux computer produces a listing of four partitions: `/dev/hda1`, `/dev/hda2`, `/dev/hda5`, and `/dev/hda6`. Which of the following is true?
  - A. The disk contains two primary partitions and two extended partitions.
  - B. Either `/dev/hda1` or `/dev/hda2` is an extended partition.
  - C. The partition table is corrupted; there should be a `/dev/hda3` and a `/dev/hda4` before `/dev/hda5`.
  - D. If you add a `/dev/hda3` with `fdisk`, `/dev/hda5` will become `/dev/hda6` and `/dev/hda6` will become `/dev/hda7`.
7. A new Linux administrator plans to create a system with separate `/home`, `/usr/local`, and `/etc` partitions. Which of the following best describes this configuration?
  - A. The system won't boot because `/etc` contains configuration files necessary to mount non-root partitions.
  - B. The system will boot, but `/usr/local` won't be available because mounted partitions must be mounted directly off their parent partition, not in a subdirectory.
  - C. The system will boot only if the `/home` partition is on a separate physical disk from the `/usr/local` partition.
  - D. The system will boot and operate correctly, provided each partition is large enough for its intended use.
8. Which of the following directories is *most* likely to be placed on its own hard disk partition?
  - A. `/bin`
  - B. `/sbin`
  - C. `/mnt`
  - D. `/home`
9. You discover that an x86 hard disk has partitions with type codes of `0x0f`, `0x82`, and `0x83`. Assuming these type codes are accurate, what can you conclude about the disk?
  - A. The disk holds a partial or complete Linux system.
  - B. The disk holds DOS or Windows 9x/Me and Windows NT/200x/XP installations.
  - C. The disk holds a FreeBSD installation.
  - D. The disk is corrupt; those partition type codes are incompatible.
10. You run Linux's `fdisk` and modify your partition layout. Before exiting the program, you realize that you've been working on the wrong disk. What can you do to correct this problem?
  - A. Nothing; the damage is done, so you'll have to recover data from a backup.
  - B. Type `w` to exit `fdisk` without saving changes to disk.
  - C. Type `q` to exit `fdisk` without saving changes to disk.
  - D. Type `u` repeatedly to undo the operations you've made in error.

11. What does the following command accomplish?  
`# mkfs -t ext2 /dev/sda4`
- A. It sets the partition table type code for `/dev/sda4` to `ext2`.
  - B. It converts a FAT partition into an `ext2fs` partition without damaging the partition's existing files.
  - C. It creates a new `ext2` filesystem on `/dev/sda4`, overwriting any existing filesystem and data.
  - D. Nothing; the `-t` option isn't valid, and so it causes `mkfs` to abort its operation.
12. Which of the following best summarizes the differences between DOS's `FDISK` and Linux's `fdisk`?
- A. Linux's `fdisk` is a simple clone of DOS's `FDISK` but written to work from Linux rather than from DOS or Windows.
  - B. The two are completely independent programs that accomplish similar goals, although Linux's `fdisk` is more flexible.
  - C. DOS's `FDISK` uses GUI controls, whereas Linux's `fdisk` uses a command-line interface, but they have similar functionality.
  - D. Despite their similar names, they're completely different tools—DOS's `FDISK` handles disk partitioning, whereas Linux's `fdisk` formats floppy disks.
13. What mount point should you associate with swap partitions?
- A. `/`
  - B. `/swap`
  - C. `/boot`
  - D. None
14. Which of the following options is used with `fsck` to force it to use a particular filesystem type?
- A. `-A`
  - B. `-N`
  - C. `-t`
  - D. `-C`
15. Which of the following pieces of information can `df` *not* report?
- A. How long the filesystem has been mounted
  - B. The number of inodes used on an `ext3fs` partition
  - C. The filesystem type of a partition
  - D. The percentage of available disk space used on a partition

16. What is an advantage of a journaling filesystem over a conventional (non-journaling) filesystem?
- A. Journaling filesystems are older and better tested than non-journaling filesystems.
  - B. Journaling filesystems never need to have their filesystems checked with `fsck`.
  - C. Journaling filesystems support Linux ownership and permissions; non-journaling filesystems don't.
  - D. Journaling filesystems require shorter disk checks after a power failure or system crash.
17. To access files on a USB pen drive, you type `mount /dev/sdc1 /media/pen` as root. Which types of filesystems will this command mount?
- A. Ext2fs
  - B. FAT
  - C. HFS
  - D. All of the above
18. Which of the following `/etc/fstab` entries will mount `/dev/sdb2` as the `/home` directory at boot time?
- A. `/dev/sdb2 reiserfs /home defaults 0 0`
  - B. `/dev/sdb2 /home reiserfs defaults 0 0`
  - C. `/home reiserfs /dev/sdb2 noauto 0 0`
  - D. `/home /dev/sdb2 reiserfs noauto 0 0`
19. What filesystem options might you specify in `/etc/fstab` to make a removable disk (USB pen drive, Zip disk, floppy disk, and so on) user-mountable? (Select all that apply.)
- A. `user`
  - B. `users`
  - C. `owner`
  - D. `owners`
20. What is the minimum safe procedure for removing a USB pen drive, mounted from `/dev/sdb1` at `/media/pen`, from a Linux computer?
- A. Type `umount /media/pen`, wait for the command to return and disk activity lights to stop, and then unplug the drive.
  - B. Unplug the drive, and then type `umount /media/pen` to ensure that Linux registers the drive's removal from the system.
  - C. Unplug the drive, and then type `sync /dev/sdb1` to flush the caches to ensure problems don't develop.
  - D. Type `pendrive-remove`, and then quickly remove the disk before its activity light stops blinking.

# Answers to Review Questions

1. B, C. IRQs 3 and 4 are common defaults for RS-232 serial ports. IRQ 1 is reserved for the keyboard. Although IRQ 16 exists on modern systems, it didn't exist on early x86 systems, and its purpose isn't standardized.
2. A. Modern BIOSs provide the means to disable many onboard devices, including sound hardware, in case you don't want to use them. Although the `alsactl` utility mentioned in option B is real, it's used to load or store sound card mixer settings, not to disable the sound hardware. The `lsmod` command mentioned in option C displays information about loaded kernel modules, but it doesn't remove them or disable the hardware they use. Contrary to option D, on-board sound hardware can usually be disabled.
3. B. The `udev` software creates and manages a dynamic `/dev` directory tree, adding entries to that directory for devices that exist on the target system. The `udev` software has nothing to do with software development (option A). It doesn't load drivers (option C), although it does respond to the loading of drivers by creating appropriate entries in `/dev`. It also doesn't store BIOS configuration options in a file (option D).
4. B. SATA disks are *usually* handled by Linux's SCSI subsystem and so are referred to as `/dev/sdx`; however, some drivers handle these disks as if they were PATA disks, and so refer to them as `/dev/hdx`. Thus, option B is correct. Option D (C:) is how Windows would likely refer to the first partition on the disk, but Linux doesn't use this style of disk identifier.
5. A, C, D. There is no `/proc/ioaddresses` file. All the other files listed contain useful information; `/proc/ioports` holds information about I/O ports, `/proc/dma` holds information about DMA port usage, and `/proc/interrupts` holds information about IRQs.
6. B. Logical partitions are numbered 5 and up, and they reside in an extended partition with a number between 1 and 4. Therefore, one of the first two partitions must be an extended partition that houses partitions 5 and 6. Because logical partitions are numbered starting at 5, their numbers won't change if `/dev/hda3` is subsequently added. The disk holds one primary, one extended, and two logical partitions.
7. A. The `/etc/fstab` file contains the mapping of partitions to mount points, so `/etc` must be an ordinary directory on the root partition, not on a separate partition. Options B and C describe restrictions that don't exist. Option D would be correct if `/etc` were not a separate partition.
8. D. The `/home` directory is frequently placed on its own partition in order to isolate it from the rest of the system and sometimes to enable use of a particular filesystem or filesystem mount options. The `/bin` and `/sbin` directories should *never* be split off from the root (`/`) filesystem because they contain critical executable files that must be accessible in order to do the most basic work, including mounting filesystems. The `/mnt` directory often contains subdirectories used for mounting floppy disks, CD-ROMs, and other removable media or may be used for this purpose itself. It's seldom used to directly access hard disk partitions, although it can be used for this purpose.

9. A. The 0x0f partition type code is one of two valid partition type codes for an extended partition. (The other is 0x05.) The 0x82 code refers to a Linux swap partition, whereas 0x83 denotes a Linux filesystem partition. Thus, it appears that this disk holds Linux partitions. Windows 9x/Me, Windows NT/200x/XP, and FreeBSD all use other partition type codes for their partitions. Partitions exist, in part, to enable different OSs to store their data side-by-side on the same disk, so mixing several partition types (even for different OSs) on one disk doesn't indicate disk corruption.
10. C. Linux's `fdisk` doesn't write changes to disk until you exit the program by typing `w`. Typing `q` exits without writing those changes, so typing `q` in this situation will avert disaster. Typing `w` would be precisely the wrong thing to do. Typing `u` would do nothing useful because it's not an undo command.
11. C. The `mkfs` command creates a new filesystem, overwriting any existing data and therefore making existing files inaccessible. This command doesn't set the partition type code in the partition table. The `-t ext2` option tells `mkfs` to create an ext2 filesystem; it's a perfectly valid option.
12. B. Although they have similar names and purposes, Linux's `fdisk` isn't modeled after DOS's `FDISK`. DOS's `FDISK` does *not* have GUI controls. Linux's `fdisk` does *not* format floppy disks.
13. D. Swap partitions aren't mounted in the way filesystems are, so they have no associated mount points.
14. C. The `-t` option is used to tell `fsck` what filesystem to use. Normally, `fsck` determines the filesystem type automatically. The `-A` option causes `fsck` to check all the filesystems marked to be checked in `/etc/fstab`. The `-N` option tells `fsck` to take no action and to display what it would normally do without doing it. The `-C` option displays a text-mode progress indicator of the check process.
15. A. A default use of `df` reports the percentage of disk space used. The number of inodes and filesystem types can both be obtained by passing parameters to `df`. This utility does *not* report how long a filesystem has been mounted.
16. D. The journal of a journaling filesystem records pending operations, resulting in quicker disk checks after an uncontrolled shutdown. Contrary to option A, journaling filesystems are, as a class, newer than non-journaling filesystems; in fact, the journaling `ext3fs` is built upon the non-journaling `ext2fs`. Although disk checks are quicker with journaling filesystems than with non-journaling filesystems, journaling filesystems do have `fsck` utilities, and these may still need to be run from time to time. All Linux native filesystems support Linux ownership and permissions; this isn't an advantage of journaling filesystems, contrary to option C.
17. D. When typed without a filesystem type specification, `mount` attempts to auto-detect the filesystem type. If the media contains any of the specified filesystems, it should be detected and the disk mounted.

18. B. The `/etc/fstab` file consists of lines that contain the device identifier, the mount point, the filesystem type code, filesystem mount options, the `dump` flag, and the filesystem check frequency, in that order. Option B provides this information in the correct order and so will work. Option A reverses the second and third fields but is otherwise correct. Options C and D both scramble the order of the first three fields and also specify the `noauto` mount option, which causes the filesystem to not mount automatically at boot time.
19. A, B, C. The `user`, `users`, and `owner` options in `/etc/fstab` all enable ordinary users to mount a filesystem, but with slightly different implications: `user` enables anybody to mount a filesystem, and only that user may unmount it; `users` enables anybody to mount a filesystem, and anybody may unmount it; and `owner` enables only the owner of the mount point to mount or unmount a filesystem. Any of these is likely to be accompanied by `noauto`, which prevents Linux from attempting to mount the filesystem at boot time. The `owners` parameter of option D doesn't exist.
20. A. Option A correctly describes the safe procedure for removing a removable medium that lacks a locking mechanism from a Linux computer. (Instead of typing `umount /media/pen`, you could type `umount /dev/sdb1`; in this context, the two commands are equivalent.) Option B reverses the order of operations; the `umount` command *must* be typed *before* you physically remove the pen drive. Option C also has it backward; the `sync` command would need to be issued *before* removing the drive. (The `sync` command can prevent damage when removing disks, but it isn't a complete substitute for `umount`.) There is no standard `pendrive-remove` command in Linux, and if you were to write a script that calls `umount` and call it `pendrive-remove`, pulling the pen drive quickly, as option D describes, would be exactly the wrong thing to do.

# Chapter 4

## Managing Files

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**THE FOLLOWING LINUX PROFESSIONAL INSTITUTE OBJECTIVES ARE COVERED IN THIS CHAPTER:**

- ✓ 1.103.3 Perform basic file management (weight: 4)
- ✓ 1.104.4 Manage disk quotas (weight: 1)
- ✓ 1.104.5 Manage file permissions and ownership (weight: 3)
- ✓ 1.104.6 Create and change hard and symbolic links (weight: 2)
- ✓ 1.104.7 Find system files and place files in the correct location (weight: 2)





Ultimately, Linux is a collection of files stored on your hard disk. Other disk files contain all your user data. For these reasons, being able to manage the files contained on your filesystems is an important skill for any Linux system administrator. Chapter 3, “Configuring Hardware,” described creating disk partitions, preparing filesystems on them, maintaining those filesystems, and mounting them. This chapter continues this topic by looking more closely at file management.

This chapter begins with an examination of the basic commands used to access and manipulate files. As a multi-user OS, Linux provides tools that enable you to restrict *who* may access your files, so I describe the Linux ownership model and the commands that are built on this model to control file access. Furthermore, Linux provides a system that enables you to restrict how much disk space individual users may consume, so I describe this feature. Finally, this chapter looks at locating files—both the formal description of where certain types of files should reside and the commands you can use to locate specific files.

## Managing Files

Basic file management is critical to the use of any computer. This is particularly true on Unix-like systems, including Linux, because these systems treat almost everything as a file, including most hardware devices and various specialized interfaces. Thus, being able to create, delete, move, rename, archive, and otherwise manipulate files is a basic skill of any Linux user or system administrator.

To begin, you should understand something of the rules that govern filenames and the shortcuts you can use to refer to files. With this information in hand, you can move on to learn how to manipulate files, how to manipulate directories, how to archive files, and how to manage links.

### File Naming and Wildcard Expansion Rules

Linux filenames are much like the filenames on any other OS. Every OS has its filename quirks, though, and these differences can be stumbling blocks to those who move between systems—or to those who want to move files between systems.

Linux filenames can contain uppercase or lowercase letters, numbers, and even most punctuation and control characters. To simplify your life and avoid confusion, though, I recommend restricting non-alphanumeric symbols to the dot (`.`), the dash (`-`), and the underscore



(`_`). Some programs create backup files that end in the tilde (`~`), as well. Although Linux filenames can contain spaces, and although such filenames are common in some OSs, they must be escaped on the Linux command line by preceding the space with a backslash (`\`) or by enclosing the entire filename in quotes (`"`). This requirement makes spaces a bit awkward in Linux, so most Linux users substitute dashes or occasionally underscores.

A few characters have special meaning and should never be used in filenames. These include the asterisk (`*`), the question mark (`?`), the forward slash (`/`), the backslash (`\`), and the quotation mark (`"`). Although you *can* create files that contain all of these characters except for the forward slash (which serves to separate directory elements) by escaping them, they're likely to cause greater confusion than other symbols.

Linux filename length depends on the filesystem in use. On `ext2fs`, `ext3fs`, `ReiserFS`, `XFS`, and many others, the limit is 255 characters. If you've ever used DOS, you're probably familiar with the *8.3 filename* limit: DOS filenames are restricted to eight characters followed by an optional three-character extension. These two components are separated by a dot. Although one- to four-character extensions are common in Linux, Linux filenames can contain an arbitrary number of dots. In fact, filenames can *begin* with a dot. These so-called *dot files* are hidden from view by most utilities that display files, so they're popular for storing configuration files in your home directory.



If you access a File Allocation Table (FAT) filesystem on a removable disk or partition used by DOS, you can do so using any of three filesystem type codes: `msdos`, which limits you to 8.3 filenames; `vfat`, which supports Windows-style long filenames; or `umsdos`, which is a Linux-only extension that supports Linux-style long filenames.

Two filenames are particularly special. A filename that consists of a single dot (`.`) refers to the current directory, whereas a filename that consists of a double dot (`..`) refers to the parent directory. For instance, if your current directory is `/home/jerry`, then `.` refers to that directory and `..` refers to `/home`.

One critical difference between Linux filenames and those of many other OSs is that Linux treats its filenames in a case-sensitive way; in other words, `Filename.txt` is different from `filename.txt` or `FILENAME.TXT`. All three files can exist in a single directory. Under Windows, all three filenames refer to the same file. Although Windows 95 and later all retain the case of the filename, they ignore it when you refer to an existing file, and they don't permit files whose names differ only in case to co-exist in a single directory. This difference isn't a major problem for most people who migrate from Windows to Linux, but you should be aware of it. It can also cause problems when you try to read a FAT disk using the Linux `vfat` driver because Linux has to follow the Windows rules when managing files on that disk.

You can use *wildcards* with many commands. A wildcard is a symbol or set of symbols that stands in for other characters. Three classes of wildcards are common in Linux:

**?** A question mark (`?`) stands in for a single character. For instance, `b??k` matches `book`, `baik`, `buck`, or any other four-character filename that begins with `b` and ends with `k`.

\* An asterisk (\*) matches any character or set of characters, including no character. For instance, `b*k` matches `book`, `ba1k`, and `buck` just as does `b??k`. `b*k` also matches `bk`, `bbk`, and `backtrack`.

**Bracketed values** Characters enclosed in square brackets ([]) normally match any character in the set. For instance, `b[ao][1o]k` matches `ba1k` and `book` but not `buck`. It's also possible to specify a range of values; for instance, `b[a-z]ck` matches `back`, `buck`, and other four-letter filenames of this form whose second character is a lowercase letter. This differs from `b?ck`—because Linux treats filenames in a case-sensitive way and because `?` matches any character (not just any letter), `b[a-z]ck` doesn't match `bAck` or `b3ck`, although `b?ck` matches both of these filenames.

Wildcards are implemented in the shell and passed to the command you call. For instance, if you type `ls b??k`, and that wildcard matches the three files `ba1k`, `book`, and `buck`, the result is precisely as if you'd typed `ls ba1k book buck`. The process of wildcard expansion is known as *file globbing* or simply *globbing*.



The way wildcards are expanded can lead to undesirable consequences. For instance, suppose you want to copy two files, specified via a wildcard, to another directory, but you forget to give the destination directory. The `cp` command (described shortly) will interpret the command as a request to copy the first of the files over the second.

## File Commands

A few file-manipulation commands are extremely important to everyday file operations. These commands enable you to list, copy, move, rename, and delete files.

### The `ls` Command

To manipulate files, it's helpful to know what they are. This is the job of the `ls` command, whose name is short for *list*. The `ls` command displays the names of files in a directory. Its syntax is simple:

```
ls [options] [files]
```

The command supports a huge number of options; consult `ls`'s man page for details. The most useful options include the following:

**Display all files** Normally, `ls` omits files whose names begin with a dot (.). These dot files are often configuration files that aren't usually of interest. Adding the `-a` or `--all` parameter displays dot files.

**Color listing** The `--color` option produces a color-coded listing that differentiates directories, symbolic links, and so on by displaying them in different colors. This works at the Linux console, in `xterm` windows in X, and from some types of remote logins, but some

remote login programs don't support color displays. Some Linux distributions configure their shells to use this option by default.

**Display directory names** Normally, if you type a directory name as one of the *files*, `ls` displays the contents of that directory. The same thing happens if a directory name matches a wildcard. Adding the `-d` or `--directory` parameter changes this behavior to list only the directory name, which is sometimes preferable.

**Long listing** The `ls` command normally displays filenames only. The `-l` parameter (a lower-case *L*) produces a long listing that includes information such as the file's permission string (described later, in "Understanding Permissions"), owner, group, size, and creation date.

**Display file type** The `-F` or `--file-type` option appends an indicator code to the end of each name so you know what type of file it is. The meanings are as follows:

```

/ Directory
@ Symbolic link
= Socket
| Pipe

```

**Recursive listing** The `-R` or `--recursive` option causes `ls` to display directory contents recursively. That is, if the target directory contains a subdirectory, `ls` displays both the files in the target directory *and* the files in its subdirectory. The result can be a huge listing if a directory has many subdirectories.

Both the *options* list and the *files* list are optional. If you omit the *files* list, `ls` displays the contents of the current directory. You may instead give one or more file or directory names, in which case `ls` displays information about those files or directories, as in this example:

```

$ ls -F /usr /bin/ls
/bin/ls

/usr:
X11R6/ games/ include/ man/ src/
bin/ i386-glibc20-linux/ lib/ merge@ tmp@
doc/ i486-linux-libc5/ libexec/ sbin/
etc/ i586-mandrake-linux/ local/ share/

```

This output shows both the `/bin/ls` program file and the contents of the `/usr` directory. The latter consists mainly of subdirectories, but it includes a couple of symbolic links as well. By default, `ls` creates a listing that's sorted by filename, as shown in this example. Note, though, that uppercase letters (as in `X11R6`) always appear before lowercase letters (as in `bin`).

One of the most common `ls` options is `-l`, which creates a listing like this:

```
$ ls -l t*
```

```
-rwxr-xr-x 1 rodsmith users 111 Apr 13 13:48 test
-rw-r--r-- 1 rodsmith users 176322 Dec 16 09:34 thttpd-2.20b-1.i686.rpm
-rw-r--r-- 1 rodsmith users 1838045 Apr 24 18:52 tomsrtbt-1.7.269.tar.gz
-rw-r--r-- 1 rodsmith users 3265021 Apr 22 23:46 tripwire.rpm
```

This output includes the permission strings, ownership, file sizes, and file creation dates in addition to the filenames. This example also illustrates the use of the `*` wildcard, which matches any string—thus, `t*` matches any filename that begins with `t`.



You can combine multiple options by merging them with a single preceding dash, as in `ls -lp` to get a long listing that also includes file type codes. This can save a bit of typing compared to the alternative of `ls -l -F`.

## The `cp` Command

The `cp` command copies a file. Its basic syntax is as follows:

```
cp [options] source destination
```

The *source* is normally one or more files, and the *destination* may be a file (when the source is a single file) or a directory (when the source is one or more files). When copying to a directory, `cp` preserves the original filename; otherwise, it gives the new file the filename indicated by *destination*. The command supports a large number of options; consult its man page for more information. Some of the more useful options enable you to modify the command's operation in helpful ways:

**Force overwrite** The `-f` or `--force` option forces the system to overwrite any existing files without prompting.

**Use interactive mode** The `-i` or `--interactive` option causes `cp` to ask you before overwriting any existing files.

**Preserve ownership and permissions** Normally, a copied file is owned by the user who issues the `cp` command and uses that account's default permissions. The `-p` or `--preserve` option preserves ownership and permissions, if possible.

**Perform a recursive copy** If you use the `-R` or `--recursive` option and specify a directory as the *source*, the entire directory, including its subdirectories, is copied. Although `-r` also performs a recursive copy, its behavior with files other than ordinary files and directories is unspecified. Most `cp` implementations use `-r` as a synonym for `-R`, but this behavior isn't guaranteed.

**Perform an archive copy** The `-a` or `--archive` option is similar to `-R`, but it also preserves ownership and copies links as is. The `-R` option copies the files to which symbolic links

point rather than the symbolic links themselves. (Links are described in more detail later in this chapter, in “Managing Links.”)

**Perform an update copy** The `-u` or `--update` option tells `cp` to copy the file only if the original is newer than the target or if the target doesn’t exist.



This list of `cp` options is incomplete but covers the most useful options. Consult `cp`’s man page for information about additional `cp` options.

As an example, the following command copies the `/etc/fstab` configuration file to a backup location in `/root`, but only if the original `/etc/fstab` is newer than the existing backup:

```
cp -u /etc/fstab /root/fstab-backup
```

## The `mv` Command

The `mv` command (short for *move*) is commonly used both to move files and directories from one location to another and to rename them. Linux doesn’t distinguish between these two types of operations, although many users do. The syntax of `mv` is similar to that of `cp`:

```
mv [options] source destination
```

The command takes many of the same *options* as `cp` does. From the earlier list, `--preserve`, `--recursive`, and `--archive` don’t apply to `mv`, but the others do.

To move one or more files or directories, specify the files as the *source* and specify a directory or (optionally, for a single-file move) a filename for the *destination*:

```
$ mv document.odt important/purchases/
```

This command copies the `document.odt` file into the `important/purchases` subdirectory. If the move occurs on one low-level filesystem, Linux does the job by rewriting directory entries; the file’s data need not be read and rewritten. This makes `mv` fast. When the target directory is on another partition or disk, though, Linux must read the original file, rewrite it to the new location, and delete the original. This slows down `mv`. Also, `mv` can move entire directories within a filesystem but not between filesystems.



The preceding example used a trailing slash (`/`) on the destination directory. This practice can help avoid problems caused by typos. For instance, if the destination directory were mistyped as `important/purchase` (missing the final `s`), `mv` would move `document.odt` into the `important` directory under the filename `purchase`. Adding the trailing slash makes it explicit that you intend to move the file into a subdirectory. If it doesn’t exist, `mv` complains, so you’re not left with mysterious misnamed files. You can also use the Tab key to avoid problems. When you press Tab in many Linux shells, such as `bash`, the shell tries to complete the filename automatically, reducing the risk of a typo.

Renaming a file with `mv` works much like moving a file, except that the source and destination filenames are in the same directory, as shown here:

```
$ mv document.odt washer-order.odt
```

This renames `document.odt` to `washer-order.odt` in the same directory. You can combine these two forms as well:

```
$ mv document.odt important/purchases/washer-order.odt
```

This command simultaneously moves and renames the file.

## The `rm` Command

To delete a file, use the `rm` command, whose name is short for *remove*. Its syntax is simple:

```
rm [options] files
```

The `rm` command accepts many of the same *options* as `cp` or `mv`. Of those described with `cp`, `--preserve`, `--archive`, and `--update` don't apply to `rm`, but all the others do. With `rm`, `-r` is synonymous with `-R`.



By default, Linux doesn't provide any sort of "trash-can" functionality for its `rm` command; once you've deleted a file with `rm`, it's gone and cannot be recovered without retrieving it from a backup or performing low-level disk maintenance (such as with `debugfs`). Therefore, you should be cautious when using `rm`, particularly when you're logged on as root. This is especially true when you're using the `-R` option—`rm -R /` will destroy an entire Linux installation! Many Linux GUI file managers do implement trash-can functionality so that you can easily recover files moved to the trash (assuming you haven't emptied the trash), so you may want to use a file manager for removing files.

## The `touch` Command

Linux-native filesystems maintain three time stamps for every file:

- Creation time
- Last modification time
- Last access time

Various programs rely on these time stamps; for instance, the `make` utility (which helps compile a program from source code) uses the time stamps to determine which source-code files must be recompiled if an object file already exists for a particular file. Thus, sometimes you may need to modify the time stamps. This is the job of the `touch` command, which has the following syntax:

```
touch [options] files
```

By default, `touch` sets the modification and access times to the current time. You might use this if, for instance, you wanted make to recompile a particular source code file even though a newer object file existed. If the specified *files* don't already exist, `touch` creates them as empty files. This can be handy if you want to create dummy files—say, to experiment with other file-manipulation commands.

You can pass various *options* to `touch` to have it change its behavior:

**Change only the access time** The `-a` or `--time=atime` option causes `touch` to change the access time alone, not the modification time.

**Change only the modification time** The `-m` or `--time=mtime` option causes `touch` to change the modification time alone, not the access time.

**Do not create file** If you don't want `touch` to create any files that don't already exist, pass it the `-c` or `--no-create` option.

**Set the time as specified** The `-t timestamp` option sets the time to the specified *timestamp*. This value is given in the form *MMDDhhmm*[[*CC*]*YY*][*.ss*], where *MM* is the month, *DD* is the day, *hh* is the hour (on a 24-hour clock), *mm* is the minute, [*CC*]*YY* is the year (such as 2009 or 09, which are equivalent), and *ss* is the second. Another way to set a particular time is with the `-r reffile` or `--reference=reffile` option, where *reffile* is a file whose time stamp you want to replicate.

## File Archiving Commands

A file archiving tool collects a group of files into a single “package” file that you can easily move around on a single system; back up to a recordable DVD, tape, or other removable media; or transfer across a network. Linux supports several archiving commands, the most prominent being `tar` and `cpio`. The `dd` command, although not technically an archiving command, is similar in some ways, because it can copy an entire partition or disk into a file, or vice versa.



The zip format, which is common on Windows, is supported by the Linux `zip` and `unzip` commands. Other archive formats, such as the Roshal Archive (RAR) and Stuffit, can also be manipulated using Linux utilities. These archive formats may be important in some environments, but they aren't covered on the LPI exam.

### The `tar` Utility

The `tar` program's name stands for “tape archiver.” Despite this fact, you can use `tar` to archive data to other media. In fact, *tarballs* (archive files created by `tar` and typically compressed with `gzip` or `bzip2`) are often used for transferring multiple files between computers in one step, such as when distributing source code.

The tar program is a complex package with many options, but most of what you'll do with the utility can be covered with a few common commands. Table 4.1 lists the primary tar commands, and Table 4.2 lists the qualifiers that modify what the commands do. Whenever you run tar, you use exactly one command, and you usually use at least one qualifier.

**TABLE 4.1** tar Commands

| Command             | Abbreviation | Description                                           |
|---------------------|--------------|-------------------------------------------------------|
| --create            | c            | Creates an archive                                    |
| --concatenate       | A            | Appends tar files to an archive                       |
| --append            | r            | Appends non-tar files to an archive                   |
| --update            | u            | Appends files that are newer than those in an archive |
| --diff or --compare | d            | Compares an archive to files on disk                  |
| --list              | t            | Lists an archive's contents                           |
| --extract or --get  | x            | Extracts files from an archive                        |

**TABLE 4.2** tar Qualifiers

| Qualifier                           | Abbreviation                | Description                                                                                         |
|-------------------------------------|-----------------------------|-----------------------------------------------------------------------------------------------------|
| --directory <i>dir</i>              | C                           | Changes to directory <i>dir</i> before performing operations                                        |
| --file [ <i>host:</i> ] <i>file</i> | f                           | Uses the file called <i>file</i> on the computer called <i>host</i> as the archive file             |
| --listed-incremental <i>file</i>    | g                           | Performs an incremental backup or restore, using <i>file</i> as a list of previously archived files |
| --one-file-system                   | 1 (on some versions of tar) | Backs up or restores only one filesystem (partition)                                                |
| --multi-volume                      | M                           | Creates or extracts a multi-tape archive                                                            |
| --tape-length <i>N</i>              | L                           | Changes tapes after <i>N</i> kilobytes                                                              |



**TABLE 4.2** tar Qualifiers (*continued*)

| Qualifier                  | Abbreviation                        | Description                                                                                               |
|----------------------------|-------------------------------------|-----------------------------------------------------------------------------------------------------------|
| --same-permissions         | p                                   | Preserves all protection information                                                                      |
| --absolute-paths           | P                                   | Retains the leading / on filenames                                                                        |
| --verbose                  | v                                   | Lists all files read or extracted; when used with --list, displays file sizes, ownership, and time stamps |
| --verify                   | W                                   | Verifies the archive after writing it                                                                     |
| --exclude <i>file</i>      | (none)                              | Excludes <i>file</i> from the archive                                                                     |
| --exclude-from <i>file</i> | X                                   | Excludes files listed in <i>file</i> from the archive                                                     |
| --gzip or --ungzip         | z                                   | Processes an archive through gzip                                                                         |
| --bzip2                    | j (some older versions used I or y) | Processes an archive through bzip2                                                                        |

Of the commands listed in Table 4.1, the most commonly used are --create, --extract, and --list. The most useful qualifiers from Table 4.2 are --file, --listed-incremental, --one-file-system, --same-permissions, --gzip, --bzip2, and --verbose. If you fail to specify a filename with the --file qualifier, tar will attempt to use a default device, which is often (but not always) a tape device file.

As an example, consider archiving and compressing the my-work subdirectory of your home directory to a USB pen drive mounted at /media/pen. The following command will do the trick:

```
$ tar cvfz /media/pen/my-work.tgz ~/my-work
```

If you then transfer this pen drive to another system, mount it at /media/usb, and want to extract the archive, you can do so with another command:

```
$ tar xvfz /media/usb/my-work.tgz
```

This command creates a subdirectory called my-work in the current working directory and populates it with the files from the archive. If you don't know what's in an archive, it's a good practice to examine it with the --list command before extracting its contents. Although common practice has tarballs with a single subdirectory, sometimes tarballs drop many files in the current working directory, which can make them difficult to track down if you run the command in a directory that already has many files.

## The *cpio* Utility

The *cpio* program is similar in principle to *tar*, but the details of its operation differ. As with *tar*, you can direct its output straight to a tape device or to a regular file. Backing up to a tape device can be a convenient way to back up the computer because it requires no intermediate storage. To restore data, you use *cpio* to read directly from the tape device file or from a regular file.

The *cpio* utility has three operating modes:

**Copy-out mode** This mode, activated by use of the `-o` or `--create` option, creates an archive and copies files into it.

**Copy-in mode** You activate copy-in mode by using the `-i` or `--extract` option. This mode extracts data from an existing archive. If you provide a filename or a pattern to match, *cpio* extracts only the files whose names match the pattern you provide.

**Copy-pass mode** This mode is activated by the `-p` or `--pass-through` option. It combines the copy-out and copy-in modes, enabling you to copy a directory tree from one location to another.



The copy-out and copy-in modes are named confusingly.

In addition to the options used to select the mode, *cpio* accepts many other options, the most important of which are summarized in Table 4.3. To create an archive, you combine the `--create` (or `-o`) option with one or more of the options in Table 4.3; to restore data, you do the same, but you use `--extract` (or `-i`). In either case, *cpio* acts on filenames that you type at the console. In practice, you'll probably use the redirection operator (`<`) to pass a filename list to the program.

**TABLE 4.3** Options for Use with *cpio*

| Option                               | Abbreviation             | Description                                                                                                                    |
|--------------------------------------|--------------------------|--------------------------------------------------------------------------------------------------------------------------------|
| <code>--reset-access-time</code>     | <code>-a</code>          | Resets the access time after reading a file so that it doesn't appear to have been read.                                       |
| <code>--append</code>                | <code>-A</code>          | Appends data to an existing archive.                                                                                           |
| <code>--pattern-file=filename</code> | <code>-E filename</code> | Uses the contents of <i>filename</i> as a list of files to be extracted in copy-in mode.                                       |
| <code>--file=filename</code>         | <code>-F filename</code> | Uses <i>filename</i> as the <i>cpio</i> archive file; if this parameter is omitted, <i>cpio</i> uses standard input or output. |

**TABLE 4.3** Options for Use with `cpio` (continued)

| Option                               | Abbreviation             | Description                                                                                                                                                                                                                                                        |
|--------------------------------------|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>--format=format</code>         | <code>-H format</code>   | Uses a specified format for the archive file. Common values for <i>format</i> include <code>bin</code> (the default, an old binary format), <code>crc</code> (a newer binary format with a checksum), and <code>tar</code> (the format used by <code>tar</code> ). |
| N/A                                  | <code>-I filename</code> | Uses the specified <i>filename</i> instead of standard input. (Unlike <code>-F</code> , this option does not redirect output data.)                                                                                                                                |
| <code>--no-absolute-filenames</code> | N/A                      | In copy-in mode, extracts files relative to the current directory, even if filenames in the archive contain full directory paths.                                                                                                                                  |
| N/A                                  | <code>-O filename</code> | Uses the specified <i>filename</i> instead of standard output. (Unlike <code>-F</code> , this option does not redirect input data.)                                                                                                                                |
| <code>--list</code>                  | <code>-t</code>          | Displays a table of contents for the input.                                                                                                                                                                                                                        |
| <code>--unconditional</code>         | <code>-u</code>          | Replaces all files without first asking for verification.                                                                                                                                                                                                          |
| <code>--verbose</code>               | <code>-v</code>          | Displays filenames as they're added to or extracted from the archive. When used with <code>-t</code> , displays additional listing information (similar to <code>ls -l</code> ).                                                                                   |

To use `cpio` to archive a directory, you must pass a list of files to the utility using standard input. You can do this with the `find` utility (described in more detail later, in “The *find* Command”):

```
$ find ./my-work | cpio -o > /media/pen/my-work.cpio
```

The resulting archive file is uncompressed, though. To compress the data, you must include the `gzip` utility in the pipe:

```
$ find ./my-work | cpio -o | gzip > /media/pen/my-work.cpio.gz
```

Extracting data from an uncompressed `cpio` archive (say, on another computer with the media mounted at `/media/usb`) entails using the `-i` option, but no pipe is required:

```
$ cpio -i < /media/usb/my-work.cpio
```

If your `cpio` archive is compressed, you must first uncompress it with `gunzip`. By using the `-c` option to this command, you can pass its output to `cpio` in a pipe:

```
$ gunzip -c /media/usb/my-work.cpio.gz | cpio -i
```

## The `dd` Utility

Sometimes you want to archive a filesystem at a very low level. For instance, you may want to create a representation of a CD-ROM that you can store on your hard disk or back up a filesystem that Linux can't understand. To do so, you can use the `dd` program. This utility is a low-level copying program, and when it's given the device file for a partition as input, it copies that partition's contents to the output file you specify. This output file can be another partition identifier, a tape device, or a regular file, to name three possibilities. The input and output files are passed with the `if=file` and `of=file` options:

```
dd if=/dev/sda3 of=/dev/st0
```

This command backs up the `/dev/sda3` disk partition to `/dev/st0` (a SCSI tape drive). The result is a very low-level backup of the partition that can be restored by swapping the `if=` and `of=` options:

```
dd if=/dev/st0 of=/dev/sda3
```

The `dd` utility can be a good way to create exact backups of entire partitions, but as a general backup tool, it has serious problems. It backs up the *entire* partition, including any empty space. For instance, a 2GB partition that holds just 5MB of files will require 2GB of storage space. Restoring individual files is also impossible unless the target device is a random access device that can be mounted; if you back up to tape, you must restore everything (at least to a temporary file or partition) to recover a single file. Finally, you can't easily restore data to a partition that's smaller than the original partition; and when restoring to a larger partition, you'll end up wasting some of the space available on that partition.

Despite these problems, `dd` can be handy in some situations. It can be a good way to make an exact copy of a CD-ROM, for instance. You can use `dd` to copy a disk for which Linux lacks filesystem drivers. If you need to create multiple identical Linux installations, you can do so by using `dd` to copy a working installation to multiple computers, as long as they have hard disks the same size.

You can also use `dd` in some other capacities. For instance, if you need an empty file of a particular size, you can copy from the `/dev/zero` device (a Linux device that returns nothing but zeroes) to a target file. You'll need to use the `bs=size` and `count=length` options to set the block size and length of the file, though:

```
$ dd if=/dev/zero of=empty-file.img bs=1024 count=720
```

This example creates a 720KB (1024 × 720 bytes) empty file. You might then manipulate this file by, for example, creating a filesystem on it with `mkfs`.



## Real World Scenario

### Backing Up Using Optical Media

Optical media require special backup procedures. Normally, `cdrecord` accepts input from a program like `mkisofs`, which creates an ISO-9660 or UDF filesystem—the type of filesystem that’s most often found on CD-ROMs and DVDs.

One option for backing up to optical discs is to use `mkisofs` and then `cdrecord` to copy files to the disc. If you copy files “raw” this way, though, you’ll lose some information, such as write permission bits. You’ll have better luck if you create a tar or `cpio` archive on disk. You can then use `mkisofs` to place that archive in an ISO-9660 or UDF filesystem, and then burn the image file to the optical disc. The result will be a disc that you can mount and that will contain an archive you can read with tar or `cpio`.

A somewhat more direct option is to create an archive file and burn it directly to the optical disc using `cdrecord`, bypassing `mkisofs`. Such a disc won’t be mountable in the usual way, but you can access the archive directly by using the CD-ROM device file. On restoration, this works much like a tape restore except that you specify the optical device filename (such as `/dev/cdrom`) instead of the tape device filename (such as `/dev/st0`).

## Managing Links

In Linux, a *link* is a way to give a file multiple identities, similar to shortcuts in Windows and aliases in Mac OS. Linux employs links to help make files more accessible, to give commands multiple names, to enable programs that look for the same files in different locations to access the same files, and so on. Two types of links exist: *hard links* and *soft links* (a.k.a. *symbolic links*). (Their differences are described in more detail shortly.) The `ln` command creates links. Its syntax is similar to that of `cp`:

```
ln [options] source link
```

The *source* is the original file, and the *link* is the name of the link you want to create. This command supports options that have several effects:

**Remove target files** The `-f` or `--force` option causes `ln` to remove any existing links or files that have the target *link* name. The `-i` or `--interactive` option has a similar effect, but it queries you before replacing existing files and links.

**Create directory hard links** Ordinarily, you can’t create hard links to directories. The root user can *attempt* to do so, though, by passing the `-d`, `-F`, or `--directory` option to `ln`. (Symbolic links to directories aren’t a problem.) In practice, this feature is unlikely to work because most filesystems don’t support it.

**Create a symbolic link** The `ln` command creates hard links by default. To create a symbolic link, pass the `-s` or `--symbolic` option to the command.

A few other options exist to perform more obscure tasks; consult `ln`'s man page for details.

By default, `ln` creates hard links, which are produced by creating two directory entries that point to the same file (more precisely, the same inode). Both filenames are equally valid and prominent; neither is a “truer” filename than the other, except that one was created first (when creating the file) and the other was created second. To delete the file, you must delete both hard links to the file. Because of the way hard links are created, they must exist on a single low-level filesystem; you can't create a hard link from, say, your root (`/`) filesystem to a separate filesystem you've mounted on it, such as `/home` (if it's a separate filesystem). The underlying filesystem must support hard links. All Linux native filesystems support this feature, but some non-Linux filesystems don't.

Symbolic links, by contrast, are special file types. The symbolic link is a separate file whose contents point to the linked-to file. Linux knows to access the linked-to file whenever you try to access the symbolic link, so in most respects accessing a symbolic link works just like accessing the original file. Because symbolic links are basically files that contain filenames, they can point across low-level filesystems—you can point from the root (`/`) filesystem to a file on a separate `/home` filesystem, for instance. The lookup process for accessing the original file from the link consumes a tiny bit of time, so symbolic link access is slower than hard link access—but not by enough that you'd notice in any but very bizarre conditions or artificial tests. Long directory listings show the linked-to file:

```
$ ls -l alink.odt
```

```
lrwxrwxrwx 1 rodsmith users 8 Dec 2 15:31 alink.odt -> test.odt
```

In practice, symbolic links are more common than hard links; their disadvantages are minor, and the ability to link across filesystems and to directories can be important. Linux employs links in certain critical system administration tasks. For instance, System V (SysV) startup scripts use symbolic links in runlevel directories, as described in Chapter 5, “Booting Linux and Editing Files.” Certain commands that have historically been known by multiple names are also often accessible via links. For example, the `/sbin/fsck.ext2`, `/sbin/fsck.ext3`, and `/sbin/e2fsck` programs are usually links (hard links on some systems, symbolic links on others). You can often leave these links alone, but sometimes you must adjust them. Chapter 5 describes changing the SysV startup script links to affect what programs run when the system boots, for instance.

## Directory Commands

Most of the commands that apply to files also apply to directories. In particular, `ls`, `mv`, `touch`, and `ln` all work with directories, with the caveats mentioned earlier. The `cp` command also works with directories, but only when you use a recursion option, such as `-r`. A couple of additional commands, `mkdir` and `rmdir`, enable you to create and delete directories, respectively.

## The *mkdir* Command

The *mkdir* command creates a directory. This command’s official syntax is as follows:

```
mkdir [options] directory-name(s)
```

In most cases, *mkdir* is used without *options*, but a few are supported:

**Set mode** The *-m mode* or *--mode=mode* option causes the new directory to have the specified permission mode, expressed as an octal number. (The upcoming section “Understanding Permissions” describes permission modes.)

**Create parent directories** Normally, if you specify the creation of a directory within a directory that doesn’t exist, *mkdir* responds with a `No such file or directory` error and doesn’t create the directory. If you include the *-p* or *--parents* option, though, *mkdir* creates the necessary parent directory.

## The *rmdir* Command

The *rmdir* command is the opposite of *mkdir*; it destroys a directory. Its syntax is similar:

```
rmdir [options] directory-name(s)
```

Like *mkdir*, *rmdir* supports few options, the most important of which handle these tasks:

**Ignore failures on non-empty directories** Normally, if a directory contains files or other directories, *rmdir* doesn’t delete it and returns an error message. With the *--ignore-fail-on-non-empty* option, *rmdir* still doesn’t delete the directory, but it doesn’t return an error message.

**Delete tree** The *-p* or *--parents* option causes *rmdir* to delete an entire directory tree. For instance, typing ***rmdir -p one/two/three*** causes *rmdir* to delete *one/two/three*, then *one/two*, and finally *one*, provided no other files or directories are present.




---

When you’re deleting an entire directory tree filled with files, *rm -R* is a better choice than *rmdir* because *rm -R* deletes files within the specified directory but *rmdir* doesn’t.

# Managing File Ownership

Security is an important topic that cuts across many types of commands and Linux subsystems. In the case of files, security is built on file ownership and file permissions. These two topics are closely intertwined; ownership is meaningless without permissions that use it, and permissions rely on the existence of ownership.

Ownership is two tiered: Each file has an individual owner and a group with which it’s associated (sometimes called the group owner, or simply the file’s group). Each group

can contain an arbitrary number of users, as described in Chapter 7, “Administering the System.” The two types of ownership enable you to provide three tiers of permissions to control access to files: by the file’s owner, by the file’s group, and to all other users. The commands to manage these two types of ownership are similar, but they aren’t identical.

## Assessing File Ownership

You can learn who owns a file with the `ls` command, which was described earlier. In particular, that command’s `-l` option produces a long listing, which includes both ownership and permission information:

```
$ ls -l
total 1141
-rw-r--r-- 1 rodsmith users 219648 Mar 8 13:06 4425ch02.doc
-rw-r--r-- 1 rodsmith users 942590 Mar 6 23:31 f0201.tif
```

This long listing includes the username of the owner (`rodsmith` for both files in this example) and the group name of the files’ groups (`users` for both files in this example). The permission string (`-rw-r--r--` for both files in this example) is also important for file security, as described later in “Controlling Access to Files.”

In most cases, the usernames associated with files are the same as login usernames. Files can, however, be owned by accounts that aren’t ordinary login accounts. For instance, some servers have accounts of their own, and server-specific files may be owned by these accounts.

If you delete an account, as described in Chapter 7, the account’s files don’t vanish, but the account name does. Internally, Linux uses numbers rather than names, so you’ll see numbers in place of the username and group name in the `ls` output. Depending on the file, you may want to archive it, reassign ownership to an existing user, or delete it.

## Changing a File’s Owner

Whenever a file is created, it’s assigned an owner. The superuser can change a file’s ownership using the `chown` command, whose syntax is as follows:

```
chown [options] [newowner][:newgroup] filenames
```

As you might expect, the `newowner` and `newgroup` variables are the new owner and group for the file; you can provide both or omit either, but you can’t omit both. For instance, suppose you want to give ownership of a file to `sally` and the `skyhook` group:

```
chown sally:skyhook forward.odt
```



Linux’s `chown` command accepts a dot (`.`) in place of a colon (`:`) to delimit the owner and group, at least as of the core file utilities version 6.10. The use of a dot has been deprecated, though, meaning that the developers favor the alternative and may eventually eliminate the use of a dot as a feature.



You can use several options with `chown`, most of which are fairly obscure. One that's most likely to be useful is `-R` or `--recursive`, which implements the ownership change on an entire directory tree. Consult the man page for `chown` for information about additional options.

The `chown` command may only be used by `root`. If an ordinary user tries to use it, the result is an `Operation not permitted` error message.

## Changing a File's Group

Both `root` and ordinary users may run the `chgrp` command, which changes a file's group. (Ordinary users may only change a file's group to a group to which the user belongs.) This command's syntax is similar to, but simpler than, that of `chown`:

```
chgrp [options] newgroup filenames
```

The `chgrp` command accepts many of the same options as `chown`, including `-R` or `--recursive`. In practice, `chgrp` provides a subset of the `chown` functionality, with the important exception that ordinary users can use `chgrp`.

# Controlling Access to Files

The bulk of the complexity in file ownership and permissions is on the permissions end of things. Linux's system of permissions is moderately complex, so understanding how it works is critical to any manipulation of permissions. With the basic information in hand, you can tackle the commands used to change file permissions.

## Understanding Permissions

Linux permissions are fairly complex. In addition to providing access control for files, a few special permission bits exist, which provide some unusual features.

### The Meanings of Permission Bits

Consider the following file access control string that's displayed with the `-l` option to `ls`:

```
$ ls -l test
-rwxr-xr-x 1 rodsmith users 111 Apr 13 13:48 test
```

This string (`-rwxr-xr-x` in this example) is 10 characters long. The first character has special meaning—it's the *file type code*. The type code determines how Linux will interpret the file—as ordinary data, a directory, or a special file type. Table 4.4 summarizes Linux type codes.

**TABLE 4.4** Linux File Type Codes

| Code | Meaning                                                                                                                                                                                                             |
|------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| -    | Normal data file; may be text, an executable program, graphics, compressed data, or just about any other type of data.                                                                                              |
| d    | Directory; disk directories are files just like any others, but they contain file-names and pointers to disk inodes.                                                                                                |
| l    | Symbolic link; the file contains the name of another file or directory. When Linux accesses the symbolic link, it tries to read the linked-to file.                                                                 |
| p    | Named pipe; a pipe enables two running Linux programs to communicate with each other. One opens the pipe for reading, and the other opens it for writing, enabling data to be transferred between the programs.     |
| s    | Socket; a socket is similar to a named pipe, but it permits network and bidirectional links.                                                                                                                        |
| b    | Block device; a file that corresponds to a hardware device to and from which data is transferred in blocks of more than one byte. Disk devices (hard disks, floppies, CD-ROMs, and so on) are common block devices. |
| c    | Character device; a file that corresponds to a hardware device to and from which data is transferred in units of one byte. Examples include parallel and RS-232 serial port devices.                                |

The remaining nine characters of the permission string (`rw-r-xr-x` in the example) are broken up into three groups of three characters. The first group controls the file owner's access to the file, the second controls the group's access to the file, and the third controls all other users' access to the file (often referred to as *world permissions*).

In each of these three cases, the permission string determines the presence or absence of each of three types of access: read, write, and execute. Read and write permissions are fairly self-explanatory, at least for ordinary files. If the execute permission is present, it means that the file may be run as a program. (Of course, this doesn't turn a non-program file into a program; it only means that a user may run a file if it's a program. Setting the execute bit on a non-program file will probably cause no real harm, but it could be confusing.) The absence of the permission is denoted by a dash (-) in the permission string. The presence of the permission is indicated by a letter—`r` for read, `w` for write, or `x` for execute.

Thus, the example permission string `rw-r-xr-x` means that the file's owner, members of the file's group, and all other users can read and execute the file. Only the file's owner has write permission to the file. You can easily exclude those who don't belong to the file's group, or even all but the file's owner, by changing the permission string, as described in "Changing a File's Mode" later in this chapter.

Individual permissions, such as execute access for the file's owner, are often referred to as *permission bits*. This is because Linux encodes this information in binary form. Because it's binary, the permission information can be expressed as a single 9-bit number. This number is usually expressed in octal (base 8) form because a base-8 number is 3 bits in length, which means that the base-8 representation of a permission string is three digits long, one digit for each of the owner, group, and world permissions. The read, write, and execute permissions each correspond to one of these bits. The result is that you can determine owner, group, or world permissions by adding base-8 numbers: 1 for execute permission, 2 for write permission, and 4 for read permission.

Table 4.5 shows some examples of common permissions and their meanings. This table is necessarily incomplete; with 9 permission bits, the total number of possible permissions is  $2^9$ , or 512. Most of those possibilities are peculiar, and you're not likely to encounter or create them except by accident.

**TABLE 4.5** Example Permissions and Their Likely Uses

| Permission String | Octal Code | Meaning                                                                                                                                                                                |
|-------------------|------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| rw-rwxrwx         | 777        | Read, write, and execute permissions for all users.                                                                                                                                    |
| rw-r-xr-x         | 755        | Read and execute permission for all users. The file's owner also has write permission.                                                                                                 |
| rw-r-x---         | 750        | Read and execute permission for the owner and group. The file's owner also has write permission. Users who aren't the file's owner or members of the group have no access to the file. |
| rw------          | 700        | Read, write, and execute permissions for the file's owner only; all others have no access.                                                                                             |
| rw-rw-rw-         | 666        | Read and write permissions for all users. No execute permissions for anybody.                                                                                                          |
| rw-rw-r--         | 664        | Read and write permissions for the owner and group. Read-only permission for all others.                                                                                               |
| rw-rw----         | 660        | Read and write permissions for the owner and group. No world permissions.                                                                                                              |
| rw-r--r--         | 644        | Read and write permissions for the owner. Read-only permission for all others.                                                                                                         |
| rw-r-----         | 640        | Read and write permissions for the owner, and read-only permission for the group. No permission for others.                                                                            |

**TABLE 4.5** Example Permissions and Their Likely Uses (*continued*)

| Permission String | Octal Code | Meaning                                                                   |
|-------------------|------------|---------------------------------------------------------------------------|
| rw-----           | 600        | Read and write permissions for the owner. No permission for anybody else. |
| r-----            | 400        | Read permission for the owner. No permission for anybody else.            |

Execute permission makes sense for ordinary files, but it’s meaningless for most other file types, such as device files. Directories, though, use the execute bit another way. When a directory’s execute bit is set, that means that the directory’s contents may be searched. This is a highly desirable characteristic for directories, so you’ll almost never find a directory on which the execute bit is *not* set in conjunction with the read bit.

Directories can be confusing with respect to write permission. Recall that directories are files that are interpreted in a special way. As such, if a user can write to a directory, that user can create, delete, or rename files in the directory, even if the user isn’t the owner of those files and does not have permission to write to those files. You can use the *sticky bit* (described shortly, in “Special Permission Bits”) to alter this behavior.

Symbolic links are unusual with respect to permissions. This file type always has *777* (*rw-rw-rw*) permissions, thus granting all users full access to the file. This access applies only to the link file itself, however, not to the linked-to file. In other words, all users can read the contents of the link to discover the name of the file to which it points, but the permissions on the linked-to file determine its file access. Changing the permissions on a symbolic link affects the linked-to file.

Many of the permission rules don’t apply to *root*. The superuser can read or write any file on the computer—even files that grant access to nobody (that is, those that have *000* permissions). The superuser still needs an execute bit to be set to run a program file, but the superuser has the power to change the permissions on any file, so this limitation isn’t very substantial. Some files may be inaccessible to *root*, but only because of an underlying restriction—for instance, even *root* can’t access a hard disk that’s not installed in the computer.

## Special Permission Bits

A few special permission options are also supported, and they may be indicated by changes to the permission string:

**Set user ID (SUID)** The *set user ID* (SUID) option is used in conjunction with executable files, and it tells Linux to run the program with the permissions of whoever owns the file rather than with the permissions of the user who runs the program. For instance, if a file is owned by *root* and has its SUID bit set, the program runs with *root* privileges and can therefore read any file on the computer. Some servers and other system programs run this

way, which is often called SUID root. SUID programs are indicated by an `s` in the owner's execute bit position in the permission string, as in `rwsr-xr-x`.

**Set group ID (SGID)** The *set group ID* (SGID) option is similar to the SUID option, but it sets the group of the running program to the group of the file. It's indicated by an `s` in the group execute bit position in the permission string, as in `rwxr-sr-x`. When the SGID bit is set on a directory, new files or subdirectories created in the original directory will inherit the group ownership of the directory, rather than be based on the user's current default group.

**Sticky bit** The sticky bit has changed meaning during the course of Unix history. In modern Linux implementations (and most modern versions of Unix), it's used to protect files from being deleted by those who don't own the files. When this bit is present on a directory, the directory's files can be deleted only by their owners, the directory's owner, or root. The sticky bit is indicated by a `t` in the world execute bit position, as in `rwxr-xr-t`.



These special permission bits all have security implications. SUID and SGID programs (and particularly SUID root programs) are potential security risks. Although some programs must have their SUID bits set to function properly, most don't, and you shouldn't set these bits unless you're certain that doing so is necessary. The sticky bit isn't dangerous this way, but because it affects who may delete files in a directory, you should consider its effect—or the effect of *not* having it—on directories to which many users should have write access, such as `/tmp`. Typically, such directories have their sticky bits set.



## Real World Scenario

### Using ACLs

Unix-style permissions have served Linux well since its creation and are emphasized on the LPI exam; but a new and improved permission system is now available. An *access control list* (ACL) is a list of users or groups and the permissions they're given. Linux ACLs, like Linux owner, group, and world permissions, consist of three permission bits, one each for read, write, and execute permissions. The file's owner can assign ACLs to an arbitrary number of users and groups, making ACLs more flexible than Linux permissions, which are limited to groups defined by the system administrator.

ACLs require support in the underlying filesystem. All the major Linux filesystems now support ACLs, but you may need to recompile your kernel (or at least the relevant kernel module) to activate this support.

ACLs require their own commands to set and view. The `setfacl` command sets an ACL, and the `getfacl` command displays the ACLs for a file. Consult these commands' man pages for more information.

## Changing a File's Mode

You can modify a file's permissions using the `chmod` command. This command may be issued in many different ways to achieve the same effect. Its basic syntax is as follows:

```
chmod [options] [mode[,mode...]] filename...
```

The `chmod` options are similar to those of `chown` and `chgrp`. In particular, `--recursive` (or `-R`) changes all the files in a directory tree.

Most of the complexity of `chmod` comes in the specification of the file's mode. You can specify the mode in two basic forms: as an octal number or as a symbolic mode, which is a set of codes related to the string representation of the permissions.

The octal representation of the mode is the same as that described earlier and summarized in Table 4.5. For instance, to change permissions on `report.tex` to `rw-r--r--`, you can issue the following command:

```
$ chmod 644 report.tex
```

In addition, you can precede the three digits for the owner, group, and world permissions with another digit that sets special permissions. Three bits are supported (hence values between 0 and 7): adding 4 sets the set user ID (SUID) bit, adding 2 sets the set group ID (SGID) bit, and adding 1 sets the sticky bit. If you omit the first digit (as in the preceding example), Linux clears all three bits. Using four digits causes the first to be interpreted as the special permissions code.

For instance, suppose you've acquired a script called `bigprogram`. You want to set both SUID and SGID bits (6); to make the program readable, writeable, and executable by the owner (7); to make it readable and executable by the group (5); and to make it completely inaccessible to all others (0). The following commands illustrate how to do this; note the difference in the mode string before and after executing the `chmod` command:

```
$ ls -l bigprogram
```

```
-rw-r--r-- 1 rodsmith users 10323 Oct 31 18:58 bigprogram
```

```
$ chmod 6750 bigprogram
```

```
$ ls -l bigprogram
```

```
-rwsr-s--- 1 rodsmith users 10323 Oct 31 18:58 bigprogram
```

A symbolic mode, by contrast, consists of three components: a code indicating the permission set you want to modify (the owner, the group, and so on); a symbol indicating whether you want to add, delete, or set the mode equal to the stated value; and a code specifying what the permission should be. Table 4.6 summarizes all these codes. Note that these codes are all case sensitive.

**TABLE 4.6** Codes Used in Symbolic Modes

| Permission Set Code | Change Type Code | Meaning | Permission to Modify Code | Meaning                                                                   |
|---------------------|------------------|---------|---------------------------|---------------------------------------------------------------------------|
| u                   | +                | Owner   | r                         | Read                                                                      |
| g                   | -                | Group   | w                         | Write                                                                     |
| o                   | =                | World   | x                         | Execute                                                                   |
| a                   |                  | All     | X                         | Execute only if the file is a directory or already has execute permission |
|                     |                  |         | s                         | SUID or SGID                                                              |
|                     |                  |         | t                         | Sticky bit                                                                |
|                     |                  |         | u                         | Existing owner's permissions                                              |
|                     |                  |         | g                         | Existing group permissions                                                |
|                     |                  |         | o                         | Existing world permissions                                                |

To use symbolic permission settings, you combine one or more of the codes from the first column of Table 4.6 with one symbol from the third column and one or more codes from the fifth column. You can combine multiple settings by separating them by commas. Table 4.7 provides some examples of `chmod` using symbolic permission settings.

**TABLE 4.7** Examples of Symbolic Permissions with *chmod*

| Command                                | Initial Permissions    | End Permissions        |
|----------------------------------------|------------------------|------------------------|
| <code>chmod a+x bigprogram</code>      | <code>rw-r--r--</code> | <code>rwxr-xr-x</code> |
| <code>chmod ug=rw report.tex</code>    | <code>r-----</code>    | <code>rw-rw----</code> |
| <code>chmod o-rwx bigprogram</code>    | <code>rw-rwxr-x</code> | <code>rw-rwx---</code> |
| <code>chmod g=u report.tex</code>      | <code>rw-r--r--</code> | <code>rw-rw-r--</code> |
| <code>chmod g-w,o-rw report.tex</code> | <code>rw-rw-rw-</code> | <code>rw-r-----</code> |

In Exercise 4.1, you'll experiment with the effect of Linux ownership and permissions on file accessibility.

## EXERCISE 4.1

### Modifying Ownership and Permissions

During this exercise, you'll need to use three accounts: root and two user accounts, each in a different group. To study these effects, follow these steps:

1. Log in three times using three virtual terminals: once as root, once as user1, and once as user2. (Use usernames appropriate for your system, though. Be sure that user1 and user2 are in different groups.) If you prefer, instead of using virtual terminals, you can open three xterm windows in an X session, using su to acquire each user's privileges.
2. As root, create a scratch directory—say, /tmp/scratch. Type **mkdir /tmp/scratch**.
3. As root, give all users read and write access to the scratch directory by typing **chmod 0777 /tmp/scratch**.
4. In the user1 and user2 login sessions, change to the scratch directory by typing **cd /tmp/scratch**.
5. As user1, copy a short text file to the scratch directory using cp, as in **cp /etc/fstab ./testfile**.
6. As user1, set 0644 (-rw-r--r--) permissions on the file by typing **chmod 0644 testfile**. Type **ls -l**, and verify that the permission string in the first column matches this value (-rw-r--r--).
7. As user2, try to access the file by typing **cat testfile**. The file should appear on the screen.
8. As user2, try to change the name of the file by typing **mv testfile changedfile**. The system won't produce any feedback, but if you type **ls**, you'll see that the file's name has changed. Note that user2 doesn't own the file but can rename it because user2 can write to the directory in which the file resides.
9. As user2, try to change the mode of the file by typing **chmod 0600 changedfile**. The system should respond with an Operation not permitted error because only the file's owner may change its permissions.
10. As user2, try to delete the file by typing **rm changedfile**. Depending on your configuration, the system may or may not ask for verification, but it should permit the deletion. This is true despite the fact that user2 doesn't own the file because user2 can write to the directory in which the file resides.
11. As user1, repeat step 5 to re-create the test file.



**EXERCISE 4.1 (continued)**

12. As user1, give the file more restrictive permissions by typing **chmod 0640**. Typing **ls -l** should reveal permissions of `-rw-r-----`, meaning that the file's owner can read and write the file, members of the file's group can read it, and other users are given no access.
13. As user2, repeat steps 7–10. The `cat` operation should fail with a `Permission denied` error, but steps 8–10 should produce the same results as they did the first time around. (If the `cat` operation succeeded, then either user2 belongs to the file's group or the file's mode is set incorrectly.)
14. Log out of the user1 and user2 accounts.
15. As root, type **rm -r /tmp/scratch** to delete the scratch directory and its contents.

If you like, you can perform tests with more file permission modes and other file-manipulation commands before step 14.

---

As a general rule, symbolic permissions are most useful when you want to make a simple change (such as adding execute or write permissions to one or more class of users) or when you want to make similar changes to many files without affecting their other permissions (for instance, adding write permissions without affecting execute permissions). Octal permissions are most useful when you want to set a specific absolute permission, such as `rw-r--r--` (644). In any event, a system administrator should be familiar with both methods of setting permissions.

A file's owner and root are the only users who may adjust a file's permissions. Even if other users have write access to a directory in which a file resides and write access to the file itself, they may not change the file's permissions (but they may modify or even delete the file). To understand why this is so, you need to know that the file permissions are stored as part of the file's inode, which isn't part of the directory entry. Read/write access to the directory entry, or even the file itself, doesn't give a user the right to change the inode structures (except indirectly—for instance, if a write changes the file's size or a file deletion eliminates the need for the inode).

## Setting the Default Mode and Group

When a user creates a file, that file has default ownership and permissions. The default owner is, understandably, the user who created the file. The default group is the user's primary group. The default permissions are configurable. These are defined by the *user mask* (umask), which is set by the `umask` command. This command takes as input an octal value that represents the bits to be removed from 777 permissions for directories, or from 666 permissions for files, when a new file or directory is created. Table 4.8 summarizes the effect of several possible umask values.

**TABLE 4.8** Sample Umask Values and Their Effects

| Umask | Created Files   | Created Directories |
|-------|-----------------|---------------------|
| 000   | 666 (rw-rw-rw-) | 777 (rwxrwxrwx)     |
| 002   | 664 (rw-rw-r--) | 775 (rwxrwxr-x)     |
| 022   | 644 (rw-r--r--) | 755 (rwxr-xr-x)     |
| 027   | 640 (rw-r-----) | 750 (rwxr-x---      |
| 077   | 600 (rw-----)   | 700 (rwx-----)      |
| 277   | 400 (r-----)    | 500 (r-x-----)      |

Note that the umask isn't a simple subtraction from the values of 777 or 666; it's a bit-wise removal. Any bit that's set in the umask is removed from the final permission for new files; but if a bit isn't set (as in the execute bit in ordinary files), its specification in the umask doesn't do any harm. For instance, consider the 7 values in several entries of Table 4.8's Umask column. This corresponds to a binary value of 111. An ordinary file might have rw- (110) permissions; but applying the umask's 7 (111) eliminates 1 values but doesn't touch 0 values, thus producing a 000 (binary) value—that is, --- permissions, expressed symbolically.

Ordinary users can enter the `umask` command to change the permissions on new files they create. The superuser can also modify the default setting for all users by modifying a system configuration file. Typically, `/etc/profile` contains one or more `umask` commands. Setting the umask in `/etc/profile` may or may not have an effect because it can be overridden at other points, such as a user's own configuration files. Nonetheless, setting the umask in `/etc/profile` or other system files can be a useful procedure if you want to change the default system policy. Most Linux distributions use a default umask of 002 or 022.

To find what the current umask is, type `umask` alone, without any parameters. Typing `umask -S` produces the umask expressed symbolically rather than in octal form. You may also specify a umask in this way when you want to change it, but in this case, you specify the bits that you *do* want set. For instance, `umask u=rwx,g=rx,o=rx` is equivalent to `umask 022`.

In addition to setting the default mask with `umask`, users can change their default group with `newgrp`, as in `newgrp skyhook` to create new files with the group set to the `skyhook` group. To use this command, the user must be a member of the specified group. The `newgrp` command also accepts the `-l` parameter, as in `newgrp -l skyhook`, which reinitializes the environment as if the user had just logged in.

## Changing File Attributes

Some filesystems support attributes in addition to those described in the preceding sections. In particular, some Linux native filesystems support several attributes that you can adjust with the `chattr` command:

**Append only** The `a` attribute sets append mode, which disables write access to the file except for appending data. This can be a security feature to prevent accidental or malicious changes to files that record data, such as log files.

**Compressed** The `c` attribute causes the kernel to automatically compress data written to the file and uncompress it when it's read back.

**Immutable** The `i` flag makes a file immutable, which goes a step beyond simply disabling write access to the file. The file can't be deleted, links to it can't be created, and the file can't be renamed.

**Data journaling** The `j` flag tells the kernel to journal all data written to the file. This improves recoverability of data written to the file after a system crash but can slow performance. This flag has no effect on ext2 filesystems.

**Secure deletion** Ordinarily, when you delete a file, its directory entry is removed and its inode is marked as being available for recycling. The data blocks that make up the bulk of the file aren't erased. Setting the `s` flag changes this behavior; when the file is deleted, the kernel zeros its data blocks, which may be desirable for files that contain sensitive data.

**No tail-merging** *Tail-merging* is a process in which small pieces of data at the ends of files that don't fill a complete block are merged with similar pieces of data from other files. The result is reduced disk space consumption, particularly when you store many small files rather than a few big ones. Setting the `t` flag disables this behavior, which is desirable if the filesystem will be read by certain non-kernel drivers, such as those that are part of the Grand Unified Boot Loader (GRUB).

**No access time updates** If you set the `A` attribute, Linux won't update the access time stamp when you access a file. This can reduce disk input/output, which is particularly helpful for saving battery life on laptops.

This list of attributes is incomplete but includes the most useful options; consult the `man` page for `chattr` for more flags. You set the options you want using the minus (`-`), plus (`+`), or equal (`=`) symbol to remove an option from an existing set, add an option to an existing set, or set a precise set of options (overwriting any that already exist), respectively. For instance, to add the immutable flag to the `important.txt` file, you enter the following command:

```
chattr +i important.txt
```

The result is that you'll be unable to delete the file, even as `root`. To delete the file, you must first remove the immutable flag:

```
chattr -i important.txt
```

# Managing Disk Quotas

Just one or two users of a multi-user system can cause serious problems for others by consuming too much disk space. If a single user creates huge files (say, multimedia recordings), those files can use enough disk space to prevent other users from creating their own files. To help manage this situation, Linux supports *disk quotas*—limits enforced by the OS on how many files or how much disk space a single user may consume. The Linux quota system supports quotas both for individual users and for Linux groups.

## Enabling Quota Support

Quotas require support in both the kernel for the filesystem being used and various user-space utilities. The ext2fs, ext3fs, ReiserFS, JFS, and XFS filesystems support quotas, but this support is missing for some filesystems in early 2.6.x kernels. Try using the latest kernel if you have problems with your preferred filesystem. You must explicitly enable support via the Quota Support kernel option in the filesystem area when recompiling your kernel. Many distributions ship with this support precompiled, so recompiling your kernel may not be necessary, but you should be aware of this option if you do recompile your kernel.

Two general quota support systems are available for Linux. The first was used through the 2.4.x kernels and is referred to as the *quota v1 support*. The second was added with the 2.6.x kernel series and is referred to as the *quota v2 system*. This description applies to the latter system, but the former works in a similar way.

Outside of the kernel, you need support tools to use quotas. For the quota v2 system, this package is usually called `quota`, and it installs a number of utilities, configuration files, SysV startup scripts, and so on.



You can install the support software from source code, if you like; however, this job is handled most easily using a package for your distribution. This description assumes that you install the software in this way. If you don't, you may need to create SysV or local startup scripts to initialize the quota support when you boot your computer. The Quota Mini-HOWTO, at <http://en.tldp.org/HOWTO/Quota.html>, provides details of how to do this.

You must modify your `/etc/fstab` entries for any partitions on which you want to use quota support. In particular, you must add the `usrquota` filesystem mount option to employ user quotas and the `grpquota` option to use group quotas. Entries that are so configured resemble the following:

```
/dev/hdc5 /home ext3 usrquota,grpquota 1 1
```

This line activates both user and group quota support for the `/dev/hdc5` partition, which is mounted at `/home`. Of course, you can add other options if you like.

Depending on your distribution, you may need to configure the quota package's SysV startup scripts to run when the system boots. Chapter 5 describes SysV startup script management in detail. Typically, you'll type a command such as **chkconfig quota on**; but you should check on the SysV scripts installed by your distribution's quota package. Some distributions require the use of commands other than `chkconfig` to do this task, as described in Chapter 5. Whatever its details, this startup script runs the `quotaon` command, which activates quota support.

After installing software and making configuration file changes, you must activate the systems. The simplest way to do this is to reboot the computer, and this step is necessary if you had to recompile your kernel to add quota support directly into the kernel. If you didn't do this, you should be able to get by with less disruptive measures: using `modprobe` to install the kernel module, if necessary; running the SysV startup script for the quota tools; and remounting the filesystems on which you intend to use quotas by typing `mount -o remount /mount-point`, where `/mount-point` is the mount point in question.

## Setting Quotas for Users

At this point, quota support should be fully active on your computer, but the quotas themselves aren't set. You can set the quotas by using `edquota`, which starts the Vi editor (described in Chapter 1, "Exploring Linux Command-Line Tools") on a temporary configuration file (`/etc/quotatab`) that controls quotas for the user you specify. When you exit the utility, `edquota` uses the temporary configuration file to write the quota information to low-level disk data structures that control the kernel's quota mechanisms. For instance, you might type `edquota sally` to edit sally's quotas. The contents of the editor show the current quota information:

Quotas for user sally:

```
/dev/hdc5: blocks in use: 3209, limits (soft = 5000, hard = 6500)
 inodes in use: 403, limits (soft = 1000, hard = 1500)
```

The temporary configuration file provides information about both the number of disk blocks in use and the number of inodes in use. (Each file or symbolic link consumes a single inode, so the inode limits are effectively limits on the number of files a user may own. Disk blocks vary in size depending on the filesystem and filesystem creation options, but they typically range from 512 bytes to 8KB.) Changing the use information has no effect, but you can alter the soft and hard limits for both blocks and inodes. The hard limit is the maximum number of blocks or inodes that the user may consume; the kernel won't permit a user to surpass these limits. Soft limits are somewhat less stringent; users may temporarily exceed soft limit values, but when they do so, the system issues warnings. Soft limits also interact with a grace period; if the soft quota limit is exceeded for longer than the grace period, the kernel begins treating it like a hard limit and refuses to allow the user to create more files. You can set the grace period by using `edquota` with its `-t` option, as in `edquota -t`. Grace periods are set on a per-filesystem basis rather than a per-user basis.

A few more quota-related commands are useful. The first is `quotacheck`, which verifies and updates quota information on quota-enabled disks. This command is normally run

as part of the quota package's SysV startup script, but you may want to run it periodically (say, once a week) as a cron job. (Chapter 7 describes cron jobs.) Although theoretically not necessary if everything works correctly, `quotacheck` ensures that quota accounting doesn't become inaccurate. The second useful auxiliary quota command is `repquota`, which summarizes the quota information about the filesystem you specify or on all filesystems if you pass it the `-a` option. This tool can be very helpful in keeping track of disk usage. The `quota` command has a similar effect. The `quota` tool takes a number of options to have them modify their outputs. For instance, `-g` displays group quotas, `-l` omits NFS mounts, and `-q` limits output to filesystems on which usage is over the limit. Consult `quota`'s man page for still more obscure options.

## Locating Files

Maintaining your filesystems in perfect health, setting permissions, and so on is pointless if you can't find your files. For this reason, Linux provides several tools to help you locate the files you need to use. The first of these tools is actually a standard for where files are located; with the right knowledge, you may be able to find files without the use of any specialized programs. The second class of tools includes just such specialized programs, which search a directory tree or a database for files that meet whatever criteria you specify.

### The FHS

Linux's placement of files is derived from 40 years of Unix history. Given that fact, the structure is remarkably simple and coherent, but it's easy for a new administrator to become confused. Some directories seem, on the surface, to fulfill similar or even identical roles, but in fact there are subtle but important differences. This section describes the Linux directory layout standards and presents an overview of what goes where.

### The FSSTND and FHS

Although Linux draws heavily on Unix, Unix's long history has led to numerous splits and variants, starting with the Berkeley Standard Distribution (BSD), which was originally a set of patches and extensions to AT&T's original Unix code. As a result of these schisms within the Unix community, early Linux distributions didn't always follow identical patterns. The result was a great deal of confusion. This problem was quite severe early in Linux's history, and it threatened to split the Linux community into factions. Various measures were taken to combat this problem, one of which was the development of the *Filesystem Standard* (FSSTND), which was first released in early 1994. The FSSTND standardized several specific features, such as the following:

- Standardized the programs that reside in `/bin` and `/usr/bin`. Differences on this score caused problems when scripts referred to files in one location or the other.

- Specified that executable files shouldn't reside in `/etc`, as had previously been common.
- Removed changeable files from the `/usr` directory tree, enabling it to be mounted read-only (a useful security measure).

There have been three major versions of FSSTND: 1.0, 1.1, and 1.2. FSSTND began to rein in some of the chaos in the Linux world in 1994. By 1995, however, FSSTND's limitations were becoming apparent. Thus, a new standard was developed: the *Filesystem Hierarchy Standard* (FHS). This new standard is based on FSSTND but extends it substantially. The FHS was created in conjunction with developers of some non-Linux Unix-like OSs, for instance. For this reason, the FHS is more than a Linux standard; it may be used to define the layout of files on other Unix-like OSs.

One important distinction made by the FHS is that between *shareable files* and *unshareable files*. Shareable files may be reasonably shared between computers, such as user data files and program binary files. (Of course, you don't *need* to share such files, but you *may* do so.) If files are shared, they're normally shared through an NFS server. Unshareable files contain system-specific information, such as configuration files. For instance, you're not likely to want to share a server's configuration file between computers.

A second important distinction used in the FHS is that between *static files* and *variable files*. The former don't normally change except through direct intervention by the system administrator. Most program executables are good examples of static files. Variable files may be changed by users, automated scripts, servers, or the like. For instance, users' home directories and mail queues are composed of variable files. The FHS tries to isolate each directory into one cell of this  $2 \times 2$  (shareable/unshareable  $\times$  static/variable) matrix. Figure 4.1 illustrates these relationships. Some directories are mixed, but in these cases, the FHS tries to specify the status of particular subdirectories. For instance, `/var` is variable, and it contains some shareable and some unshareable subdirectories, as shown in Figure 4.1.

Like the FSSTND, the FHS comes in numbered versions. Version 2.3, the latest version as I write, was released in January 2004. The URL for FHS's official Web page is <http://www.pathname.com/fhs/>.

**FIGURE 4.1** The FHS attempts to fit each important directory in one cell of a  $4 \times 4$  matrix.

|          | Shareable                                    | Unshareable                                     |
|----------|----------------------------------------------|-------------------------------------------------|
| Static   | <code>/usr</code><br><code>/opt</code>       | <code>/etc</code><br><code>/boot</code>         |
| Variable | <code>/home</code><br><code>/var/mail</code> | <code>/var/run</code><br><code>/var/lock</code> |

## Important Directories and Their Contents

The FHS defines some directories very precisely, but details for others are left unresolved. For instance, users' files normally go in the `/home` directory, but you may have reason to call this something else or to use two or more separate directories for users' files. Overall, the most common directories defined by the FHS or used by convention are the following:

**/** Every Linux filesystem traces its roots to a single directory, known as `/` (pronounced, and often referred to, as the *root filesystem* or *root directory*). All other directories branch off this one. Linux doesn't use drive letters; instead, every partition or removable disk is mounted at a mount point within another partition (`/` or something else). Certain critical subdirectories, such as `/etc` and `/sbin`, must reside on the root partition, but others can optionally be on separate partitions. Don't confuse the root directory with the `/root` directory, described shortly.

**/boot** The `/boot` directory contains static and unshareable files related to the initial booting of the computer. Higher-level startup and configuration files reside in another directory, `/etc`. Some systems impose particular limits on `/boot`. For instance, older x86 BIOSs and older versions of the Linux Loader (LILO) may require that `/boot` reside below the 1,024th cylinder of the hard disk. These requirements sometimes, but not always, necessitate that the `/boot` directory be a separate partition.

**/bin** This directory contains certain critical executable files, such as `ls`, `cp`, and `mount`. These commands are accessible to all users and constitute the most important commands that ordinary users might issue. You won't normally find commands for big application programs in `/bin` (although the Vi editor is located here). The `/bin` directory contains static files. Although in some sense the `/bin` files are shareable, because they're so important to the basic operation of a computer, the directory is almost never shared—any potential clients must have their own local `/bin` directories.

**/sbin** This directory is similar to `/bin`, but it contains programs that are normally run only by the system administrator—tools like `fdisk` and `e2fsck`. It's static and theoretically shareable, but in practice, it makes no sense to share it.

**/lib** This directory is similar to `/bin` and `/sbin`, but it contains program libraries, which are made up of code that's shared across many programs and stored in separate files to save disk space and RAM. The `/lib/modules` subdirectory contains kernel modules—drivers that can be loaded and unloaded as required. Like `/bin` and `/sbin`, `/lib` is static and theoretically shareable, although it's not shared in practice.

**/usr** This directory hosts the bulk of a Linux computer's programs. Its contents are shareable and static, so it can be mounted read-only and may be shared with other Linux systems. For these reasons, many administrators split `/usr` off into a separate partition, although doing so isn't required. Some subdirectories of `/usr` are similar to their namesakes in the root directory (such as `/usr/bin` and `/usr/lib`), but they contain programs and libraries that aren't absolutely critical to the basic functioning of the computer.



**/usr/local** This directory contains subdirectories that mirror the organization of `/usr`, such as `/usr/local/bin` and `/usr/local/lib`. The `/usr/local` directory hosts files that a system administrator installs locally—for instance, packages that are compiled on the target computer. The idea is to have an area that’s safe from automatic software upgrades when the OS as a whole is upgraded. Immediately after Linux is installed, `/usr/local` should be empty except for some stub subdirectories. Some system administrators split this off into its own partition to protect it from OS reinstallation procedures that might erase the parent partition.

**/usr/X11R6** This directory houses files related to the X Window System (X for short), Linux’s GUI environment. Like `/usr/local`, this directory contains subdirectories similar to those in `/usr`, such as `/usr/X11R6/bin` and `/usr/X11R6/lib`.

**/opt** This directory is similar to `/usr/local` in many ways, but it’s intended for ready-made packages that don’t ship with the OS, like commercial word processors or games. Typically, these programs reside in subdirectories in `/opt` named after themselves, such as `/opt/app1ix`. The `/opt` directory is static and shareable. Some system administrators break it into a separate partition or make it a symbolic link to a subdirectory of `/usr/local` and make that a separate partition.

**/home** This directory contains users’ data, and it’s shareable and variable. Although the `/home` directory is considered optional in FHS, in practice it’s a matter of the *name* being optional. For instance, if you add a new disk to support additional users, you might leave the existing `/home` directory intact and create a new `/home2` directory to house the new users. The `/home` directory often resides on its own partition.

**/root** This is the home directory for the `root` user. Because the `root` account is so critical and system specific, this variable directory isn’t really shareable.

**/var** This directory contains transient files of various types—system log files, print spool files, mail and news files, and so on. As such, the directory’s contents are variable. Some subdirectories are shareable, but others are not. Many system administrators put `/var` in its own partition, particularly on systems that see a lot of activity in `/var`, like major Usenet news or mail servers.

**/tmp** Many programs need to create temporary (hence variable) files, and the usual place to do so is in `/tmp`. Most distributions include routines that clean out this directory periodically and sometimes wipe the directory clean at bootup. The `/tmp` directory is seldom shared. Some administrators create a separate `/tmp` partition to prevent runaway processes from causing problems on the root filesystem when processes create too-large temporary files. A similar directory exists as part of the `/var` directory tree (`/var/tmp`).

**/mnt** Linux mounts removable-media devices within its normal directory structure, and `/mnt` is provided for this purpose. Some (mostly older) distributions create subdirectories within `/mnt`, such as `/mnt/floppy` and `/mnt/cdrom`, to function as mount points. Others use `/mnt` directly or even use separate mount points off `/`, such as `/floppy` and `/cdrom`. The FHS mentions only `/mnt`; it doesn’t specify how it’s to be used. Specific media mounted in `/mnt` may be either static or variable. As a general rule, these directories are shareable.

**/media** This directory is an optional part of the FHS. It's like /mnt, but it should contain subdirectories for specific media types, such as /media/floppy and /media/cdrom. Many modern distributions use /media subdirectories as the default mount points for common removable disk types.

**/dev** Because Linux treats most hardware devices as if they were files, the OS must have a location in its filesystem where these device files reside. The /dev directory is that place. It contains a large number of files that function as hardware interfaces. If a user has sufficient privileges, that user may access the device hardware by reading from and writing to the associated device file. The Linux kernel supports a device filesystem that enables /dev to be an automatically created *virtual filesystem*—the kernel and support tools create /dev entries on-the-fly to accommodate the needs of specific drivers. Most distributions now use this facility.

**/proc** This is an unusual directory because it doesn't correspond to a regular directory or partition. Instead, it's a virtual filesystem that's created dynamically by Linux to provide access to certain types of hardware information that aren't accessible via /dev. For instance, if you type `cat /proc/cpuinfo`, the system responds by displaying information about your CPU—its model name, speed, and so on.

Knowledge of these directories and their purposes is invaluable in properly administering a Linux system. For instance, understanding the purpose of directories like /bin, /sbin, /usr/bin, /usr/local/bin, and others will help you when it comes time to install a new program. Placing a program in the wrong location can cause problems at a later date. For example, if you put a binary file in /bin when it should go in /usr/local/bin, that program may later be overwritten or deleted during a system upgrade when leaving it intact would have been more appropriate.

## Tools for Locating Files

You use file-location commands to locate a file on your computer. Most frequently, these commands help you locate a file by name; but sometimes you can use other criteria, such as modification date. These commands can search a directory tree (including root, which scans the entire system) for a file matching the specified criteria in any subdirectory.

### The *find* Command

The `find` utility implements a brute-force approach to finding files. This program finds files by searching through the specified directory tree, checking filenames, file creation dates, and so on to locate the files that match the specified criteria. Because of this method of operation, `find` tends to be slow; but it's very flexible and is very likely to succeed, assuming the file for which you're searching exists. The `find` syntax is as follows:

```
find [path...] [expression...]
```

You can specify one or more paths in which `find` should operate; the program will restrict its operations to these paths. The *expression* is a way of specifying what you want

to find. The man page for `find` includes information about these expressions, but some of the more common enable you to search by various common criteria:

**Search by filename** You can search for a filename using the `-name pattern` expression. Doing so finds files that match the specified *pattern*. If *pattern* is an ordinary filename, `find` matches that name exactly. You can use wildcards if you enclose *pattern* in quotes, and `find` will locate files that match the wildcard filename.

**Search by permission mode** If you need to find files that have certain permissions, you can do so by using the `-perm mode` expression. The *mode* may be expressed either symbolically or in octal form. If you precede *mode* with a `+`, `find` locates files in which *any* of the specified permission bits are set. If you precede *mode* with a `-`, `find` locates files in which *all* the specified permission bits are set.

**Search by file size** You can search for a file of a given size with the `-size n` expression. Normally, *n* is specified in 512-byte blocks, but you can modify this by trailing the value with a letter code, such as `c` for bytes or `k` for kilobytes.

**Search by group** The `-gid GID` expression searches for files whose group ID (GID) is set to *GID*. The `-group name` option locates files whose group name is *name*. The former can be handy if the GID has been orphaned and has no name, but the latter is generally easier to use.

**Search by user ID** The `-uid UID` expression searches for files owned by the user whose user ID (UID) is *UID*. The `-user name` option searches for files owned by *name*. The former can be handy if the UID has been orphaned and has no name, but the latter is generally easier to use.

**Restrict search depth** If you want to search a directory and, perhaps, some limited number of subdirectories, you can use the `-maxdepth levels` expression to limit the search.

There are many variant and additional options; `find` is a very powerful command. As an example of its use, consider the task of finding all C source code files, which normally have names that end in `.c`, in all users' home directories. If these home directories reside in `/home`, you might issue the following command:

```
find /home -name "*.c"
```

The result will be a listing of all the files that match the search criteria.



Ordinary users may use `find`, but it doesn't overcome Linux's file permission features. If you lack permission to list a directory's contents, `find` will return that directory name and the error message `Permission denied`.

## The *locate* Command

The `locate` utility works much like `find` if you want to find a file by name, but it differs in two important ways:

- The `locate` tool is far less sophisticated in its search options. You normally use it to search only on filenames, and the program returns all files that contain the specified

string. For instance, when searching for `rpm`, `locate` will return other programs, like `gnorpm` and `rpm2cpio`.

- The `locate` program works from a database that it maintains. Most distributions include a cron job that calls `locate` with options that cause it to update its database periodically, such as once a night or once a week. (You can also use the `updatedb` command to do this task at any time.) For this reason, `locate` may not find recent files, or it may return the names of files that no longer exist. If the database-update utilities omit certain directories, files in them won't be returned by a `locate` query.

Because `locate` works from a database, it's typically much faster than `find`, particularly on system-wide searches. It's likely to return many false alarms, though, especially if you want to find a file with a short name. To use it, type `locate search-string`, where *search-string* is the string that appears in the filename.



Some Linux distributions use `slocate` rather than `locate`. The `slocate` program includes security features to prevent users from seeing the names of files in directories they shouldn't be able to access. On most systems that use `slocate`, the `locate` command is a link to `slocate`, so `locate` implements `slocate`'s security features. A few distributions don't install either `locate` or `slocate` by default.

## The *whereis* Command

The `whereis` program searches for files in a restricted set of locations, such as standard binary file directories, library directories, and man page directories. This tool does *not* search user directories or many other locations that are easily searched by `find` or `locate`. The `whereis` utility is a quick way to find program executables and related files like documentation or configuration files.

The `whereis` program returns filenames that begin with whatever you type as a search criterion, even if those files contain extensions. This feature often turns up configuration files in `/etc`, man pages, and similar files. To use the program, type the name of the program you want to locate. For instance, the following command locates `ls`:

```
$ whereis ls
ls: /bin/ls /usr/share/man/man1/ls.1.bz2
```

The result shows both the `ls` executable (`/bin/ls`) and the `ls` man page. The `whereis` program accepts several parameters that modify its behavior in various ways. These are detailed in the program's man page.

## The *which* Command

Considered as a search command, `which` is very weak; it merely searches your path for the command that you type and lists the complete path to the first match it finds. (You can

search for all matches by adding the `-a` option.) For instance, you might want to know where the `xterm` program is located:

```
$ which xterm
/usr/bin/xterm
```

Because the files that `which` finds are on your path, it won't help you to run these programs. Instead, it's likely to be useful if you need to know the complete path for some reason—say, because you want to call the program from a script and don't want to make assumptions about the path available to the script and so want to include the complete path in the script.

## The *type* Command

This command isn't really a search command; instead, it tells you how a command you type will be interpreted—as a built-in command, an external command, an alias, and so on. For instance, you can use it to identify several common commands:

```
$ type type
type is a shell builtin
$ type cat
cat is /bin/cat
$ type ls
ls is aliased to `ls --color`
```

This example identifies `type` itself as a built-in shell command, `cat` as a separate program stored in `/bin`, and `ls` as an alias for `ls --color`. You can add several options to modify the command's behavior. For instance, `-t` shortens the output to `builtin`, `file`, `alias`, or other short identifiers; and `-a` provides a complete list, for instance providing both the alias expansion and the location of the ultimate executable when provided with an alias name.

In Exercise 4.2, you'll get to use several ways to locate files.

## EXERCISE 4.2

### Locating Files

This exercise demonstrates several methods of locating files. You'll locate the `startx` program. (If your system doesn't have X installed, you can try searching for another program or file, such as `pwd` or `fstab`. You may need to change the path passed to `find` in step 5.) To find a file, follow these steps:

1. Log into the Linux system as a normal user.
2. Launch an `xterm` from the desktop environment's menu system if you used a GUI login method.

**EXERCISE 4.2 (continued)**

3. Type **locate startx**. The system should display several filenames that include the string `startx`. This search should take very little time. (A few distributions lack the `locate` command, so this step won't work on some systems.)
  4. Type **whereis startx**. The system responds with the names of a few files that contain the string `startx`. Note that this list may be slightly different than the list returned by step 3 but that the search proceeds quickly.
  5. Type **find /usr -name startx**. This search takes longer, and when run as an ordinary user, most likely returns several `Permission denied` error messages. It should also return a single line listing the `/usr/bin/startx` or `/usr/X11R6/bin/startx` program file. Note that this command searches only `/usr`. If you searched `/usr/X11R6`, the command would take less time; if you searched `/`, the command would take more time.
  6. Type **which startx**. This search completes almost instantaneously, returning the complete filename of the first instance of `startx` the system finds on its path.
  7. Type **type startx**. Again, the search completes very quickly. It should identify `startx` as an external command stored at `/usr/bin/startx`, `/usr/X11R6/bin/startx`, or possibly some other location.
- 

## Summary

File management is basic to being able to administer or use a Linux system. Various commands are useful to both users and administrators for copying, moving, renaming, and otherwise manipulating files and directories. You may also want to set up access controls, both to limit the amount of disk space users may consume and to limit who may access specific files and directories. Finally, Linux provides tools to help you locate files using various criteria.

## Exam Essentials

**Describe commands used to copy, move, and rename files in Linux.** The `cp` command copies files, as in **`cp first second`** to create a copy of `first` called `second`. The `mv` command does double duty as a file-moving and a file-renaming command. It works much like `cp`, but `mv` moves or renames the file rather than copying it.

**Summarize Linux's directory-manipulation commands.** The `mkdir` command creates a new directory, and `rmdir` deletes a directory. You can also use many file-manipulation commands, such as `mv` and `rm` (with its `-r` option), on directories.

**Explain the difference between hard and symbolic links.** Hard links are duplicate directory entries that both point to the same inode and hence to the same file. Symbolic links are special files that point to another file or directory by name. Hard links must reside on a single filesystem, but symbolic links may point across filesystems.

**Summarize the common Linux archiving programs.** The tar and cpio programs are both file-based archiving tools that create archives of files using ordinary file access commands. The dd program is a file-copy program; but when it's fed a partition device file, it copies the entire partition on a very low-level basis, which is useful for creating low-level image backups of Linux or non-Linux filesystems.

**Describe Linux's file ownership system.** Every file has an owner and a group, identified by number. File permissions can be assigned independently to the file's owner, the file's group, and all other users.

**Explain Linux's file permissions system.** Linux provides independent read, write, and execute permissions for the file's owner, the file's group, and all other users, resulting in nine main permission bits. Special permission bits are also available, enabling you to launch program files with modified account features or alter the rules Linux uses to control who may delete files.

**Summarize the commands Linux uses to modify permissions.** The chmod command is Linux's main tool for setting permissions. You can specify permissions using either an octal (base 8) mode or a symbolic notation. The chown and chgrp commands enable you to change the file's owner and group, respectively. (The chown command can do both but can only be run by root.)

**Describe the prerequisites of using Linux's disk quota system.** Linux's disk quota system requires support in the Linux kernel for the filesystem on which quotas are to be used. You must also run the quotaon command, typically from a SysV startup script, to enable this feature.

**Explain how quotas are set.** You can edit quotas for an individual user via the edquota command, as in **edquota larry** to edit larry's quotas. This command opens an editor on a text file that describes the user's quotas. You can change this description, save the file, and exit from the editor to change the user's quotas.

**Summarize how Linux's standard directories are structured.** Linux's directory tree begins with the root (/) directory, which holds mostly other directories. Specific directories may hold specific types of information, such as user files in /home and configuration files in /etc. Some of these directories and their subdirectories may be separate partitions, which helps isolate data in the event of filesystem corruption.

**Describe the major file-location commands in Linux.** The find command locates files by brute force, searching through the directory tree for files that match the criteria you specify. The locate (or slocate) command searches a database of files in important directories. The whereis command searches a handful of important directories, and which searches the path. The type command identifies another command as a built-in shell command, a shell alias, or an external command (including the path to that command).

## Review Questions

1. You want to use `/media/cdrom` to access your CD-ROM drive, so you insert a CD-ROM into the drive and type `mount /media/cdrom /dev/cdrom` as root. You receive the error message `/media/cdrom is not a block device`. Why did this happen?
  - A. You must first prepare the mount point by typing `mountpoint /media/cdrom`; only then will the `mount` command succeed.
  - B. The command reverses the order of the CD-ROM device file and the mount point; it should be `mount /dev/cdrom /media/cdrom`.
  - C. The `/dev/cdrom` filename isn't valid; you must determine what device file is associated with your CD-ROM drive.
  - D. The CD-ROM is defective or the CD-ROM drive is malfunctioning. Try another CD-ROM and, if necessary, replace the drive.
2. What is wrong with the following `/etc/fstab` file entry? (Select all that apply.)  
`/dev/hda8 nfs default 0 0`
  - A. The entry is missing a mount point specification.
  - B. All `/etc/fstab` fields should be separated by commas.
  - C. The `default` option may only be used with `ext2` filesystems.
  - D. `/dev/hda8` is a disk partition, but `nfs` indicates a network filesystem.
3. You want to discover the sizes of several dot files in a directory. Which of the following commands might you use to do this?
  - A. `ls -la`
  - B. `ls -p`
  - C. `ls -R`
  - D. `ls -d`
4. You want to move a file from your hard disk to a USB pen drive. Which of the following is true?
  - A. You'll have to use the `--preserve` option to `mv` to keep ownership and permissions set correctly.
  - B. The `mv` command will adjust filesystem pointers without physically rewriting data if the pen drive uses the same filesystem type as the hard disk partition.
  - C. You must use the same filesystem type on both media to preserve ownership and permissions.
  - D. The `mv` command will delete the file on the hard disk after copying it to the pen drive.



5. You type **mkdir one/two/three** and receive an error message that reads, in part, **No such file or directory**. What can you do to overcome this problem? (Select all that apply.)
  - A. Add the **--parents** parameter to the **mkdir** command.
  - B. Issue three separate **mkdir** commands: **mkdir one**, then **mkdir one/two**, and then **mkdir one/two/three**.
  - C. Type **touch /bin/mkdir** to be sure the **mkdir** program file exists.
  - D. Type **rmdir one** to clear away the interfering base of the desired new directory tree.
6. Which of the following commands are commonly used to create archive files? (Select all that apply.)
  - A. **restore**
  - B. **tar**
  - C. **tape**
  - D. **cpio**
7. You've received a tarball called **data79.tar** from a colleague, but you want to check the names of the files it contains before extracting them. Which of the following commands would you use to do this?
  - A. **tar uvf data79.tar**
  - B. **tar cvf data79.tar**
  - C. **tar xvf data79.tar**
  - D. **tar tvf data79.tar**
8. You want to create a link from your home directory on your hard disk to a directory on a CD-ROM drive. Which of the following types of links might you use?
  - A. Only a symbolic link.
  - B. Only a hard link.
  - C. Either a symbolic or a hard link.
  - D. None of the above; such links aren't possible under Linux.
9. What command would you type (as **root**) to change the ownership of **somefile.txt** from **ralph** to **tony**?
  - A. **chown ralph:tony somefile.txt**
  - B. **chmod somefile.txt tony**
  - C. **chown somefile.txt tony**
  - D. **chown tony somefile.txt**
10. Typing **ls -ld wonderjaye** reveals a symbolic file mode of **drwxr-xr-x**. Which of the following are true? (Select all that apply.)
  - A. **wonderjaye** is a symbolic link.
  - B. **wonderjaye** is an executable program.
  - C. **wonderjaye** is a directory.
  - D. **wonderjaye** may be read by all users of the system.

11. When should programs be configured SUID root?
  - A. At all times; this permission is required for executable programs.
  - B. Whenever a program should be able to access a device file.
  - C. Only when they require root privileges to do their job.
  - D. Never; this permission is a severe security risk.
12. Which of the following commands would you type to enable world read access to the file `myfile.txt`? (Assume that you're the owner of `myfile.txt`.)
  - A. `chmod 741 myfile.txt`
  - B. `chmod 0640 myfile.txt`
  - C. `chmod u+r myfile.txt`
  - D. `chmod o+r myfile.txt`
13. Which of the following `umask` values will result in files with `rw-r-----` permissions?
  - A. 640
  - B. 210
  - C. 022
  - D. 027
14. You see the `usrquota` and `grpquota` options in the `/etc/fstab` entry for a filesystem. What is the consequence of these entries?
  - A. Quota support will be available if it's compiled into the kernel; it will be automatically activated when you mount the filesystem.
  - B. Quota support will be available if it's compiled into your kernel, but you must activate it with the `quotaon` command.
  - C. Quota support will be disabled on the filesystem in question unless you activate it with the `quotaon` command.
  - D. Nothing; these options are malformed and so will have no effect.
15. Which of the following commands can be used to summarize the quota information about all filesystems?
  - A. `repquota`
  - B. `repquota -a`
  - C. `quotacheck`
  - D. `quotacheck -a`
16. You've installed a commercial spreadsheet program called WonderCalc on a workstation. In which of the following directories are you *most* likely to find the program executable file?
  - A. `/usr/sbin`
  - B. `/etc/X11`
  - C. `/bin`
  - D. `/opt/wcalc/bin`

17. Which of the following file-location commands is likely to take the *most* time to find a file that may be located anywhere on the computer (assuming the operation succeeds)?
- A. The `find` command.
  - B. The `locate` command.
  - C. The `whereis` command.
  - D. They're all equal in speed.
18. What can the `type` command do that `whereis` can't do?
- A. Identify the command as being for *x86* or *x86-64* CPUs
  - B. Locate commands based on their intended purpose, not just by name
  - C. Identify a command as an alias, internal command, or external command
  - D. Assist in typing a command by finishing typing it for you
19. You want to track down all the files in `/home` that are owned by `karen`. Which of the following commands will do the job?
- A. `find /home -uid karen`
  - B. `find /home -user karen`
  - C. `locate /home -username karen`
  - D. `locate /home karen`
20. What can you conclude from the following interaction?
- ```
$ which man
/usr/bin/man
```
- A. The only file called `man` on the system is in `/usr/bin`.
 - B. The `/usr/bin/man` program was installed by system package tools.
 - C. The `/usr/bin/man` program will be run by any user who types `man`.
 - D. The first instance of the `man` program, in path search order, is in `/usr/bin`.

Answers to Review Questions

1. B. The `mount` command takes a device filename first and a mount point second, so option B is correct. There is no need for special mount point preparation, as option A implies, other than the existence of the mount point directory. Contrary to option C, `/dev/cdrom` is often a valid device file for CD-ROMs (or more precisely, a symbolic link to a valid device file). Furthermore, the error message mentions `/media/cdrom`, not `/dev/cdrom`. Defective CD-ROMs and drives can certainly cause problems, as option D implies, but this error message refers to block devices, suggesting the problem is one of Linux configuration, not media viability.
2. A, D. A mount directory must be specified between the device entry (`/dev/hda8`) and the filesystem type code (`nfs`). The `nfs` filesystem type code may only be used with an NFS export specification of the form `server:/export` as the device specification. Fields in `/etc/fstab` are separated by spaces or tabs, not commas (but commas are used between individual options if several options are specified in the options column). The `default` option may be used with *any* filesystem type.
3. A. The `-l` parameter produces a long listing, including file sizes. The `-a` parameter produces a listing of all files in a directory, including the dot files. Combining the two produces the desired information (along with information about other files). The `-p`, `-R`, and `-d` options don't have the specified effects.
4. D. When moving from one partition or disk to another, `mv` must necessarily read and copy the file and then delete the original if that copy was successful. If both filesystems support ownership and permissions, they'll be preserved; `mv` doesn't need an explicit `--preserve` option to do this, and this preservation does not rely on having exactly the same filesystem types. Although `mv` doesn't physically rewrite data when moving within a single low-level filesystem, this approach can't work when you're copying to a separate low-level filesystem (such as from a hard disk to a pen drive); if the data isn't written to the new location, it won't be accessible should the disk be inserted in another computer.
5. A, B. If you try to create a directory inside a directory that doesn't exist, `mkdir` responds with a `No such file or directory` error. The `--parents` parameter tells `mkdir` to automatically create all necessary parent directories in such situations. You can also manually do this by creating each necessary directory separately. (It's possible that `mkdir -one` wouldn't be necessary in this example if the directory `one` already existed. No harm will come from trying to create a directory that already exists, although `mkdir` will return a `File exists` error.)
6. B, D. The `tar` and `cpio` programs are common Linux archive-creation utilities. The `restore` command restores (but does not back up) data; its backup counterpart command is `dump`, but `dump` is no longer a recommended backup tool on Linux. There is no standard `tape` command in Linux.
7. D. With the `tar` utility, the `--list (t)` command is used to read the archive and display its contents. The `--verbose (v)` option creates a verbose file listing, and `--file (f)` specifies the filename—`data79.tar` in this case. Option D uses all of these features. Options A, B, and C all substitute other commands for `--list`, which is required by the question.

8. A. Symbolic links can point across filesystems, so creating a symbolic link from one filesystem (in which your home directory resides) to another (on the CD-ROM) isn't a problem. Hard links, as in options B and C, are restricted to a single filesystem and so won't work for the described purpose. Because symbolic links will work as described, option D is incorrect.
9. D. Option D is the correct command. Typing `chown ralph:tony somefile.txt`, as in option A, sets the owner of the file to `ralph` and the group to `tony`. The `chmod` command used in option B is used to change file permissions, not ownership. Option C reverses the order of the filename and the owner.
10. C, D. The `d` character that leads the mode indicates that the file is actually a directory, whereas the `r` symbol in the `r-x` triplet at the end of the symbolic mode indicates that all users of the system have read access to the directory. Symbolic links are denoted by leading `l` characters, which this mode lacks, so option A is incorrect. Although the `x` symbols usually denote executable program files, as specified in option B, in the case of directories this permission bit indicates that the directory's contents may be searched; executing a directory is meaningless.
11. C. The set user ID (SUID) bit enables programs to run as the program's owner rather than as the user who ran them. This makes SUID root programs risky, so setting the SUID bit on root-owned programs should be done only when it's required for the program's normal functioning, as stated in option C. This should certainly *not* be done for all programs because the SUID bit is *not* required of all executable programs as option A asserts. Although the SUID root configuration does enable programs to access device files, the device files' permissions can be modified to give programs access to those files, if this is required, so option B is incorrect. Although SUID root programs are a security risk, as stated in option D, they're a necessary risk for a few programs, so option D goes too far.
12. D. Using symbolic modes, the `o+r` option adds read (`r`) permissions to the world (`o`). Thus, option D is correct. Option A sets the mode to `rw-r---x`, which is a bit odd and doesn't provide world read access to the file, although it does provide world execute access. Option B sets the mode to `rw-r-----`, which gives the world no access whatsoever to the file. Option C adds read access to the file for the owner (`u`) if the owner doesn't already have this access; it doesn't affect the world permissions.
13. D. Option D, `027`, removes write permissions for the group and all world permissions. (Files normally don't have execute permissions set, but explicitly removing write permissions when removing read permissions ensures reasonable behavior for directories.) Option A, `640`, is the octal equivalent of the desired `rw-r-----` permissions; but the `umask` sets the bits that are to be *removed* from permissions, not those that are to be set. Option B, `210`, would remove write permission for the owner, but it wouldn't remove write permission for the group, which is incorrect. This would also leave all world permissions open. Finally, option C, `022`, wouldn't remove world read permission.
14. B. Using quotas requires kernel support, the `usrquota` or `grpquota` (for user or group quotas) filesystem mount option, and activation via the `quotaon` command (which often appears in SysV startup scripts). Thus, option B is correct. Option A suggests that `quotaon` is not necessary, and option C suggests that `quotaon` is sufficient, but neither is true. The `usrquota` and `grpquota` options are both valid, so option D is incorrect.

15. B. The `repquota` utility is used to summarize the quota information about the filesystem. When used with the `-a` option, it shows this information for all filesystems. The `quotacheck` utility checks quota information about a disk and writes corrections.
16. D. The `/opt` directory tree exists to hold programs that aren't a standard part of a Linux distribution, such as commercial programs. These programs should install in their own directories under `/opt`; these directories usually have `bin` subdirectories of their own, although this isn't required. The `/usr/sbin` directory holds programs that are normally run only by the system administrator, and `/bin` holds critical basic binary files. The `/etc/X11` directory holds X-related configuration files. None of these directories is an appropriate place for a spreadsheet program.
17. A. The `find` utility operates by searching all files in a directory tree, and so it's likely to take a long time to search all of a computer's directories. The `locate` program uses a pre-compiled database, and `whereis` searches a limited set of directories, so these commands will take less time.
18. C. The `type` command identifies a command, as executed by the shell, as being a built-in shell command, a shell alias, or an external command, whereas the `whereis` command helps find the location of external command files. Neither `type` nor `whereis` identifies the CPU architecture of a program file, can locate commands based on intended purpose, or complete an incompletely typed command.
19. B. The `find` command includes the ability to search by username using the `-user name` option, where `name` is the username; thus, option B is correct. The `-uid` option to `find` can also locate files owned by a user; but it takes a numeric user ID (UID) number as an argument, so option A isn't quite correct. The `locate` command provides no ability to search by user, so options C and D are incorrect.
20. D. The `which` program searches the path just as `bash` does, but it prints the path to the first executable program it finds on the path. Thus, option D is correct. The `which` program doesn't conduct an exhaustive search of the system, so there could be many more files called `man` on the system, contrary to option A. System package tools and `which` aren't closely related; option B is incorrect. Although `/usr/bin/man` would be run when the user whose `which` output matches that in the question types `man`, this may not be true of others because the path can vary from one user to another. Thus, option C is incorrect.

Chapter 5

Booting Linux and Editing Files

THE FOLLOWING LINUX PROFESSIONAL INSTITUTE OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ 1.101.2: Boot the system (weight: 3)
- ✓ 1.101.3: Change runlevels and shutdown or reboot system (weight: 3)
- ✓ 1.102.2: Install a boot manager (weight: 2)
- ✓ 1.103.8: Perform basic file editing operations using vi (weight: 3)





So far, this book has dealt largely with a running Linux system, but from time to time, you'll need to boot Linux. Ordinarily this process is a painless one: You press the power button, wait a couple of minutes, and see a Linux login prompt. Sometimes, though, you'll have to intervene in this process in one way or another.

Linux boot loaders can be configured to boot Linux with particular options and even to boot other operating systems, so knowing how to configure them and use them can help you to accomplish your boot-related goals. Once the system is booted, you should know how to study log files related to the boot process. This can help you to diagnose problems or verify that the system is operating the way it should be.

Finally, this chapter looks at editing files with Vi. Vi isn't particularly boot-related, knowing how to edit files is vital to many administrative tasks, including editing the boot loader configuration files.

Installing Boot Loaders

Hard disks contain more than partitions and their contents. One very small part of the disk is unusually important: The *master boot record (MBR)* contains the partition table and a *boot loader* (also sometimes called a *boot manager*). The boot loader is the software that the BIOS reads and executes when the system begins to boot. The boot loader, in turn, is responsible for loading the Linux kernel into memory and starting it running. Thus, configuring a hard disk (or at least your boot hard disk) isn't complete until the boot loader is configured. Although Linux distributions provide semi-automated methods of configuring a boot loader during system installation, you may need to know more, particularly if you recompile your kernel or need to set up an advanced configuration—say, one to select between several OSs.

In practice, two boot loaders are important in Linux: the *Linux Loader (LILO)* and the *Grand Unified Boot Loader (GRUB)*. LILO is older, and it's slowly being replaced by GRUB as the most common Linux boot loader, but LILO is still common.

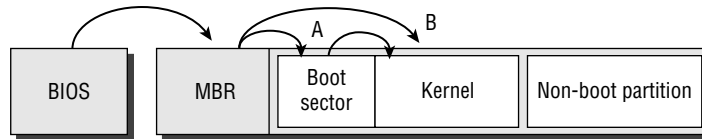


LILO and GRUB are both x86 and x86-64 boot loaders. Other platforms have their own boot loaders. Some of these are similar to LILO in operation (and may even be called LILO), but they aren't quite identical. You should consult platform-specific documentation if you need to reconfigure a non-x86 boot loader.

Boot Loader Principles

The *x86* and *x86-64* boot process can be a bit convoluted, in part because so many options are available. Figure 5.1 depicts a typical configuration, showing a couple of possible boot paths. In both cases, the boot process begins with the BIOS. As described in Chapter 3, “Configuring Hardware,” you tell the BIOS which boot device to use—a hard disk, a floppy disk, a CD-ROM drive, or something else. Assuming you pick a hard disk as the primary boot device, or if higher-priority devices aren’t bootable, the BIOS loads code from the MBR. This code is the primary boot loader code. In theory, it could be just about anything, even a complete (if tiny) OS.

FIGURE 5.1 The *x86* boot system provides several options for redirecting the process, but ultimately an OS kernel is loaded.



In practice, the primary boot loader does one of two things:

- It examines the partition table and locates the partition that’s marked as bootable. The primary boot loader then loads the boot sector from that partition and executes it. This boot sector contains a secondary boot loader, which continues the process by locating an OS kernel, loading it, and executing it. This option is depicted by the A arrows in Figure 5.1.
- It locates an OS kernel, loads it, and executes it directly. This approach bypasses the secondary boot loader entirely, as depicted by the B arrow in Figure 5.1.

Traditionally, *x86* systems running DOS or Windows follow path A. DOS and Windows 9x/Me ship with very simple boot loaders that provide little in the way of options. Windows NT/200x/XP/Vista provides a boot loader that can provide limited redirection in the second stage of the A path.

Linux’s boot loaders, LILO and GRUB, are both much more flexible. They support installation in either the MBR or the boot sector of a boot partition. Thus, you can either keep a DOS/Windows-style primary boot loader and direct the system to boot a kernel from a boot sector installation (path A) or bypass this step and load the kernel straight from the MBR (path B). The first option has the advantage that another OS is unlikely to wipe out LILO or GRUB, because it’s stored safely in a Linux partition. Windows has a tendency to write its standard MBR boot loader when it’s installed, so if you need to re-install Windows on a dual-boot system, this action will wipe out an MBR-based boot loader. If the boot loader is stored in a Linux partition’s boot sector, it will remain intact, although Windows might configure the system to bypass it. To reactivate the Linux boot loader, you must use a tool such as the DOS/Windows FDISK to mark the Linux partition as the boot partition.

A drawback of placing LILO or GRUB in a partition's boot sector is that this partition must normally be a primary partition. (An exception is if you're using some other boot loader in the MBR or in another partition. If this third-party boot loader can redirect the boot process to a logical partition, this restriction goes away.) For this reason, many people prefer to put LILO or GRUB in the hard disk's MBR.

In the end, both approaches work, and for a Linux-only installation, the advantages and disadvantages of both approaches are very minor. Some distributions don't give you an option at install time. For them, you should review your boot loader configuration and, when you must add a kernel or otherwise change the boot loader, modify the existing configuration rather than try to create a new one.



Both LILO and GRUB can be installed to a floppy disk as well as to a hard disk. Even if you don't want to use a floppy disk as part of your regular boot process, you may want to create an emergency floppy disk with LILO or GRUB. You can then use it to boot Linux if something goes wrong with your regular LILO or GRUB installation.

This description provides a somewhat simplified view of boot loaders. LILO and GRUB are both much more complex than this. They can redirect the boot process to non-Linux boot sectors and present menus that enable you to boot multiple OSs or multiple Linux kernels. You can chain several boot loaders, including third-party boot loaders such as System Commander or BootMagic. Chaining boot loaders in this way enables you to take advantage of unique features of multiple boot loaders, such as the ability of System Commander to boot several versions of DOS or Windows on a single partition.



LPI objective 102.2 mentions the superblock. Despite its placement in an objective about boot loaders, the superblock isn't really a boot loader concept; rather, it's part of the filesystem. The superblock describes basic filesystem features, such as the filesystem's size and status. The `debugfs` and `dumpe2fs` commands, described in Chapter 3, provide some basic superblock information.

Using LILO as the Boot Loader

LILO was once the default boot loader for Linux on the x86 architecture. Although LILO has since been usurped in popularity by GRUB, it's still a small, useful boot loader. To use LILO, you must configure it and install it in your boot sector. Once it's installed, you can reboot the computer and tell LILO which OS or kernel you want to boot.



The term *LILO* can denote one of two things. The uppercase LILO refers to the boot loader that is installed into your boot sector. The lowercase `lilo` refers to the program that is used to install the LILO boot loader.

Configuring LILO

You configure LILO using the `/etc/lilo.conf` file. This file is generally broken into two main sections: global and per-image options. (The latter are kept in sections known as *stanzas*.) Some per-image options are further separated depending on whether they're for a Linux kernel or another OS. To further confound the matter, many of the per-image options may be used at the global level to indicate a default value.

Essential LILO Global Options

Listing 5.1 shows a typical `/etc/lilo.conf` file, including both global options and three stanzas for booting two Linux kernels and a non-Linux OS. Most configuration lines take the form *option* or *option=value*, but lines that begin with hash marks (`#`) are comments and are ignored. All but the first line of each stanza are traditionally indented. This practice makes it easy to spot where a new stanza begins.

Listing 5.1: A Typical LILO Configuration File

```
# lilo.conf
#
# Global Options:
#
boot=/dev/hda
prompt
timeout=150
default=fedora
lba32
vga=normal
root=/dev/hda5
read-only
#
# Kernel Options (may have multiple):
#
image=/boot/vmlinuz-2.6.25
    label=fedora
    initrd=/boot/initrd-2.6.25
    append="mem=2048M"
image=/boot/bzImage-2.6.26-experimental
    label=debian
    root=/dev/hda6
#
# Other Operating Systems Options (may have multiple):
#
other=/dev/hda2
    label=dos
```



The system described by Listing 5.1 contains DOS, Fedora Linux, and Debian GNU/Linux. DOS resides on `/dev/hda2`, Fedora Linux resides on `/dev/hda5`, and Debian GNU/Linux resides on `/dev/hda6`. Fedora and Debian share a separate `/boot` partition, `/dev/hda1`.

The `lilo.conf` file supports many options. Most of these are fairly obscure; chances are you'll only need to use a handful of them in order to achieve specific common goals:

Boot loader location The `boot=` option specifies the name of the device that contains the boot sector (`/dev/hda` in the case of Listing 5.1). In this example, the MBR of the first PATA hard drive is used as the boot sector. In this configuration, LILO functions as the primary boot loader—it's the first one loaded by the BIOS. If you wanted LILO to reside in a partition on `/dev/hda`, you would give a specific partition identifier, such as `/dev/hda1`. In this configuration, the BIOS would load a standard x86 MBR boot loader, which would then load LILO.

Default stanza The `default=` setting specifies the default kernel or OS that boots. If this option is omitted, the first image listed in `lilo.conf` is used as the default.

Boot prompt The `prompt` line instructs LILO to issue the `boot: prompt` and wait for user input. This option is usually desirable, but it can be omitted if you want the system to directly boot a single configuration.

Boot timeout The `timeout=` setting specifies the amount of time, in tenths of a second, that LILO will wait for keyboard input before booting the default kernel image. You must use the `prompt` option to enable the timeout. Listing 5.1's setting of 150 indicates a 15-second timeout.

Large disk support The `lba32` option enables LILO to boot from disks where the kernel image resides on a partition that is past the 1,024th cylinder. This option is almost always desirable, but you may omit it if you're using a very old computer.

Video options The `vga=` line selects the VGA text mode that is used when booting. Choices include `normal`, `extended`, `ask`, and a number. Unless you're having problems with the video display during the boot process, you should probably leave this alone.

Linux root partition The `root=` option's value is passed to the Linux kernel to tell it what partition to use as its root (`/`) partition. You can set a default value for this option and override it in individual stanzas, as Listing 5.1 does.

Boot in read-only mode The `read-only` option indicates that the root filesystem should be mounted read-only. Usually, the operating system will remount the filesystem to read-write.



Want to password-protect your booting process? Look into the `password`, `restricted`, `mandatory`, and `bypass` options, which are documented in the man page for `lilo.conf`. Modern BIOSs also provide password protection.

Essential LILO Per-image Options

LILO supports two main types of stanzas: those for Linux kernels and those for other OSs. The `image=` option is used to indicate a Linux kernel, and the `other=` option is used to indicate some other OS. Either type of line begins a stanza, and subsequent lines are conventionally indented until the next stanza or the end of the file. You may want to adjust several types of per-image options:

Linux boot image The `image=` line indicates the Linux kernel file to use when booting. You must pass the complete path to the Linux kernel image file.

Non-Linux boot partition An `other=` line indicates the partition that contains its own boot loader. When this option is selected, LILO passes control to the boot loader in that partition. DOS, Windows, OS/2, BeOS, FreeBSD, and other OSs can all place their own boot loaders in their partitions, so this tool enables you to pass control to these OSs.

OS label The `label=` option provides a name for LILO to use. When you boot, you type the name of the label or press the Tab key to get a list of available labels, as described later in “Interacting with LILO.”

RAM disk The `initrd=` line points to an initial RAM disk. This is a small filesystem in a file that the boot loader loads into memory and delivers to the kernel as a RAM-based substitute for a disk drive. Linux distributions frequently use RAM disks like this to store kernel drivers as a way of keeping the kernel size down while still supporting a wide range of drivers. When you build your own kernel, it’s usually simpler to build drivers that are necessary to the boot process (such as those for your hard disk controller and the root filesystem) into the main kernel file.

Extra kernel options You can pass arbitrary options to the kernel with the `append=` option. For instance, Listing 5.1’s `fedora` stanza passes the `mem=2048M` option to the kernel in this way. (This specific option tells the computer that it has 2048MB of RAM. Linux usually detects available RAM correctly, but sometimes this or some other option is necessary.)

In addition, some of the options described in the section “Essential LILO Global Options” can be used in per-image stanzas. In particular, `vga=`, `root=`, and `read-only` are often found in per-image stanzas. If they aren’t used in stanzas, the global options apply.

Adding a Kernel to LILO

To add a new kernel to LILO, follow these steps as `root`:

1. Load `/etc/lilo.conf` into your favorite text editor.
2. Copy a working Linux stanza.
3. In the copied stanza, modify the `label=` line to give the copy a new name. The name should be a string of letters, numbers, or both, without spaces.
4. Change the `image=` line to point to the new kernel file.
5. Change any other options that may need changing. For instance, if you’ve prepared a new RAM disk, change the `initrd=` line to point to it. If your new configuration doesn’t use a RAM disk, you can eliminate any `initrd=` line that’s present in the stanza.

6. Save your changes, and exit the text editor.
7. At a root command prompt, type `lilo`. This command installs LILO in the MBR or boot partition's boot sector. You should see a list of stanza names echo to the screen. Ensure that your new configuration is present.



Remember to perform step 7! It's easy to overlook this step, and if you do so, your changes won't take effect. If you forget and reboot before typing `lilo`, you should boot using a working kernel, log in as root, type `lilo`, and reboot again.

A similar procedure can be used to add a new non-Linux OS, but you would then copy and modify a working `other=` configuration (or copy the one shown in Listing 5.1).



Don't remove old `image=` or `other=` configurations until you're certain the new images are working. This will allow you to boot to the old kernel image in case of failure. Another alternative is to install LILO with your new configuration onto a temporary device such as a floppy disk or a USB memory stick. To do this, change the `boot=` line to point to the test boot device, such as `boot=/dev/fd0` to install LILO to a floppy disk.

You can pass some options to `lilo` to modify what it does:

Specify an alternate configuration file The `-C config-file` option specifies an alternate configuration file to use rather than `/etc/lilo.conf`.

Test the configuration The `-t` option tests the configuration; it doesn't write anything to the boot sector.

Produce verbose output The `-v` option produces verbose output when `lilo` is run. This is useful with the `-t` option to see how your changes will work out.

Specify a boot device The `-b bootdev` option specifies a boot device, overriding the `boot=` option in `lilo.conf`.



It's possible to install a new LILO boot loader and still have it fail when you try to use it. The `lilo` man page describes the errors that may occur. LILO prints the letters L, I, L, and O to indicate how it's progressing.

Interacting with LILO

Sometimes you'll need to boot with options that you didn't place in the `/etc/lilo.conf` file. If you've configured LILO to provide a `boot:` (or sometimes `lilo:`) prompt, you can pass extra options to the boot loader on that command line.

One thing you may wish to do is boot into single-user mode. Assuming that the image you want to use is called `linux`, you can type something like this:

```
boot: linux 1
```



Instead of supplying the number 1 for single-user mode, you can specify the letter `s` or `S` or the word `single`.

It's also possible that your `init` program (usually `/sbin/init`) is corrupt, missing, or incorrectly configured. At times like this, it's possible to specify an alternate `init` program. A common technique is to use a regular shell program like `bash` in place of `init`. You do so at the `boot:` prompt like this:

```
boot: linux init=/bin/sh
```

Using GRUB as the Boot Loader

GRUB has taken over as the default boot loader for many Linux distributions because it offers numerous features that LILO lacks. For example, you don't have to reinstall GRUB after editing its configuration, and you have many more interactive options while booting. As with LILO, you must still explicitly add a new kernel to the GRUB configuration if you intend to use that kernel. If GRUB isn't installed in your boot sector, you must also install it, although this step isn't necessary if GRUB is already working. As with LILO, you can interact with GRUB during the boot process, passing options to control how the system boots.

Configuring GRUB

The usual location for GRUB's configuration file is `/boot/grub/menu.lst`. Some distributions (such as Fedora, Red Hat, and Gentoo) use the filename `grub.conf` rather than `menu.lst`. GRUB can read its configuration file at boot time, which means you needn't reinstall the boot loader to the boot sector when you change the configuration file. As with LILO, the GRUB configuration file is broken into global and per-image sections, each of which has its own options. Before getting into section details, though, you should understand a few GRUB quirks.

GRUB Nomenclature and Quirks

Listing 5.2 shows a sample GRUB configuration file. This file is roughly equivalent to the LILO configuration file shown in Listing 5.1. In particular, it can boot the same OSs using the same kernels—Fedora on `/dev/hda5`, Debian on `/dev/hda6`, and DOS on `/dev/hda2`. Fedora and Debian share a `/boot` partition (`/dev/hda1`), on which the GRUB configuration resides.

Listing 5.2: A Sample GRUB Configuration File

```
# grub.conf/menu.lst
#
# Global Options:
#
default=0
timeout=15
splashimage=/grub/bootimage.xpm.gz
#
# Kernel Image Options:
#
title Fedora (2.6.25)
    root (hd0,0)
    kernel /vmlinuz-2.6.25 ro root=/dev/hda5 mem=2048M
    initrd /initrd-2.6.25
title Debian (2.6.26-experimental)
    root (hd0,0)
    kernel (hd0,0)/bzImage-2.6.26-experimental ro root=/dev/hda6
#
# Other operating systems
#
title DOS
    rootnoverify (hd0,1)
    chainloader +1
```

GRUB doesn't refer to disk drives by device filename the way Linux does. GRUB numbers drives so that instead of `/dev/hda`, GRUB uses `(hd0)`. Similarly, `/dev/hdb` is likely to be `(hd1)`. GRUB doesn't distinguish between PATA, SATA, and SCSI drives, so on a SCSI-only system, the first SCSI drive is `(hd0)`. On a mixed system, ATA drives normally receive the lower numbers, although this isn't always the case. GRUB's drive mappings can be found in the `/boot/grub/device.map` file.

Additionally, GRUB numbers partitions on a drive starting at 0 instead of the 1 that is used by Linux. GRUB separates partition numbers from drive numbers with a comma, as in `(hd0,0)` for the first partition on the first disk (normally Linux's `/dev/hda1` or `/dev/sda1`) or `(hd0,4)` for the first logical partition on the first disk (normally Linux's `/dev/hda5` or `/dev/sda5`). Floppy devices are referred to as `(fd0)`, or conceivably `(fd1)` or higher if you have more than one floppy drive. Floppy disks aren't partitioned, so they don't receive partition numbers.

GRUB defines its own root partition, which can be different from the Linux root partition. GRUB's root partition is the partition in which GRUB's configuration file (`menu.lst` or `grub.conf`) resides. Because this file is normally in Linux's `/boot/grub/` directory, the GRUB root partition will be the same as Linux's root partition if you do *not* use a separate

/boot or /boot/grub partition. If you split off /boot into its own partition, as is fairly common, GRUB's root partition will be the same as Linux's /boot partition. You must keep this difference in mind when referring to files in the GRUB configuration directory.

Essential Global GRUB Options

GRUB's global section precedes its per-image configurations. Typically, you'll find fewer options in this global section than in a LILO global configuration:

Default OS The `default=` option tells GRUB which OS to boot. Listing 5.2's `default=0` causes the first listed OS to be booted (remember, GRUB indexes from 0). If you want to boot the second listed operating system, use `default=1`, and so on through all your OSs.

Timeout The `timeout=` option defines how long, in seconds, to wait for user input before booting the default operating system. Note that GRUB measures its timeout period in seconds, whereas LILO uses tenths of a second.

Background graphic The `splashimage=` line points to a graphics file that's displayed as the background for the boot process. This line is optional, but most Linux distributions point to an image to spruce up the boot menu. The filename reference is relative to the GRUB root partition, so if /boot is on a separate partition, that portion of the path is omitted. Alternatively, the path may begin with a GRUB device specification, such as `(hd0,5)` to refer to a file on that partition.

Essential GRUB Per-Image Options

GRUB's per-image options are typically indented after the first line, much like LILO's, but this is a convention, not a requirement of the file format. The options begin with an identification and continue with options that tell GRUB how to handle the image:

Title The `title` line begins a per-image stanza and specifies the label to display when the boot loader runs. Unlike LILO's `label` option, the GRUB `title` can accept spaces and is conventionally much more descriptive, as shown in Listing 5.2.

GRUB root The `root` option specifies the location of GRUB's root partition. This is the /boot partition if a separate one exists; otherwise it's usually the Linux root (/) partition. GRUB *can* reside on a FAT partition, on a floppy disk, or on certain other OSs' partitions, though, so GRUB's root could conceivably be somewhere more exotic.

Kernel specification The `kernel` setting describes the location of the Linux kernel as well as any kernel options that are to be passed to it. Paths are relative to GRUB's root partition. As an alternative, you can specify devices using GRUB's syntax, such as `kernel (hd0,5)/vmlinuz ro root=/dev/hda5`. Note that you pass most kernel options on this line. LILO splits off kernel options on separate lines, such as the `append=` line, the `root=` line, and the `read-only` option. In GRUB, you incorporate these options onto the `kernel` line. The `ro` option tells the kernel to mount its root filesystem read-only (it's later remounted read/write), and the `root=` option specifies the *Linux* root filesystem. Because these options are being passed to the kernel, they use Linux-style device identifiers, when necessary, unlike other options in the GRUB configuration file.

Initial RAM disk Use the `initrd` option to specify an initial RAM disk, much like the option of the same name in LILO.

Non-Linux root The `rootnoverify` option is similar to the `root` option except that GRUB won't try to access files on this partition. It's used to specify a boot partition for OSs for which GRUB can't directly load a kernel, such as DOS and Windows.

Chain loading The `chainloader` option tells GRUB to pass control to another boot loader. Typically, it's passed a `+1` option to load the first sector of the root partition (usually specified with `rootnoverify`) and to hand over execution to this secondary boot loader.

To add a kernel to GRUB, follow these steps:

1. As `root`, load the `menu.lst` or `grub.conf` file into a text editor.
2. Copy a working configuration for a Linux kernel.
3. Modify the `title` line to give your new configuration a unique name.
4. Modify the `kernel` line to point to the new kernel. If you need to change any kernel options, do so.
5. If you're adding, deleting, or changing a RAM disk, make appropriate changes to the `initrd` line.
6. If desired, change the global `default` line to point to the new kernel.
7. Save your changes, and exit the text editor.

At this point, GRUB is configured to boot your new kernel. When you reboot, you should see it appear in your menu, and you should be able to boot it. If you have problems, boot a working configuration to debug the issue.



Don't eliminate a working configuration for an old kernel until you've determined that your new kernel works correctly.

Installing the GRUB Boot Loader

Installation of GRUB is a little different than for LILO. The command for installing GRUB is `grub-install`. Also, you must specify the boot sector by device name when you install the boot loader. The basic command looks like

```
# grub-install /dev/hda
```

or

```
# grub-install '(hd0)'
```

Either command will install GRUB into the first sector (or the MBR) of your first hard drive. In the second example, you need single quotes around the device name. If you want to install GRUB in the boot sector of a partition rather than in the MBR, you include a partition identifier, as in `/dev/hda1` or `(hd0,0)`.

Remember that you do *not* need to reinstall GRUB after making changes to its configuration file! You only need to install GRUB this way if you make certain changes to your disk configuration, such as resizing or moving the GRUB root partition, moving your entire installation to a new hard disk, or possibly reinstalling Windows (which tends to wipe out MBR-based boot loaders). In some of these cases, you may need to boot Linux via a backup boot loader, such as LILO or GRUB installed to floppy disk. (Type `grub-install /dev/fd0` to create one, and then label it and store it in a safe place.)



Real World Scenario

Using Third-Party Boot Loaders

LILO, GRUB, and the basic DOS/Windows boot loaders aren't the only ones available. Products such as System Commander (<http://avanquest.com>) and GAG (<http://gag.sourceforge.net>) provide alternatives to LILO and GRUB. Some of these products, though, can't directly boot Linux; instead, they function as primary boot loaders that then call LILO or GRUB, which must be installed as secondary boot loaders on a Linux partition's MBR.

Why would you want to do this? The main reason is that these third-party boot loaders sometimes provide features that LILO and GRUB lack. For instance, System Commander enables you to boot multiple copies of DOS or Windows from a single partition, which can help you get around problems related to the limited number of primary partitions available on x86 computers. GAG provides GUI menus that may be less intimidating to some users than the text-mode menus of GRUB, or especially LILO. In any event, you can either implement a two-tiered boot system that employs both the third-party boot loader's OS options and redundant or unique options in LILO or GRUB; or you can configure LILO or GRUB to immediately boot your preferred kernel. Which approach is appropriate depends on your specific needs.

Another boot loader that deserves mention is LOADLIN. This boot loader is actually an ordinary DOS program. If you place a Linux kernel on a FAT partition, you can boot to DOS and use LOADLIN to boot Linux. This practice used to be common, particularly for emergency recovery situations, but GRUB and native Linux emergency recovery tools have become sophisticated enough that LOADLIN is seldom required. Nonetheless, it can still be handy as an emergency boot option if you happen to have DOS installed or available.

Non-x86 platforms have their own boot loaders, such as BootX (<http://penguinppc.org/bootloaders/bootx/>) on PowerPC-based Macs. You may need to consult your distribution's documentation to learn about such boot loaders, if you're using Linux on a non-x86 computer.

Interacting with GRUB

The first screen the GRUB boot loader shows you is a list of all the operating systems you specified with the `title` option in your GRUB configuration file. You can wait for the time-out to expire for the default operating system to boot. To select an alternative, use your arrow keys to highlight the operating system that you want to boot. Once your choice is highlighted, press the Enter key to start booting.

Follow these steps when you want to change or pass additional options to your operating system:

1. Use your arrow keys to highlight the operating system that most closely matches what you want to boot.
2. Press the E key to edit this entry. You'll see a new screen listing all the options for this entry.
3. Use your arrow keys to highlight the `kernel` option line.
4. Press the E key to edit the kernel options.
5. Edit the `kernel` line to add any options, such as `1` to boot to single-user mode. GRUB passes the extra option to the kernel.
6. Press the Enter key to complete the edits.
7. Press the B key to start booting.

You can make whatever changes you like in step 5, such as using a different `init` program. You do this by appending `init=/bin/bash` (or whatever program you want to use) to the end of the `kernel` line.

Understanding the Boot Process

Any time you modify the way your computer boots, the possibility exists that you won't get the results you expect. In these cases, it's useful to know where you can turn for more information about what is happening during startup. The reports you receive on a particular boot can better guide you once you understand something about what's *supposed* to happen when a Linux system boots.

Extracting Information about the Boot Process

Certain Linux kernel and module log information is stored in what is called the *kernel ring buffer*. By default, Linux displays messages destined for the kernel ring buffer during the boot process—they're those messages that scroll past too quickly to read. (Some distributions hide all but the earliest of these messages unless you select a special option during the boot process.) You can inspect this information with this command:

```
# dmesg
```

This command generates a lot of output, so you may want to pipe it through the `less` pager or redirect it to a file. Here are some examples of these commands:

```
# dmesg | less
# dmesg > boot.messages
```



Many Linux distributions store the kernel ring buffer to `/var/log/dmesg` soon after the system boots. Because new information is logged to the kernel ring buffer as the system operates, and because the kernel ring buffer's size is finite, you may need to consult this log file to learn about the boot process once the system has been operating for a while.

Another source of logging information is the system logger (`syslogd`). The most useful `syslogd` file to look at is usually `/var/log/messages`, but `/var/log/syslog` and other log files in `/var/log` can also hold helpful information.



Some Linux distributions also log boot-time information to other files. Debian uses a daemon called `bootlogd` that, by default, logs any messages that go to `/dev/console` to the `/var/log/boot` file. Fedora and Red Hat use `syslogd` services to log information to `/var/log/boot.log`.

Locating and Interpreting Boot Messages

Boot messages in the kernel ring buffer or `/var/log` files can be cryptic to the uninitiated. Some tips can help you locate and interpret the information you find in these sources:

Use `less` and its search functions The `less` pager is a great tool for examining both the kernel ring buffer and log files. The search function (accessed by pressing the slash key, `/`) can help you look for particular strings.

Look for hardware type names Many boot messages, particularly in the kernel ring buffer, relate to hardware. Try searching for the name of the hardware type, such as SCSI or USB, if you're having problems with these subsystems. Remember that Linux treats many disk devices as SCSI disks, too!

Look for hardware chipset names Linux drivers sometimes log messages along with their driver names, which are usually based on the chipset in question. If you know your hardware well enough to know the chipset name, search for it, or for a subset of it. For instance, searching for 8169 may turn up messages related to a RealTek 8169 Ethernet interface. Similarly, you can search for higher-level kernel module names, such as `ReiserFS` for messages from the ReiserFS filesystem driver.

Study the output from a working system Familiarize yourself with the contents of the kernel ring buffer and log files on a working system. If you know what to expect when a system is functioning correctly, you'll find it easier to identify problems when they occur.

Sometimes, a system won't boot at all. In this case, kernel boot messages (which ordinarily go into the kernel ring buffer) are displayed on the screen, which can help you identify the cause of a failure. Many modern Linux distributions hide these messages by default, but you can sometimes reveal them by pressing the Esc key during the boot process. Once the kernel boot process has completed, other systems take over, and the last few messages displayed on the screen can also provide clues—for instance, if the last message displayed mentions starting a particular server, it's possible that the server is hanging and interrupting the boot process. You may be able to disable the server by using a single-user boot mode and therefore bypass the problem.

The Boot Process

The process of taking an x86 computer from its initial state when the power is turned on to having a working operating system running is complex due to the way modern personal computers have evolved. The steps a computer goes through in order to boot an operating system are as follows:

1. The system is given power, and a special hardware circuit causes the CPU to look at a predetermined address and execute the code stored in that location. The BIOS resides at this location, so the CPU runs the BIOS.
2. The BIOS code performs some tasks. These include checking for hardware, configuring hardware, and looking for a boot sector. This boot sector contains the boot loader. (If the computer uses a multi-staged loader, the boot sector's boot loader is called the primary boot loader).
3. When the boot loader takes over from the BIOS, if it's a multi-staged loader, it looks for a secondary loader. Some boot loaders go straight to a secondary loader in a hard drive's *active partition*. Other boot loaders, like LILO and GRUB, can do much more, as just described.



Active partitions are simply partitions that are marked with a special flag. Some boot loaders and OSs, such as DOS and Windows, use the active flag as a way of determining which OS to boot. Linux and its boot loaders ignore the active flag for most purposes. That doesn't stop Linux from being able to mark a partition as active. Use disk partitioning tools such as `fdisk`, `cdisk`, and `sfdisk` for this task. Each hard drive should have only one active partition.

4. The final goal of the boot loader is to find a kernel (Linux or otherwise), load it into memory, and execute it.
5. Once the Linux kernel takes over, it performs tasks such as initializing devices, mounting the root partition, and finally loading and executing the initial program for your system. By default, this is the program `/sbin/init`.

6. The initial program gets the process ID (PID) of 1 because it's the first program to run on the system. Assuming that `/sbin/init` is the initial program, it reads a file called `/etc/inittab` to determine what other programs to run. Other programs usually include `getty` programs for console logins, system initialization scripts for mounting more partitions or starting up system services, and an X Display Manager (XDM) program to give you a graphical login.

How the `init` program and the initialization scripts work is covered next, in “Dealing with Runlevels and the Initialization Process.”



If you would like more details about this boot process, read http://www.linuxdevcenter.com/pub/a/linux/excerpts/linux_kernel/how_computer_boots.html. This page describes the process from the computer being powered up to the kernel being loaded and launching `/sbin/init`.

Dealing with Runlevels and the Initialization Process

Linux relies on *runlevels* to determine what features are available. Runlevels are numbered from 0 to 6, and each one is assigned a set of services that should be active. Upon booting, Linux enters a predetermined runlevel, which you can set. Knowing what these functions are, and how to manage runlevels, is important if you're to control the Linux boot process and ongoing operations. Toward this end, you must understand the purpose of runlevels, be able to identify the services that are active in a runlevel, be able to adjust those services, be able to check your default and current runlevels, and be able to change the default and current runlevels.

Runlevel Functions

Earlier in this chapter, I described single-user mode. To get to this mode when booting Linux, you use the number 1, the letter `S` or `s`, or the word `single` as an option passed to the kernel by the boot loader. Single-user mode is simply an available runlevel for your system. The available runlevels on most systems are the numbers 0 through 6. The letters `S` and `s` are synonymous with runlevel 1 as far as many utilities are concerned.

Runlevels 0, 1, and 6 are reserved for special purposes; the remaining runlevels are available for whatever purpose you or your Linux distribution provider decide. Table 5.1 summarizes the conventional uses of the runlevels. Other assignments—and even runlevels outside the range of 0 to 6—are possible, but such configurations are rare. (Gentoo uses an unusual

runlevel system, as described shortly.) If you run into peculiar runlevel numbers, consult `/etc/inittab`—it defines them and often contains comments explaining the various runlevels.

TABLE 5.1 Runlevels and Their Purposes

Runlevel	Purpose
0	A transitional runlevel, meaning that it's used to shift the system from one state to another. Specifically, it shuts down the system. On modern hardware, the system should completely power down. If not, you're expected to either reboot the computer manually or power it off.
1, s, or S	Single-user mode. What services, if any, are started at this runlevel varies by distribution. It's typically used for low-level system maintenance that may be impaired by normal system operation, such as resizing partitions.
2	On Debian and its derivatives, a full multi-user mode with X running and a graphical login. Most other distributions leave this runlevel undefined.
3	On Fedora, Mandriva, Red Hat, and most other distributions, a full multi-user mode with a console (non-graphical) login screen.
4	Usually undefined by default and therefore available for customization.
5	On Fedora, Mandriva, Red Hat, and most other distributions, the same behavior as runlevel 3 with the addition of having X run with an XDM (graphical) login.
6	Used to reboot the system. This runlevel is also a transitional runlevel. Your system is completely shut down, and then the computer reboots automatically.



Don't configure your default runlevel to 0 or 6. If you do, your system will immediately shut down or reboot once it finishes powering up. Runlevel 1 could conceivably be used as a default, but chances are you'll want to use 2, 3, or 5 as your default runlevel, depending on your distribution and use for the system.

As a general rule, distributions have been drifting toward Red Hat's runlevel set; however, there are some exceptions and holdouts, such as Debian. Gentoo also deserves special attention. Although it uses numbered runlevels at its core, Gentoo builds on this by enabling an arbitrary number of *named* runlevels. The default runlevel is called, appropriately enough, `default`. Gentoo's system permits you to create named runlevels for, say, connecting a laptop to half a dozen different networks, each with its own unique network configuration requirements. When you move from one network to another, enter the appropriate runlevel, as described later in "Changing Runlevels on a Running System."

Identifying the Services in a Runlevel

There are two main ways to affect what programs run when you enter a new runlevel. The first is to add or delete entries in your `/etc/inittab` file. A typical `/etc/inittab` file contains many entries, and except for a couple of special cases, inspecting or changing the contents of this file is best left to experts. Once all the entries in `/etc/inittab` for your runlevel are executed, your boot process is complete and you can log in.



Linux distributions are moving away from `/etc/inittab` as a startup control file. The new system uses entries in `/etc/event.d` to control `init`'s startup sequence. Most distributions still use `/etc/inittab` to specify the default runlevel, though. Ubuntu Linux is an exception to this rule; it has no `/etc/inittab` file by default. If you want to change your default runlevel in Ubuntu, you can create an `/etc/inittab` file that contains nothing but the `initdefault` line described shortly.

Basics of the `/etc/inittab` File

Entries in `/etc/inittab` follow a simple format. Each line consists of four colon-delimited fields:

```
id:runlevels:action:process
```

Each of these fields has a specific meaning:

Identification code The *id* field consists of a sequence of 1–4 characters that identifies its function.

Applicable runlevels The *runlevels* field consists of a list of runlevels for which this entry applies. For instance, 345 means the entry is applicable to runlevels 3, 4, and 5.

Action to be taken Specific codes in the *action* field tell `init` how to treat the process. For instance, `wait` tells `init` to start the process once when entering a runlevel and to wait for the process's termination, and `respawn` tells `init` to restart the process whenever it terminates (which is great for login processes). Several other actions are available; consult the man page for `inittab` for details.

Process to run The *process* field is the process to run for this entry, including any options and arguments that are required.

The part of `/etc/inittab` that tells `init` how to handle each runlevel looks like this:

```
# grep "rc [0-6]" /etc/inittab
l0:0:wait:/etc/init.d/rc 0
l1:1:wait:/etc/init.d/rc 1
l2:2:wait:/etc/init.d/rc 2
l3:3:wait:/etc/init.d/rc 3
```

```
l4:4:wait:/etc/init.d/rc 4
l5:5:wait:/etc/init.d/rc 5
l6:6:wait:/etc/init.d/rc 6
```

These lines start with codes that begin with an *l* (a lowercase letter *L*, not a number 1) followed by the runlevel number—for instance, *l0* for runlevel 0, *l1* for runlevel 1, and so on. These lines specify scripts or programs that are to be run when the specified runlevel is entered. In the case of this example (which was taken from a Fedora 6 system), all the scripts are the same (`/etc/init.d/rc`), but the script is passed the runlevel number as an argument. Some distributions call specific programs for certain runlevels, such as `shutdown` for runlevel 0.



The upcoming section “Checking and Changing Your Default Runlevel” describes how to tell `init` what runlevel to enter when the system boots.

On systems that use the new startup system based on `/etc/event.d`, you’ll find equivalent startup information in the form of scripts in `/etc/event.d`. For instance, `/etc/event.d/rc3` controls entry into runlevel 3. This script in turn runs the SysV startup scripts for runlevel 3, as described next.

The SysV Startup Scripts

The `/etc/init.d/rc` or `/etc/rc.d/rc` script performs the crucial task of running all the scripts associated with the runlevel. The runlevel-specific scripts are stored in `/etc/rc.d/rc?.d`, `/etc/init.d/rc?.d`, `/etc/rc?.d`, or a similar location. (The precise location varies between distributions.) In all these cases, *?* is the runlevel number. When entering a runlevel, `rc` passes the `start` parameter to all the scripts with names that begin with a capital *S* and the `stop` parameter to all the scripts with names that begin with a capital *K*. These *System V (SysV) startup scripts* start or stop services depending on the parameter they’re passed, so the naming of the scripts controls whether they’re started or stopped when a runlevel is entered. These scripts are also numbered, as in `S10network` and `K35smb`.

The `rc` program runs the scripts in numeric order. This feature enables distribution designers to control the order in which scripts run by giving them appropriate numbers. This control is important because some services depend on others. For instance, network servers must normally be started after the network is brought up.

In reality, the files in the SysV runlevel directories are symbolic links to the main scripts, which are typically stored in `/etc/rc.d`, `/etc/init.d`, or `/etc/rc.d/init.d` (again, the exact location depends on the distribution). These original SysV startup scripts have names that lack the leading *S* or *K* and number, as in `smb` instead of `K35smb`.



You can also start services by hand. Run them with the `start` option, as in `/etc/init.d/smb start` to start the `smb` (Samba) server. Other useful options are `stop`, `restart`, and `status`. Most scripts support all these options.

To determine which services are active in a runlevel, search the appropriate SysV startup script directory for scripts with filenames that begin with an S. Alternatively, you can use a runlevel management tool, as described next.

Managing Runlevel Services

The SysV startup scripts in the runlevel directories are symbolic links back to the original script. This is done so you don't need to copy the same script into each runlevel directory. Instead, you can modify the original script without having to track down its copies in all the SysV runlevel directories. You can also modify which programs are active in a runlevel by editing the link filenames. Numerous utility programs are available to help you manage these links, such as `chkconfig`, `ntsysv`, `update-rc.d`, and `rc-update`. I describe the first two of these tools because they're supported on most distributions. If your distribution doesn't support these tools, you should check distribution-centric documentation.

Managing Runlevel Services with *chkconfig*

To list the services and their applicable runlevels with `chkconfig`, use the `--list` option. The output looks something like this but is likely to be much longer:

```
# chkconfig --list
pcmcia      0:off  1:off  2:on   3:on   4:on   5:on   6:off
nfs-common  0:off  1:off  2:off  3:on   4:on   5:on   6:off
xprint     0:off  1:off  2:off  3:on   4:on   5:on   6:off
setserial  0:off  1:off  2:off  3:off  4:off  5:off  6:off
```

This output shows the status of the services in all seven runlevels. For instance, you can see that `nfs-common` is inactive in runlevels 0–2, active in runlevels 3–5, and inactive in runlevel 6.



On Red Hat, Fedora, and some other distributions, `chkconfig` can manage servers that are handled by `xinetd` as well as SysV startup scripts. The `xinetd`-mediated servers appear at the end of the `chkconfig` listing.

If you're interested in a specific service, you can specify its name:

```
# chkconfig --list nfs-common
nfs-common  0:off  1:off  2:off  3:on   4:on   5:on   6:off
```

To modify the runlevels in which a service runs, use a command like this:

```
# chkconfig --level 23 nfs-common on
```



The previous example is for Debian-based systems. On Red Hat and similar systems, you would probably want to target runlevels 3, 4, and 5 with something like `--level 345` rather than `--level 23`.

You can set the script to be on (to activate it), off (to deactivate it), or reset (to set it to its default value).

If you've added a startup script to the main SysV startup script directory, you can have `chkconfig` register it and add appropriate start and stop links in the runlevel directories. When you do this, `chkconfig` inspects the script for special comments to indicate default runlevels. If these comments are in the file and you're happy with the suggested levels, you can add it to these runlevels with a command like this:

```
# chkconfig --add nfs-common
```

This command adds the `nfs-common` script to those managed by `chkconfig`. You would, of course, change `nfs-common` to your script's name. This approach may not work if the script lacks the necessary comment lines with runlevel sequence numbers for `chkconfig`'s benefit.

Managing Runlevel Services with *ntsysv*

The `ntsysv` utility is an interactive text-mode tool. It was created by Red Hat and is used mainly on Red Hat and related distributions, such as Fedora and Mandriva. If you run `ntsysv` without any arguments, you can configure your current runlevel. If you want to specify alternate runlevels to configure, run it with the `--level` option, as in `ntsysv --level 1` to configure runlevel 1 or `ntsysv --level 23` to configure runlevels 2 and 3. In either event, the result resembles Figure 5.2, which shows `ntsysv` running in an `xterm` window.

FIGURE 5.2 The `ntsysv` program enables you to control services from a menu of available services.



To adjust services, use your keyboard's arrow keys to select a service, and press the spacebar to toggle the service on or off. An asterisk in the square brackets indicates that the service is on. No asterisk means the service won't execute for the runlevels you've selected. When you're done, press the Tab key to highlight the OK button, and then press the Enter key.

Checking Your Runlevel

Sometimes it's necessary to check your current runlevel. Typically, you'll do this prior to changing the runlevel or to check the status if something isn't working correctly. Two different runlevel checks are possible: checking your default runlevel and checking your current runlevel.

Checking and Changing Your Default Runlevel

You can determine your default runlevel by inspecting the `/etc/inittab` file with the `less` command or opening it in an editor. Alternatively, you may use the `grep` command to look for the line specifying the `initdefault` action. On a Fedora system, you'll see something like this:

```
# grep :initdefault: /etc/inittab
id:5:initdefault:
```

On Debian, you'll probably see this:

```
# grep :initdefault: /etc/inittab
id:2:initdefault:
```

You may notice that neither system defines a process to run. In the case of the `initdefault` action, the process field is ignored.

If you want to change the default runlevel for the next time you boot your system, edit the `initdefault` line in `/etc/inittab` and change the runlevel field to the value that you want. If your system lacks an `/etc/inittab` file, create one that contains *only* an `initdefault` line that specifies the runlevel you want to enter by default.

Determining Your Current Runlevel

If your system is up and running, you can determine your runlevel information with the `runlevel` command:

```
# runlevel
N 2
```

The first character is the previous runlevel. When the character is `N`, this means the system hasn't switched runlevels since booting. It's possible to switch to different runlevels on a running system with the `init` and `telinit` programs, as described next. The second character in the `runlevel` output is your current runlevel.

Changing Runlevels on a Running System

Sometimes you may want to change runlevels on a running system. You might do this to get more services, such as going from a console to a graphical login runlevel, or to shut down or reboot your computer. This can be accomplished with the `init` (or `telinit`), `shutdown`, `halt`, `reboot`, and `poweroff` commands.

Changing Runlevels with *init* or *telinit*

The `init` process is the first process run by the Linux kernel, but you can also use it to have the system reread the `/etc/inittab` file and implement changes it finds there or to change to a new runlevel. The simplest case is to have it change to the runlevel you specify. For instance, to change to runlevel 1 (the runlevel reserved for single-user or maintenance mode), you would type this command:

```
# init 1
```

To reboot the system, you can use `init` to change to runlevel 6 (the runlevel reserved for reboots):

```
# init 6
```

A variant of `init` is `telinit`. This program can take a runlevel number just like `init` to change to that runlevel, but it can also take the `Q` or `q` option to have the tool reread `/etc/inittab` and implement any changes it finds there. Thus, if you've made a change to the runlevel in `/etc/inittab`, you can immediately implement that change by typing **`telinit q`**.

**NOTE**

The man pages for these commands indicate slightly different syntaxes; but `telinit` is sometimes a symbolic link to `init`, and in practice `init` responds just like `telinit` to the `Q` and `q` options.

Changing Runlevels with *shutdown*

Although you can shut down or reboot the computer with `init`, doing so has some problems. One issue is that it's simply an unintuitive command for this action. Another is that changing runlevels with `init` causes an immediate change to the new runlevel. This may cause other users on your system some aggravation because they'll be given no warning about the shutdown. Thus, it's better to use the `shutdown` command in a multi-user environment when you want to reboot, shut down, or switch to single-user mode. This command supports extra options that make it friendlier in such environments.

The `shutdown` program sends a message to all users who are logged into your system and prevents other users from logging in during the process of changing runlevels. The `shutdown` command also lets you specify when to effect the runlevel change so that users have time to exit editors and safely stop other processes they may have running.

When the time to change runlevels is reached, `shutdown` signals the `init` process for you. In the simplest form, `shutdown` is invoked with a time argument like

```
# shutdown now
```

This changes the system to runlevel 1, the single-user or maintenance mode. The `now` parameter causes the change to occur immediately. Other possible time formats include `hh:mm`, for a time in 24-hour clock format (such as `6:00` for 6:00 am or `13:30` for 1:30 pm), and `+m` for a time `m` minutes in the future.

You can add extra parameters to specify that you want to reboot or halt (that is, power off) the computer. Specifically, `-r` reboots the system, `-H` halts it (terminates operation but doesn't power it off), and `-P` powers it off. The `-h` option may halt or power off the computer, but usually it powers it off. For instance, you can type **shutdown -r +10** to reboot the system in 10 minutes.

To give people some warning about the impending shutdown, you can add a message to the end of the command:

```
# shutdown -h +15 "system going down for maintenance"
```

If you schedule a shutdown but then change your mind, you can use the `-c` option to cancel it:

```
# shutdown -c "never mind"
```

Changing Runlevels with the *halt*, *reboot*, and *poweroff* Commands

Three additional shortcut commands are `halt`, `reboot`, and `poweroff`. (In reality, `reboot` and `poweroff` are usually symbolic links to `halt`. This command behaves differently depending on the name with which it's called.) As you might expect, these commands halt the system (shut it down without powering it off), reboot it, or shut it down and (on hardware that supports this feature) turn off the power, respectively.

In Exercise 5.1, you'll experiment with some of the methods of changing runlevels just described.

EXERCISE 5.1

Changing Runlevels

This exercise will demonstrate the effects of changing the runlevel in various ways on a working system. Be aware that some of the effects will be different from one system to another, depending on both the distribution and the system-specific configuration of the computer. Also, in the course of running this exercise, you'll reboot the computer, so you shouldn't do it on a system that anybody else is using. To manage your runlevels, follow these steps:

1. Log in as root, or acquire root privileges by using `su` or by using `sudo` with each of the following commands. Use a text-mode or remote login; some of the exercise activities will shut down X.
2. Type `runlevel` to learn your current runlevel. Recall that the first character returned refers to the previous runlevel (N denotes no previous runlevel; it hasn't been changed since the system booted). The second output character is the current runlevel. This is likely to be 2 on Debian or Debian-derived systems, and 3 or 5 on Red Hat or Red Hat-derived systems.

EXERCISE 5.1 (continued)

3. If your system reports it's in runlevel 5, type **telinit 3** to switch to runlevel 3. Chances are your X server will stop working. (Pressing Alt+F7 from a text-mode console will show a blank text-mode screen rather than the X display this key-stroke would normally reveal.)
 4. If your system initially reported a runlevel of 3, type **telinit 5** to switch to runlevel 5. This will probably start X; however, if X is misconfigured, the screen is likely to blink two or three times and possibly display an error message. If X isn't installed, nothing much will happen, aside from a display about a few services being stopped and started. If X starts, you can get back to your text-mode console by pressing Ctrl+Alt+F1.
 5. If your system reported that it was in runlevel 2, you can try other runlevels, such as 3, 4, or 5; however, this isn't likely to have much effect. You can temporarily start or stop X by typing **/etc/init.d/gdm start** or **/etc/init.d/gdm stop**. (You may need to change gdm to xdm or kdm.)
 6. Return to your original runlevel using **telinit**, as in **telinit 5**.
 7. On Red Hat or similar systems, edit **/etc/inittab** and change the default runlevel by changing the number in the line that reads **id:n:initdefault:.** The number, *n*, is likely to be either 3 or 5; change it to the other value. (It's wise to make a backup of **/etc/inittab** before editing it!)
 8. Reboot the computer by typing **reboot now** or **shutdown -r now**.
 9. Log in as root again, and type **runlevel** to verify that you're running in the runlevel you specified in step 7.
 10. Edit **/etc/inittab** to restore it to its original state, or restore it from its backup.
 11. Type **telinit 6**. This enters runlevel 6, which reboots the system. The computer should now be running as it was before you began this exercise.
-

Editing Files with Vi

Vi was the first full-screen text editor written for Unix. It's designed to be small and simple. Vi is small enough to fit on tiny, floppy-based emergency boot systems. For this reason alone, Vi is worth learning; you may need to use it in an emergency recovery situation. Vi is, however, a bit strange, particularly if you're used to GUI text editors. To use Vi, you should first understand the three modes in which it operates. Once you understand those modes, you can begin learning about the text-editing procedures Vi implements. You'll also examine how to save files and exit Vi.



Most Linux distributions ship with a variant of Vi known as Vim, or “Vi Improved.” As the name implies, Vim supports more features than the original Vi does. The information presented here applies to both Vi and Vim. Most distributions that ship with Vim support launching it by typing `vi`, as if it were the original Vi.

Understanding Vi Modes

At any given moment, Vi is running in one of three modes:

Command mode This mode accepts commands, which are usually entered as single letters. For instance, `i` and `o` both enter insert mode, although in somewhat different ways, as described shortly, and `o` opens a line below the current one.

Ex mode To manipulate files (including saving your current file and running outside programs), you use ex mode. You enter ex mode from command mode by typing a colon (`:`), typically directly followed by the name of the ex mode command you want to use. After you run the ex mode command, Vi returns automatically to command mode.

Insert mode You enter text in insert mode. Most keystrokes result in text appearing on the screen. One important exception is the Esc key, which exits insert mode and returns to command mode.



If you’re not sure what mode Vi is in, press the Esc key. Doing so returns you to command mode, from which you can reenter insert mode, if necessary.

Unfortunately, terminology surrounding Vi modes is inconsistent at best. For instance, command mode is sometimes referred to as normal mode, and insert mode is sometimes called edit mode or entry mode. Ex mode often isn’t described as a mode at all, but is referred to as *colon commands*.

Exploring Basic Text-Editing Procedures

As a method of learning Vi, consider the task of editing `/etc/lilo.conf` to add a new kernel. Listing 5.3 shows the original `lilo.conf` file used in this example. If you want to follow along, enter it using a text editor with which you’re already familiar, and save it to a file on your disk.

Listing 5.3: Sample `/etc/lilo.conf` File

```
boot=/dev/sda
map=/boot/map
install=/boot/boot.b
prompt
```

```

default=linux
timeout=50
image=/boot/vmlinuz
    label=linux
    root=/dev/sda6
    read-only

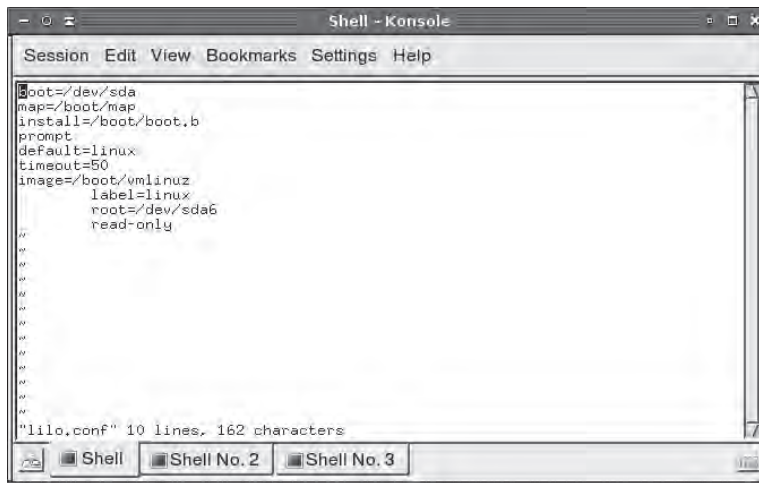
```



Don't try editing your *real* `/etc/lilo.conf` file as a learning exercise; a mistake could render your system unbootable the next time you type `lilo`. You might put your test `lilo.conf` file in your home directory for this exercise.

The first step to using Vi is to launch it and have it load the file. In this example, type `vi lilo.conf` while in the directory holding the file. The result should resemble Figure 5.3, which shows Vi running in a Konsole window. The tildes (~) down the left side of the display indicate the end of the file. The bottom line shows the status of the last command—an implicit file load command because you specified a filename when launching the program.

FIGURE 5.3 The last line of a Vi display is a status line that shows messages from the program.



Adding a new entry to `lilo.conf` involves duplicating the lines beginning with the `image=` line and modifying the duplicates. Therefore, the first editing task is to duplicate these four lines. To do this, follow these steps:

1. Move the cursor to the beginning of the `image=` line by using the Down arrow key; you should see the cursor resting on the `i`.



You can also use the *h*, *j*, *k*, and *l* keys in place of the Left, Down, Up, and Right arrow keys. This is a holdover from the days before all keyboards had arrow keys. Some people prefer to use these keys because they can be faster to use, once the mappings are learned, than the arrow keys.

2. You must now *yank* four lines of text. This term is used much as *copy* is used in most text editors—you copy the text to a buffer from which you can later paste it back into the file. To yank text, you use the `yy` command, preceded by the number of lines you want to yank. Thus, type `4yy` (*do not* press the Enter key, though). Vi responds with the message `4 lines yanked` on its bottom status line. The `dd` command works much like `yy`, but it deletes the lines as well as copying them to a buffer. Both `yy` and `dd` are special cases of the `y` and `d` commands, respectively, which yank or delete text in amounts specified by the next character, as in `dw` to delete the next word.
3. Move the cursor to the last line of the file by using the arrow keys.
4. Type `p` (again, without pressing the Enter key). Vi pastes the contents of the buffer starting on the line after the cursor. The file should now have two identical `image=` stanzas. The cursor should be resting at the start of the second one. If you want to paste the text into the document starting on the line *before* the cursor, use an uppercase `P` command.

Now that you've duplicated the necessary lines, you must modify one copy to point to your new kernel. To do so, follow these steps:

1. Move the cursor to the `v` in `vmLinux` on the second `image=` line. You're about to begin customizing this second stanza.
2. Until now, you've operated Vi in command mode. You can use any of several commands to enter insert mode. At this point, the most appropriate is `R`, which enters insert mode so that it's configured for text replacement rather than insertion. If you prefer to insert text rather than overwrite it, you can use `i` or `a` (the latter advances the cursor one space, which is sometimes useful at the end of a line). For the purposes of these instructions, type `R` to enter insert mode. You should see `-- REPLACE --` appear in the status line.
3. Type the name of a new Linux kernel. For the purposes of this example, let's say you've called it `bzImage-2.6.26`, so that's what you type. This entry should replace `vmLinux`.
4. Use the arrow keys to move the cursor to the start of `linux` on the next line. You must replace this label so that your new entry has its own label.
5. Type a new label, such as `mykernel`. This label should replace the existing `linux` label.
6. Exit insert mode by pressing the Esc key.
7. Save the file and quit by typing `:wq`. This is an ex-mode command, as described shortly. (The `ZZ` command is equivalent to `:wq`.)

Many additional commands are available that you may want to use in some situations. Here are some of the highlights:

Change case Suppose you need to change the case of a word in a file. Instead of entering insert mode and retyping the word, you can use the tilde (`~`) key in command mode to

change the case. Position the cursor on the first character you want to change, and press `~` repeatedly until the task is done.

Undo To undo any change, type `u` in command mode.

Open text In command mode, typing `o` opens text—that is, it inserts a new line immediately below the current one and enters insert mode on that line.

Search To search forward for text in a file, type `/` in command mode, followed immediately by the text you want to locate. Typing `?` searches backward rather than forward.

Change text The `c` command changes text from within command mode. You invoke it much like the `d` or `y` command, as in `cw` to change the next word or `cc` to change an entire line.

Go to a line The `G` key brings you to a line that you specify. The `H` key “homes” the cursor—that is, it moves the cursor to the top line of the screen. The `L` key brings the key to the bottom line of the screen.

Replace globally To replace all occurrences of one string with another, type `:%s/original/replacement`, where *original* is the original string and *replacement* is its replacement. Change `%` to a starting line number, comma, and ending line number to perform this change on a small range of lines.

Vi offers a great deal more depth than is presented here; the editor is quite capable, and some Linux users are very attached to it. Entire books have been written about Vi. Consult one of these, or a Vi Web page like <http://www.vim.org>, for more information.

Saving Changes

To save changes to a file, type `:w` from command mode. This enters ex mode and runs the `w` ex-mode command, which writes the file using whatever filename you specified when you launched Vi. Related commands enable other functions:

Edit a new file The `:e` command edits a new file. For instance, `:e /etc/inittab` loads `/etc/inittab` for editing. Vi won't load a new file unless the existing one has been saved since its last change or unless you follow `:e` with an exclamation mark (!).

Include an existing file The `:r` command includes the contents of an old file in an existing one.

Execute an external command The ex-mode command `:!` executes the external command that you specify. For instance, typing `:!ls` runs `ls`, enabling you to see what files are present in the current directory.

Quit Use the `:q` command to quit the program. As with `:e`, this command won't work unless changes have been saved or you append an exclamation mark to the command (as in `:q!`).

You can combine ex commands such as these to perform multiple actions in sequence. For instance, typing `:wq` writes changes and then quits from Vi.

Summary

Although Linux distributions are designed to boot painlessly and reliably once installed, understanding the boot process will help you overcome problems and maintain your system. Most Linux systems employ a boot loader known as LILO or GRUB. Although these programs are rather different, they both fit themselves into the standard x86 boot system, enabling the computer to load the Linux kernel. The kernel then runs the `init` program, which in turn reads various configuration files to boot all the services that make a running Linux system.

Modifying your LILO or GRUB configuration enables you to boot different Linux kernels or non-Linux OSs. You can also pass new boot options to Linux. Once the system is booted, you can use the `dmesg` command or log files to study the boot process in order to verify that it went correctly or to find clues as to why it didn't.

You can use the Vi editor to edit your LILO or GRUB configuration file, or any other plain text file on your computer. Although Vi is old-fashioned in many ways, it's small and fits on emergency disk systems. Every administrator should be familiar with Vi, even if it's not your editor of choice for day-to-day operations.

Exam Essentials

Explain how LILO is configured and used. LILO uses the `/etc/lilo.conf` configuration file. This file contains global options and per-image options. Use the `lilo` program to install the LILO boot loader in your boot sector. When the system boots, LILO presents a boot: prompt at which you type the name of the kernel or OS you want to boot.

Describe how GRUB is configured and used. GRUB uses the `menu.lst` or `grub.conf` configuration file in `/boot/grub`. This file contains global and per-image options. Use the `grub-install` program to install the boot loader. When GRUB boots, it presents a menu of OS options that you select using the keyboard arrow keys.

Describe the boot process. The CPU runs the BIOS, the BIOS loads and runs a boot loader, the boot loader loads and runs secondary boot loaders (if needed) and the Linux kernel, the Linux kernel loads and runs the initial system program (`init`), and `init` starts the rest of the system services via SysV and other startup scripts. The BIOS looks for boot loaders in various boot sectors, including the MBR of a hard drive or the boot sector of a disk partition or floppy disk.

Summarize where to look for boot-time log information. The `dmesg` command prints out logs from the kernel ring buffer, which holds boot-time and other kernel messages. Other useful log information can be found in `/var/log/messages` and other files in `/var/log`.

Summarize the role of `/sbin/init`. The `init` program is responsible for starting many programs and services on your Linux operating system. This is done by running processes that are listed in `/etc/inittab`, including an `rc` script that runs the SysV initialization scripts.

Explain how runlevels are configured. The default runlevel is specified with a line like `id:2:initdefault:` in the `/etc/inittab` file. Use commands such as `chkconfig`, `update-rc.d`, and `ntsysv` to change which services are started when switching to specific runlevels. Runlevels 0, 1, and 6 are reserved for shutdown, single-user mode, and rebooting, respectively. Runlevels 3, 4, and 5 are the common user runlevels on Red Hat and most other distributions, and runlevel 2 is the usual user runlevel on Debian systems.

Describe how to change runlevels. The programs `init` and `telinit` can be used to change to other runlevels. `shutdown`, `halt`, `poweroff`, and `reboot` are also useful when shutting down, rebooting, or switching to single-user mode.

Describe Vi's three editing modes. You enter text using insert mode, which supports text entry and deletion. The `command` and `ex` modes are used to perform more complex commands or to run outside programs to operate on the text entered or changed in insert mode.

Review Questions

- Where might the BIOS find a boot loader?
 - RAM
 - `/dev/boot`
 - MBR
 - `/dev/kmem`
- You want to boot a Linux system into single-user mode. What might you type at a LILO boot: prompt to accomplish this task?
 - `s`
 - `single-user`
 - `linux 1`
 - `telinit 6`
- After booting, one of your hard disks doesn't respond. What might you do to find out what's gone wrong?
 - Check the `/var/log/diskerror` log file to see what's wrong.
 - Verify that the disk is listed in `/mnt/disks`.
 - Check the contents of `/etc/inittab` to be sure it's mounting the disk.
 - Type `dmesg | less`, and peruse the output for disk-related messages.
- What is the first program that the Linux kernel runs once it's booted in a normal boot process?
 - `dmesg`
 - `init`
 - `startup`
 - `rc`
- Which of the following is the LILO boot loader configuration file?
 - `/dev/lilo`
 - The MBR
 - `/boot/lilo/lilo.conf`
 - `/etc/lilo.conf`
- What should be the first line of a LILO configuration file stanza intended to boot a Linux kernel stored as `/boot/bzImage-2.6.26`?
 - `image=/boot/bzImage-2.6.26`
 - `image /boot/bzImage-2.6.26`
 - `kernel /boot/bzImage-2.6.26`
 - `kernel=/boot/bzImage-2.6.26`

7. Which command is used to install GRUB into the MBR of your first ATA hard drive?
- A. `grub (hd0,1)`
 - B. `grub-install /dev/hda1`
 - C. `lilo /dev/hda`
 - D. `grub-install /dev/hda`
8. The string `root (hd1,5)` appears in your `/boot/grub/menu.lst` file. What does this mean?
- A. GRUB tells the kernel that its root partition is the fifth partition of the first disk.
 - B. GRUB looks for files on the sixth partition of the second disk.
 - C. GRUB looks for files on the fifth partition of the first disk.
 - D. GRUB installs itself in `/dev/hd1,5`.
9. What line in `/etc/inittab` would indicate that your default runlevel is 5?
- A. `ca:12345:ctrlaltdel:/sbin/shutdown -t1 -a -r now`
 - B. `id:5:initdefault:`
 - C. `si:5:sysinit:/etc/init.d/rcS`
 - D. `ls:5:wait:/etc/init.d/rc 5`
10. Which runlevels are reserved by `init` for reboot, shutdown, and single-user mode purposes? (Select all that apply.)
- A. 0
 - B. 1
 - C. 5
 - D. 6
11. You type the following command:
- ```
$ runlevel
```
- ```
5 3
```
- What can you tell about your runlevel status? (Select all that apply.)
- A. The current runlevel is 5.
 - B. The current runlevel is 3.
 - C. The previous runlevel is 5.
 - D. The previous runlevel is 3.
12. A system administrator types the following command:
- ```
shutdown -c
```
- What is the effect of this command?
- A. A previously scheduled shutdown is cancelled.
  - B. The system shuts down and reboots immediately.
  - C. The system shuts down and halts immediately.
  - D. The system asks for confirmation and then shuts down.



13. Which of the following commands may *not* be used instead of `shutdown` in certain circumstances?
- A. `reboot`
  - B. `halt`
  - C. `poweroff`
  - D. `takedown`
14. You want to change to single-user mode on a running system. What command might you use to do this?
- A. `runlevel 1`
  - B. `telinit 1`
  - C. `shutdown -1`
  - D. `single-user`
15. What does `runlevel 4` do?
- A. It reboots the computer.
  - B. It starts a multi-user system without X running.
  - C. It starts a multi-user system with X and an X-based login running.
  - D. Its purpose isn't standardized, so it can be used for anything you like.
16. How would you remove two lines of text from a file using Vi?
- A. In command mode, position the cursor on the first line and type `2dd`.
  - B. In command mode, position the cursor on the last line and type `2yy`.
  - C. In insert mode, position the cursor at the start of the first line, hold down the Shift key while pressing the Down arrow key twice, and press the Delete key on the keyboard.
  - D. In insert mode, position the cursor at the start of the first line and press `Ctrl+K` twice.
17. In Vi's command mode, you type `:q!`. What is the effect?
- A. Nothing; this isn't a valid Vi command.
  - B. The text `:q!` is inserted into the file you're editing.
  - C. The program terminates and saves any existing files that are in memory.
  - D. The program terminates without saving your work.
18. What is an advantage of Vi over Emacs?
- A. Vi is X-based and so is easier to use than Emacs.
  - B. Vi is smaller and so can fit on compact emergency systems and embedded devices.
  - C. Vi's mode-based operations permit it to handle non-English languages.
  - D. Vi includes a built-in Web browser and e-mail client; Emacs doesn't.

19. From Vi's command mode, you want to enter insert mode. How might you do this? (Select all that apply.)
- A. Type R.
  - B. Type i.
  - C. Type a.
  - D. Type :.
20. How do you exit Vi's insert mode in order to type command-mode commands?
- A. Press the ~ key.
  - B. Press the Esc key.
  - C. Type Ctrl+X followed by Ctrl+C.
  - D. Press the F10 key.

# Answers to Review Questions

1. C. The Master Boot Record (MBR) can contain a boot loader that is up to 512 bytes in size. If more space is required, the boot loader must load a secondary boot loader. Although the boot loader is loaded into RAM, it's not stored there permanently because RAM is volatile storage. Both `/dev/boot` and `/dev/kmem` are references to files on Linux filesystems; they're meaningful only after the BIOS has found a boot loader and run it and lots of other boot processes have occurred.
2. C. You can type a stanza name (such as `linux`, although this can vary) and a runlevel number (such as `1`) at a `LILO boot:` prompt to boot into the specified runlevel; runlevel `1` is single-user mode. Option A won't do the trick unless you've got a stanza called `s` and your system is configured to boot into single-user mode by default. Option B is similar. Option C is a command you can type once Linux has booted to reboot the computer, but it won't work as described at a `LILO boot:` prompt.
3. D. The kernel ring buffer, which can be viewed by typing `dmesg` (piping this through `less` is a good supplement), contains messages from the kernel, including those from hardware drivers. These messages may provide a clue about why the disk didn't appear. The `/var/log/diskerror` file is fictitious, as is `/mnt/disks`. The `/etc/inittab` file doesn't directly control disk access and so is unlikely to provide useful information.
4. B. Ordinarily, Linux runs `init` as the first program; `init` then runs, via various scripts, other programs. The `dmesg` program is a user diagnostic and information tool used to access the kernel ring buffer; it's not part of the startup process. The `startup` program is fictitious. The `rc` program is a script that `init` calls, typically indirectly, during the startup sequence, but it's not the first program the kernel runs.
5. D. Option D is the correct LILO configuration file. Option A is a fictitious file; it doesn't exist. Although LILO's boot loader code may be written to the MBR, as implied by option B, this isn't the location of the LILO configuration file. Option C is reminiscent of the location of the GRUB configuration file; it's not the location of the LILO configuration file.
6. A. The `image` keyword identifies a kernel file in the LILO configuration file, and an equal sign (=) separates this keyword from the filename. Option B lacks this equal sign, and options C and D use the `kernel` keyword instead of `image`. (GRUB uses `kernel`, but slightly differently from the way LILO uses `image`.)
7. D. You use `grub-install` to install the GRUB boot loader code into an MBR or boot sector. When using `grub-install`, you specify the boot sector on the command line. The MBR is the first sector on a hard drive, so you give it the Linux device identifier for the entire hard disk, `/dev/hda`. Option A specifies using the `grub` utility, which is an interactive tool, and the device identifier shown in option A is a GRUB-style identifier for what would probably be the `/dev/hda3` partition in Linux. Option B is almost correct but installs GRUB to the `/dev/hda1` partition's boot sector rather than the hard disk's MBR. Option C is the command to install LILO to the MBR rather than to install GRUB.

8. B. The `root` keyword in a GRUB configuration file tells GRUB where to look for files, including its own configuration files, kernel files, and so on. Because GRUB numbers starting from 0, `(hd1, 5)` refers to the sixth partition on the second disk. Option A is incorrect because you pass the Linux root partition to the kernel on the kernel line. Options A and C both misinterpret the GRUB numbering scheme. The GRUB installation location is specified on the `grub-install` command line, and `/dev/hd1, 5` isn't a standard Linux device file.
9. B. The `initdefault` action specifies the default runlevel.
10. A, B, D. Runlevel 0 is the reserved runlevel for halting the system. Runlevel 1 is reserved for single-user mode. Runlevel 6 is reserved for rebooting. Runlevel 5 is a regular, user-configurable runlevel. (Many systems use it for a regular boot with a GUI login prompt.)
11. B, C. The first number in the `runlevel` output is the previous runlevel (the letter N is used to indicate that the system hasn't changed runlevels since booting). The second number is the current runlevel.
12. A. The `-c` option to `shutdown` cancels a previously scheduled shutdown. Options B and C describe the effects of the `-r` and `-h` options to `shutdown`, respectively. No `shutdown` option asks for confirmation before taking action, although you can delay a shutdown by specifying a shutdown time in the future.
13. D. There is no standard `takedown` command in Linux. The `reboot` command is equivalent to `shutdown -r`, `halt` is equivalent to `shutdown -H`, and `poweroff` is equivalent to `shutdown -P`.
14. B. The `telinit` command is used to change runlevels; when it's passed the 1 parameter, `telinit` changes to runlevel 1, which is single-user mode. The `runlevel` command displays the current runlevel but doesn't change runlevels. Although `telinit` can be used to shut down or reboot the computer, the `shutdown` command can't be used to change runlevels except to runlevel 0 or 6. There is no standard `single-user` command.
15. D. Runlevel 4 isn't standardized, and most distributions don't use it for anything specific (although in practice it will do *something* if you enter it). You can safely redefine runlevel 4 to achieve specific goals. Option A describes runlevel 6. Option B describes runlevel 3 on Red Hat and related distributions. Option C describes runlevel 5 on Red Hat and related distributions.
16. A. In Vi, `dd` is the command-mode command that deletes lines. Preceding this command by a number deletes that number of lines. Although `yy` works similarly, it copies (yanks) text rather than deleting it. Option C works in many more modern text editors, but not in Vi. Option D works in Emacs and similar text editors, but not in Vi.
17. D. The `:q!` Vi command does as option D states. Option A is simply incorrect. Option B would be correct if this command were typed while in Vi's insert mode, but the question specifies that command mode is in use. To achieve option C, the command would be `:wq`, not `:q!`.

18. B. Vi is included on Linux emergency disks, embedded systems, and other systems where space is at a premium because its executable is tiny. Emacs is, in contrast, a behemoth. Contrary to option A, Vi isn't an X-based program (although X-based Vi variants are available); Emacs can be used in text mode or with X. Vi's modes, referred to in option C, have nothing to do with non-English language support. Option D is backward; it's Emacs that includes a Web browser, e-mail client, and other add-ons.
19. A, B, C. Typing R in command mode enters insert mode with the system configured to overwrite existing text. Typing i or a enters insert mode with the system configured to insert text. (The i and a commands differ in how they place the cursor; a advances one space.) Typing : in command mode enters ex mode (you typically type the ex-mode command on the same command line immediately after the colon).
20. B. The Esc key exits Vi's insert mode. Typing a tilde (~) inserts that character into the file. The Ctrl+X, Ctrl+C key combination exits from Emacs, but it's not a defined Vi key sequence. The F10 key also isn't defined in Vi.



# The LPI 102 Exam (60 Weights)

PART







# Chapter 6

## Configuring the X Window System, Localization, and Printing

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**THE FOLLOWING LINUX PROFESSIONAL  
INSTITUTE OBJECTIVES ARE COVERED IN  
THIS CHAPTER:**

- ✓ 1.106.1 Install and configure X11 (weight: 2)
- ✓ 1.106.2 Set up a display manager (weight: 2)
- ✓ 1.106.3 Accessibility (weight: 1)
- ✓ 1.107.3 Localization and internationalization (weight: 3)
- ✓ 1.108.4: Manage printers and printing (weight: 2)





Major modern desktop OSs all provide some form of *graphical user environment* (GUI), which provides the windows, menus, dialog boxes, flexible fonts, and so on, with which you're probably familiar. In Linux, the main GUI is known as the *X Window System* (or *X* for short). X configuration is either very easy or moderately hard; most distributions today provide auto-detection and easy configuration options during installation, and these usually work correctly. When they don't, or when you want to tweak the configuration, you must delve into the X configuration file or use a GUI X configuration tool. Doing either requires that you know how X treats the video hardware, among other things.

Beyond basic X configuration are a few extra topics. These include fonts, GUI login tools, user desktop environments, using X for remote access, and localization. Each of these topics is closely associated with basic X configuration, but they all go beyond it in one way or another, extending X's capabilities or providing more features for users, as described in this chapter.

The X display can be considered one form of output. Another is printing, and this chapter covers that topic, as well. With a properly configured printer, you can obtain hardcopy of the documents you create and edit using both X and text-based applications.

## Configuring Basic X Features

Basic X configuration sets features such as the mouse used, the keyboard layout, the screen resolution, the video refresh rate, the display color depth, and the video card you're using. Some of these options require telling X about what hardware you have installed, whereas others enable you to adjust settings on your hardware. In any event, before you proceed with actual configuration, you should know something about the X servers that are available for Linux because your selection will determine what additional tools are available and what files you may need to adjust manually. GUI and text-mode configuration utilities can help you configure X; but sometimes you must delve into the configuration files, so knowing their format is important. This requires that you know what the major option groups do so you can adjust them.

### X Server Options for Linux

Although X is by far the dominant GUI for Linux, several implementations of X are available: **XFree86** The dominant X server in Linux until 2004 was XFree86 (<http://www.xfree86.org>). This open-source server supports a wide array of video cards and input devices, and

most Linux software is designed with XFree86 in mind. As I write, the most recent version is 4.7.0. Significant changes occurred between 3.3.6 and the 4.x series, and some older utilities work only with the 3.3.6 and earlier versions of XFree86. Although a tiny number of systems must run XFree86 3.3.6 or earlier for driver support reasons, most systems today run XFree86 4.x or X.org-X11; the latter is more common on distributions released since 2004.

**X.org-X11** In 2004, most Linux distributions shifted from XFree86 to X.org-X11 because of some licensing changes to XFree86. X.org-X11 6.7.0 was based on XFree86 4.3.99, but it's developed independently up to the current version 7.4. Because X.org-X11 is based on XFree86, the two are virtually identical in most important respects. One significant difference is the name of the configuration file; another is the default location for fonts. Subsequent sections of this chapter point out these differences. You can learn more at <http://www.x.org/wiki/>.

**Accelerated-X** The commercial Accelerated-X server from Xi Graphics (<http://www.xig.com>) is an alternative to the open-source XFree86 and X.org-X11. In practice, running Accelerated-X is seldom necessary, but if you have problems getting your video card working, you may want to look into Accelerated-X; its driver base is independent of the more popular open-source choices, so it's possible you'll have better luck with it. The Accelerated-X configuration tools and files are completely different from those described in "Methods of Configuring X" and "X Configuration Options," so you'll need to consult its documentation for help. The rest of this chapter's topics still apply to Accelerated-X.

In practice, it's usually easiest to stick with whatever X server your distribution provides. For modern distributions, this is most often X.org-X11, but it may be XFree86, particularly if you're running an older distribution. For a handful of rare video cards, you may need to run the rather elderly XFree86 3.3.6 rather than a more recent version.

## Methods of Configuring X

Configuring X has traditionally been a difficult process because the X configuration file includes many arcane options. The task is made simpler if you can use a configuration utility, and most Linux distributions now run such a utility as part of the installation process. If the configuration utility doesn't do everything you want it to do, though, you may need to delve into the X configuration file to set options manually, so knowing something about its format will help a lot. You must also know how to go about restarting X in order to test your changes.



The upcoming section "X Configuration Options" describes in more detail the major X features and how to control them.

## X Configuration Utilities

X configuration utilities vary from one version of X to another. Most important, the tools for XFree86 4.x and X.org-X11 are very different from those for XFree86 3.3.6 and earlier.



## Real World Scenario

### Using Manufacturer-Provided Video Drivers

One of X's functions is to provide drivers that control the video card. XFree86, X.org-X11, and Accelerated-X all ship with a wide variety of drivers that support most video cards. Some cards, though (particularly very new ones), have weak support in the stock packages. XFree86 4.x and X.org-X11 both support a modular driver architecture, which means you can drop in a driver module for your card and, with minimal changes to your X configuration, use it without recompiling the main X package. Some video card manufacturers provide Linux video card drivers designed to work with XFree86 and X.org-X11. (Both X servers can use the same drivers.) Thus, if you have problems with the standard X video drivers, you may want to check with your video card manufacturer and the video card chipset manufacturers for Linux drivers.

Installing and using the manufacturer-provided video drivers is usually a matter of extracting files from a tarball and making a few configuration file changes. Sometimes manufacturers provide scripts that do this automatically. Consult the documentation that comes with these drivers for details. Many of these drivers are particularly helpful for enabling 3D acceleration features of modern cards. This support is most important for certain Linux games, but some non-game software can also benefit from 3D acceleration.

Note that some manufacturers have a habit of placing the standard Linux drivers (or, in this case, the standard XFree86 or X.org-X11 drivers) on their Web site. Thus, you should try to ascertain whether the drivers are genuinely different from what you already have before you bother installing them.

Users of video cards based on nVidia chipsets are most likely to benefit from using nVidia's proprietary drivers. These drivers provide superior 3D and real-time video acceleration compared to the standard X drivers.

One problem with manufacturer-supplied drivers is that they're often proprietary. You might not have source code, which means the drivers might not work on more exotic CPUs, and the drivers could cease working with a future upgrade to your X server.

### Configuration Tools for XFree86 4.x and X.org-X11

Several configuration tools for XFree86 4.x and X.org-X11 are available:

**The X server itself** The X server itself includes the capacity to query the hardware and produce a configuration file. To do this, type **XFree86 -configure** (for XFree86) or **Xorg -configure** (for X.org-X11) when no X server is running. The result should be a file called `/root/XF86Config.new` (for XFree86) or `/root/xorg.conf.new` (for X.org-X11). This file may not produce optimal results, but it's at least a starting point for manual modifications.

**Distribution-specific tools** Many modern distributions ship with their own custom X configuration tools. These include Red Hat's (and Fedora's) Display Settings tool (accessible from the default desktop menu or by typing **system-config-display** in an xterm) and SUSE's YaST and YaST2. These tools frequently resemble the distribution's install-time X configuration tools, which can vary substantially.

**xf86cfg or xorgcfg** This utility works only on XFree86 4.x or X.org-X11 (each package ships with a version named after itself). It's deprecated, meaning it's no longer supported; but if it's present on your system, it can help you tweak settings once X is at least partially running.

All of these utilities gather the same type of information needed to manually configure X. Your best bet for understanding these tools and what they want is to understand the underlying X configuration file's format and contents.

### Configuration Tools for XFree86 3.3.6 and Earlier

Many configuration tools are available for XFree86 3.3.6 and before. The most common of these tools are `xf86config`, `Xconfigurator`, and `XF86Setup`. If you must use XFree86 3.3.6 or earlier, you should consult the documentation for one of these programs or edit your X configuration file manually. Chances are you won't need to do so, however, because most systems can use XFree86 4.x or X.org-X11.

As a general rule, `Xconfigurator` can be a good tool to use for configuring a new system for the first time, and `XF86Setup` is good for adjusting an existing system without digging into XFree86's `XF86Config` file. (This file has the same name as one configuration utility, but its case is different.) Unfortunately for those forced to use XFree86 3.3.6, these tools are very hard to find and use with modern distributions, so you may be forced to use `xf86config` or edit the configuration file manually.

## The X Configuration File Format

The X configuration file's name and location varies with the version of X being run:

**X.org-X11** This server's configuration file is called `xorg.conf`, and it's usually stored in `/etc/X11`, although `/etc` and several other locations are also acceptable to the server.

**XFree86 4.x** The XFree86 4.x configuration file format is slightly different from that of XFree86 3.3.6 and earlier. To support the transition period, XFree86 4.x supports a configuration file called `XF86Config-4`, which is typically located in `/etc/X11`. If this file isn't found, XFree86 4.x looks for a file called `XF86Config` in `/etc/X11` or `/etc`. This file's format is exactly the same as for the X.org-X11 configuration file.

**XFree86 3.3.6 and earlier** The X configuration file's name is `XF86Config`, and the file is most commonly located in `/etc/X11` or `/etc`.

All three of these classes of X server use configuration files that are broken down into multi-line sections, one section for each major feature. These sections begin with a line consisting of the keyword `Section` and the section name in quotes and end with the keyword `EndSection`:

```
Section "InputDevice"
 Identifier "Keyboard0"
```

```

Driver "kbd"
Option "XkbModel" "pc105"
Option "XkbLayout" "us"
Option "AutoRepeat" "500 200"
EndSection

```

This section tells X about the keyboard—its model, layout, and so on. Details for the sections you’re most likely to need to adjust are described shortly, in “X Configuration Options.”

For the most part, the different X servers support the same sections and most of the same option names. A few exceptions to this rule do exist, though:

- The `Option` keyword isn’t used in XFree86 3.3.6 and earlier. Instead, the option name (such as `XkbLayout` or `AutoRepeat` in the preceding example) appears without quotes as the first word on the line.
- XFree86 3.3.6 and earlier don’t use the `ServerLayout` section, described later in “Putting It All Together.”
- XFree86 3.3.6 and earlier lack the `Identifier` and `Driver` lines, which are common in the XFree86 4.x and X.org-X11 configuration files.
- Some section-specific features vary between versions. I describe the most important of these in the coming pages.

## The X Configure-and-Test Cycle

If your X configuration isn’t working correctly, you need to be able to modify that configuration and then test it. Many Linux distributions configure the system to start X automatically; but starting X automatically can make it difficult to test the X configuration. To a new Linux administrator, the only obvious way to test a new configuration is to reboot the computer.

A better solution is to kick the system into a mode in which X is *not* started automatically. On Red Hat, Fedora, and similar distributions, this goal can be achieved by typing **telinit 3**. This action sets the computer to use runlevel 3, in which X normally doesn’t run. Chapter 5, “Booting Linux and Editing Files,” covers runlevels in more detail.

Some distributions, such as Debian, Ubuntu, and Gentoo, don’t use runlevels as a signal for whether to start X. With such distributions, you must shut down the GUI login server by typing **/etc/init.d/xdm stop**. (You may need to change `xm` to `gdm` or `kdm`, depending on your configuration.)

Once the X session is shut down, you can log in using a text-mode login prompt and tweak your X settings manually, or you can use text-based X configuration programs. You can then type **startx** to start the X server again. If you get the desired results, quit from X and type **telinit 5** (**/etc/init.d/xdm start** in Debian and other distributions that don’t use runlevels to start the GUI login prompt) to restore the system to its normal X login screen. If after typing **startx** you don’t get the results you want, you can end your X session and try modifying the system some more.

If X is working minimally but you want to modify it using X-based configuration tools, you can do so after typing **startx** to get a normal X session running. Alternatively, you can reconfigure the system before taking it out of the X-enabled runlevel.

Another approach to restarting X is to leave the system in its X-enabled runlevel and then kill the X server. The **Ctrl+Alt+Backspace** keystroke does this on many systems, or you can do it manually with the **kill** command after finding the appropriate process ID with the **ps** command, as shown here:

```
ps ax | grep X
1375 ? S 6:32 /etc/X11/X -auth /etc/X11/xdm/authdir/
kill 1375
```

This approach works better on systems that don't map the running of X to specific runlevels, such as Debian and its derivatives.

## X Configuration Options

When editing the X configuration file, the best approach is usually to identify the feature that's not working and zero in on the section that controls this feature. You can then edit that section, save your changes, and test the new configuration. In XFree86 4.x and X.org-X11, the major sections described here are called **Module**, **InputDevice**, **Monitor**, **Device**, **Screen**, and **ServerLayout**. You're likely to have two **InputDevice** sections, one for the keyboard and one for the mouse. (In XFree86 3.3.6 and earlier, the mouse is handled by a separate **Pointer** section.) The section order doesn't matter.



Fonts are a complex enough topic that they're described in more detail later, in "Configuring X Fonts." Part of this configuration is handled in the **Files** section.

## Loading Modules

The **Module** section controls the loading of X server modules—drivers for specific features or hardware. A typical example looks like this:

```
Section "Module"
 Load "dbe"
 Load "extmod"
 Load "fbdevhw"
 Load "glx"
 Load "record"
 Load "freetype"
 Load "type1"
 Load "dri"
EndSection
```



Each module is named (`dbe`, `extmod`, and so on) and is loaded by name using the `Load` option. Most of these module names can be deciphered with a bit of knowledge about the features they control. For instance, `freetype` and `type1` handle TrueType and Adobe Type 1 font rendering, respectively. If you're perusing your `Module` section and see modules you don't understand, you shouldn't worry about it; generally speaking, modules that are configured automatically are necessary for normal operation, or at least they do no harm.

For the most part, if an X configuration works, you shouldn't try to adjust the `Module` section, even if you want to tweak the X configuration. Sometimes, though, you'll need to add lines to or remove lines from this section. This is particularly likely to be necessary if you're activating 3D acceleration support or some sort of exotic feature. In such cases, you should consult the documentation for the feature you want to activate.

## Setting the Keyboard

The keyboard is one of two common input devices configured via an `InputDevice` section:

```
Section "InputDevice"
 Identifier "Keyboard0"
 Driver "kbd"
 Option "XkbModel" "pc105"
 Option "XkbLayout" "us"
 Option "AutoRepeat" "500 200"
EndSection
```

The `Identifier` line provides a label that's used by another section (`ServerLayout`, described in “Putting It All Together”). This line and the `ServerLayout` section aren't present in XFree86 3.3.6 or earlier. The string given on this line is arbitrary, but for a keyboard, a descriptive name such as this example's `Keyboard0` will help you understand the file.

The `Driver` line tells X what driver to use to access the keyboard. This should be `kbd` or `Keyboard`, depending on your X server. Unless your keyboard isn't working at all, you shouldn't adjust this line.

The `Option` lines set various options that adjust various keyboard features, such as the model, the layout, and the repeat rate. For the most part, the defaults work well; however, you may want to change the `AutoRepeat` option or add it if it's not present. This option tells X when to begin repeating characters when you hold down a key and how often to repeat them. It takes two numbers as values, enclosed in quotes: the time until the first repeat and the time between subsequent repeats, both expressed in milliseconds (ms). In the preceding example, the system waits 500ms (half a second) for the first repeat and then 200ms for each subsequent repeat (that is, five repeats per second).



Many desktop environments and other user-level utilities provide tools to set the keyboard repeat rate. Thus, the options you set in the X configuration file are used as defaults only and may be overridden by users' settings.



## Setting the Mouse

A second `InputDevice` section controls how X treats the mouse:

```
Section "InputDevice"
 Identifier "Mouse0"
 Driver "mouse"
 Option "Protocol" "IMPS/2"
 Option "Device" "/dev/input/mice"
 Option "Emulate3Buttons" "no"
 Option "ZAxisMapping" "4 5"
EndSection
```



In XFree86 3.3.6 and earlier, this section is called `Pointer` rather than `InputDevice`.

As with the keyboard, the `Identifier` line is used in the `ServerLayout` section to tell X which input device to use. The `Driver` line identifies the driver to use: `mouse`. The `Option` lines set mouse control options. The most important of these are `Device` and `Protocol`.

The `Device` line tells X what Linux device file to read to access the mouse. In this example, it's `/dev/input/mice`, but other common possibilities include `/dev/mouse` (a pointer to the real mouse device, whatever its name), `/dev/psaux` (for the PS/2 mouse port), `/dev/usb/usbmouse` (an old identifier for USB mice), `/dev/ttyS0` (the first RS-232 serial port mouse), and `/dev/ttyS1` (the second RS-232 serial port mouse). If your mouse is working at all (even if its motions are erratic), don't change this line. If your mouse isn't working, you may need to experiment.

The `Protocol` option tells X what signals to expect from the mouse for various movements and button presses. The most common protocols for new mice today are `IMPS/2` and `ExplorerPS/2`, which are very similar in practice. (Note that "PS/2" is both a hardware interface and a software protocol; many USB mice use the PS/2 mouse protocol even though they don't use the PS/2 mouse port.) If your mouse has a scroll wheel, chances are you should use one of these protocols. If your mouse is older, you may need to try an older protocol, such as `PS/2`, `Microsoft`, or `Logitech`. The `Auto` protocol causes X to try to guess the mouse's protocol, which often works correctly.

Additional options are usually less critical than the `Device` and `Protocol` options. The `Emulate3Buttons` option tells X whether to treat a *chord* (that is, a simultaneous press) of both buttons on a two-button mouse as if it were a middle button press. This option is usually disabled on three-button mice and scroll mice (the scroll wheel does double duty as a middle mouse button). The `ZAxisMapping` option in the preceding example maps the scroll wheel actions to the fourth and fifth buttons, because X must treat scroll wheels as if they were buttons. When you scroll up or down, these "button" presses are generated. Software can detect this and take appropriate actions.

## Setting the Monitor

Some of the trickiest aspects of X configuration relate to the monitor options. You set these in the `Monitor` section, which has a tendency to be quite large, particularly in XFree86 3.3.6 and earlier. A shortened `Monitor` section looks like this:

```
Section "Monitor"
 Identifier "Monitor0"
 ModelName "VisionMaster Pro 450"
 HorizSync 27.0-115.0
 VertRefresh 50.0-160.0
 # My custom 1360x1024 mode
 Modeline "1360x1024" 197.8 \
 1360 1370 1480 1752 \
 1024 1031 1046 1072 -HSync -VSync
EndSection
```

As in the keyboard and mouse configurations, the `Identifier` option is a free-form string that contains information that's used to identify a monitor. The `Identifier` can be just about anything you like. Likewise, the `ModelName` option can be anything you like; it's used mainly for your own edification when reviewing the configuration file.

As you continue down the section, you'll see the `HorizSync` and `VertRefresh` lines, which are extremely critical; they define the range of horizontal and vertical refresh rates that the monitor can accept, in kilohertz (kHz) and hertz (Hz), respectively. Together, these values determine the monitor's maximum resolution and refresh rate. Despite the name, the `HorizSync` item alone doesn't determine the maximum horizontal refresh rate. Rather, this value, the `VertRefresh` value, and the resolution determine the monitor's maximum refresh rate. X selects the maximum refresh rate that the monitor will support given the resolution you specify in other sections. Some X configuration utilities show a list of monitor models or resolution and refresh rate combinations (such as "1024 × 768 at 72 Hz"). You select an option and the utility then computes the correct values based on that selection. This approach is often simpler to handle, but it's less precise than entering the exact horizontal and vertical sync values. You should enter these values from your monitor's manual.



Don't set random horizontal and vertical refresh rates; particularly on older hardware, setting these values too high can damage a monitor. (Modern monitors ignore signals presented at too high a refresh rate.)

To settle on a resolution, X looks through a series of *mode lines*, which are specified via the `Modeline` option. Computing mode lines is tricky, so I don't recommend you try it unless you're skilled in such matters. The mode lines define combinations of horizontal and vertical timing that can produce a given resolution and refresh rate. For instance, a particular mode line might define a 1024 × 768 display at a 90Hz refresh rate, and another might

represent  $1024 \times 768$  at 72Hz. The preceding example splits the mode line across multiple lines, but more frequently it appears as a single line in the file.

Some mode lines represent video modes that are outside the horizontal or vertical sync ranges of a monitor. X can compute these cases and discard the video modes that a monitor can't support. If asked to produce a given resolution, X searches all the mode lines that accomplish the job, discards those that the monitor can't handle, and uses the remaining mode line that creates the highest refresh rate at that resolution. (If no mode line supports the requested resolution, X drops down to another specified resolution, as described shortly, and tries again.)

As a result of this arrangement, you'll see a large number of `Modeline` entries in the `XF86Config` file for XFree86 3.3.6 and earlier. Most end up unused because they're for resolutions you don't use or because your monitor can't support them. You can delete these unused mode lines, but it's usually not worth the effort.

XFree86 4.x and X.org-X11 support a feature known as *Data Display Channel (DDC)*. This is a protocol that enables monitors to communicate their maximum horizontal and vertical refresh rates and appropriate mode lines to the computer. The `XFree86 -configure` or `Xorg -configure` command uses this information to generate mode lines, and on every start, the system can obtain horizontal and vertical refresh rates. The end result is that an XFree86 4.x or X.org-X11 system can have a substantially shorter `Monitor` section than is typical with XFree86 3.3.x.

## Setting the Video Card

Your monitor is usually the most important factor in determining your maximum refresh rate at any given resolution, but X sends data to the monitor only indirectly, through the video card. Because of this, it's important that you be able to configure this component correctly. An incorrect configuration of the video card is likely to result in an inability to start X.

### Choosing the Server or Driver

XFree86 4.x and X.org-X11 use driver modules that are stored in separate files from the main X server executable. The server can't determine what module is required automatically, however. Instead, you must give it that information in the `XF86Config` or `xorg.conf` file. In particular, the driver module is set by a line in the `Device` section, which resembles the following:

```
Driver "nv"
```

This line sets the name of the driver. The drivers reside in the `/usr/X11R6/lib/modules/drivers/` directory. Most of the drivers' filenames end in `_drv.o`, and if you remove this portion, you're left with the driver name. For instance, `nv_drv.o` corresponds to the `nv` driver.



Some X configuration utilities provide a large list of chipsets and specific video card models, so you can select the chipset or board from this list to have the utility configure this detail.

## Setting Card-Specific Options

The `Device` section of the `xorg.conf` file sets various options related to specific X servers. A typical `Device` section resembles the following:

```
Section "Device"
 Identifier "Videocard0"
 Driver "nv"
 VendorName "nVidia"
 BoardName "GeForce 6100"
 VideoRam 131072
EndSection
```

The `Identifier` line provides a name that's used in the subsequent `Screen` section to identify this particular `Device` section. (X configuration files frequently host multiple `Device` sections—for instance, one for a bare-bones VGA driver and one for an accelerated driver.) The `VendorName` and `BoardName` lines provide information that's useful mainly to people reading the file.

The `VideoRam` line is unnecessary with most boards because the driver can detect the amount of RAM installed in the card. With some devices, however, you may need to specify the amount of RAM installed in the card, in kilobytes. For instance, the preceding example indicates a card with 128MB of RAM installed.

Many drivers support additional driver-specific options. They may enable support for features such as hardware cursors (special hardware that enables the card to handle mouse pointers more easily) or caches (using spare memory to speed up various operations). Consult the `XF86Config` or `xorg.conf` man page or other driver-specific documentation for details.

## Setting the Resolution and Color Depth

The `Screen` section tells X about the combination of monitors and video cards you're using. `XFree86 4.x` and `X.org-X11` support multiple video cards and monitors on one system, and even in `XFree86 3.3.6` and earlier you can define several monitors or video cards and switch between them by editing the `Screen` section. This can be handy if you're testing a new monitor or video card driver. In any event, the `Screen` section looks something like this:

```
Section "Screen"
 Identifier "Screen0"
 Device "Videocard0"
 Monitor "Monitor0"
 DefaultDepth 24
 SubSection "Display"
 Depth 24
 Modes "1024x768" "1024x600" "800x600" "640x480"
```

```

EndSubSection
SubSection "Display"
 Depth 8
 Modes "1024x768" "800x600" "640x480"
EndSubSection
EndSection

```

The `Device` and `Monitor` lines refer to the `Identifier` lines in your `Device` and `Monitor` sections, respectively. The `Screen` section includes one or more `Display` subsections, which define the video modes that X may use. This example creates two such displays. The first uses a color depth of 24 bits (`Depth 24`) and possible video mode settings of 1024x768, 1024x600, 800x600, and 640x480. (These video modes are actually names that refer to the mode lines defined in the `Monitor` section, or to standard mode lines.) The second possible display uses an 8-bit color depth (`Depth 8`) and supports only 1024x768, 800x600, and 640x480 video modes.

To choose between the `Display` subsections, you include a `DefaultDepth` line. (This line is called `DefaultColorDepth` in XFree86 3.3.6 and earlier.) In this example, X uses the 24-bit display if possible, unless it's overridden by other options when starting X.

Graphical video modes require a certain amount of RAM on the video card. (On some laptop computers and computers with video hardware integrated into the motherboard, a portion of system RAM is reserved for this use by the BIOS.) The total amount of RAM required is determined by an equation:

$$R = xres \times yres \times bpp \div 8,388,608$$

In this equation,  $R$  is the RAM in megabytes,  $xres$  is the x resolution in pixels,  $yres$  is the y resolution in pixels, and  $bpp$  is the bit depth. For instance, consider a 1280 × 1024 display at 24-bit color depth:

$$R = 1280 \times 1024 \times 24 \div 8,388,608 = 3.75\text{MB}$$

All modern video cards have at least 32MB of RAM—usually much more. This is more than enough to handle even very high resolutions at 32-bit color depth (the greatest depth possible). Thus, video RAM shouldn't be a limiting factor in terms of video mode selection, at least not with modern video hardware. Very old video cards can impose limits, so you should be aware of those limits.



Modern video cards ship with large amounts of RAM to support 3D acceleration features. X supports such features indirectly through special 3D acceleration packages, but 3D acceleration support is limited compared to basic video card support. If 3D acceleration is important to you, you should research the availability of this support.

In Exercise 6.1, you'll adjust the X resolution and color depth by editing the `XF86Config` or `xorg.conf` file.

**EXERCISE 6.1****Changing the X Resolution and Color Depth**

To adjust the X resolution and color depth by editing the `XF86Config` or `xorg.conf` file, follow these steps:

1. Log onto the Linux system as a normal user.
2. Launch an `xterm` from the desktop environment's menu system.
3. Acquire root privileges. You can do this by typing `su` in an `xterm`, by selecting `Session > New Root Console` from a `Konsole`, or by using `sudo` (if it's configured) to run the following commands.
4. Back up the current `xorg.conf` file by typing `cp /etc/X11/xorg.conf /root`. (Some distributions may place this file in `/etc` rather than `/etc/X11`. If you're using `XFree86` rather than `X.org-X11`, the file is called `XF86Config` or `XF86Config-4`. You may need to adjust this command as appropriate.)
5. Load the `xorg.conf` file into a text editor by typing the editor's name followed by the complete path to the file in the `xterm`. For instance, `gedit /etc/X11/xorg.conf` loads the file into the `gedit` editor, which is part of `GNOME`. Other popular editor names include `emacs`, `vi`, `ked`, and `edit`.
6. Locate the `Screen` section of the file, identified by a line that reads `Section "Screen"`.
7. Within the `Screen` section, locate a line that begins `DefaultDepth`. This line sets the default color depth of the display, in bits. Adjust the value to one you want to use. Common values include 8 (256 colors), 15 (32,768 colors), 16 (65,536 colors), 24 (16,777,216 colors), and 32 (over 4 million colors). Note that greater color depths often look better but may slow down the display.
8. Examine the `Display` subsections, which begin with the line `Subsection "Display"`. If a `Display` subsection doesn't exist for the color depth you've selected, create one by copying an existing `Display` subsection for another color depth and changing the `Depth` line to match the color depth you selected. Copy all the lines from the `Subsection "Display"` line to the matching `EndSubSection` line, inclusive.
9. In the `Display` subsection for the color depth you've selected, locate the `Modes` line. This line specifies the display modes (resolutions) that X will try to use, in order. A typical `Modes` line lists one or more display modes, in order, as in `Modes "1280x1024" "1024x768" "800x600"`. In this case, X will try a 1280 × 1024 display first. If it can't produce that resolution, X will try a 1024 × 768 display. If X can't produce that display, it will try 800 × 600.
10. Adjust the `Modes` line so that your desired resolution is first in the list. If you want to have fallback resolutions, list them after the primary resolution. Be sure to enclose your mode in quotation marks. (You can't list arbitrary display modes; for instance, `"700x500"` is unlikely to work. X should recognize common display resolutions, though.)

11. Save the changes to the file, and exit from your editor.
  12. If X isn't started, try starting it by typing **startx** at a text-mode command prompt.
  13. If X is already running, log out of your session and, if necessary, select an option to restart X or press Ctrl+Alt+Backspace to force X to quit and restart.
- 

## Putting It All Together

XFree86 4.x and X.org-X11 require a section that's not present in the XFree86 3.3.6 configuration file: `ServerLayout`. This section links together all the other components of the X configuration:

```
Section "ServerLayout"
 Identifier "single head configuration"
 Screen "Screen0" 0 0
 InputDevice "Mouse0" "CorePointer"
 InputDevice "Keyboard0" "CoreKeyboard"
EndSection
```

Typically, this section identifies one `Screen` section and two `InputDevice` sections (for the keyboard and the mouse). Other configurations are possible, though. For instance, XFree86 4.x and X.org-X11 support *multi-head displays*, in which multiple monitors are combined to form a larger desktop than either one alone would support. In these configurations, the `ServerLayout` section includes multiple `Screen` sections.

## Obtaining X Display Information

Sometimes it's helpful to know about the capabilities of your display, because it's managed by X. The tool for this job is `xdpinfo`. When you type **xdpinfo**, the result is copious information about the current display, such as the X version number, the resolution and color depth of all the current displays, and so on. Much of this information is highly technical in nature, so you may not understand it all. That's OK. I recommend you run this program and peruse the output to see what you can learn from it. If you should later want to obtain similar information on another computer's display, you'll know how to obtain it.

For still more technical information, you can use the `-ext extension` option to `xdpinfo`. The *extension* is the name of an X extension, which is a software module that provides extended capabilities to X. (The basic `xdpinfo` command, without any options, lists all the available extensions.)

You can obtain detailed technical information about a specific window with the `xwininfo` command. In basic use, you type **xwininfo**, move the mouse cursor over a window, and click. The result is a list of assorted data about the window you clicked, such as its size, location, and ID number. Alternatively, you can use the `-id id` or `-name name` options to specify the window by ID number or name; or you can use `-root` to specify the root window—that is, the entire display.

# Configuring X Fonts

Fonts have long been a trouble spot for Linux (or more precisely, for X). X was created at a time when available font technologies were primitive by today's standards, and although X has been updated in various ways to take advantage of newer technologies, these updates have been lacking compared to the font subsystems in most competing OSs. X's core font system can be set up from the X configuration file. Alternatively, you can configure a *font server*—a program that delivers fonts to one or many computers using network protocols—to handle the fonts. The latest Linux font technology sets up fonts in a way that's more independent of X and that produces more pleasing results, at least to most peoples' eyes.

## Font Technologies and Formats

Font technologies can be classified as falling into one of two broad categories:

**Bitmap fonts** The simplest type of font format is the *bitmap font*, which represents fonts much like bitmap graphics, in which individual pixels in an array are either active or inactive. Bitmap fonts are fairly easy to manipulate and display, from a programming perspective, which makes them good for low-powered computers. The problem is that each font must be optimized for display at a particular resolution. For instance, a font that's 20 pixels high will appear one size on the screen (typically 72 to 100 dots per inch, or dpi) but will be much smaller when printed (typically at 300 to 600 dpi). Similarly, you need multiple files to display a single font at multiple sizes (such as 9 point versus 12 point). This means a single font, such as Times, requires potentially dozens of individual files for display at different sizes and on different display devices. If you lack the correct font file, the result will be an ugly scaled display.

**Outline fonts** Most modern fonts are distributed as *outline fonts* (a.k.a. *scalable fonts*). This type of format represents each character as a series of lines and curves in a high-resolution matrix. The computer can scale this representation to any font size or for any display resolution, enabling a single font file to handle every possible use of the font. The main problem with outline fonts is that this scaling operation is imperfect; scalable fonts often look slightly worse than bitmap fonts, particularly at small sizes. Scaling and displaying the fonts also takes more CPU time than displaying a bitmap font. This factor used to be important, but on modern CPUs it's not much of an issue.

Both bitmap and outline fonts come in several different formats. X ships with a number of basic bitmap and outline fonts, and you're unlikely to need to deal explicitly with bitmap fonts or their formats, so I don't describe them in any detail. Outline fonts are another matter, though. The two main formats are Adobe's *PostScript Type 1* (Type 1 for short) and Apple's *TrueType*. Fonts available on the Internet and on commercial font CDs come in one or both of these formats.

XFree86 3.3.6 and earlier supported Type 1 fonts but not TrueType fonts. XFree86 4.x and X.org-X11 support both Type 1 and TrueType fonts. If you want to use TrueType fonts



with XFree86 3.3.6 or earlier, you must do so with the help of a font server, as described shortly in “Configuring a Font Server.”

## Configuring X Core Fonts

*X core fonts* are those that are handled directly by X. To configure these fonts, you must do two things: prepare a font directory that holds the fonts, and add the font directory to X’s font path.

### Preparing a Font Directory

The first step to installing fonts is to prepare a directory in which to store them. XFree86 has traditionally stored its fonts in subdirectories of `/usr/X11R6/lib/X11/fonts/`, but X.org-X11 changes this to `/usr/share/fonts` or `/usr/share/X11/fonts`. In either case, if you’re adding fonts you’ve downloaded from the Internet or obtained from a commercial font CD-ROM, you may want to store your fonts elsewhere, such as `/opt/fonts` or `/usr/local/fonts`. (Chapter 4, “Managing Files,” includes information about the logic behind Linux’s directory system.) You may want to create separate subdirectories for fonts in different formats or from different sources.

When you’re installing Type 1 fonts, Linux needs the font files with names that end in `.pfa` or `.pfb`; these files contain the actual font data. (The `.pfa` and `.pfb` files store the data in slightly different formats, but the two file types are equivalent.) Additional files distributed with Type 1 fonts aren’t necessary for Linux. TrueType fonts come as `.ttf` files, and that’s all you need for Linux.



Linux uses fonts in the same format that Windows, OS/2, and most other OSs use. Mac OS uses font files in special Macintosh-only “suitcases,” which Linux can’t use directly. If you want to use such fonts in Linux, you must convert them. The FontForge program (<http://fontforge.sourceforge.net>) can do this conversion, among other things.

Once you’ve copied fonts to a directory, you must prepare a summary file that describes the fonts. This file is called `fonts.dir`, and it begins with a line that specifies the number of fonts that are described. Subsequent lines provide a font filename and an *X logical font description (XLFD)*, which is a tedious-looking description of the font. A complete `fonts.dir` line can be rather intimidating:

```
courb.pfa -ibm-Courier-bold-r-normal--0-0-0-m-0-iso8859-1
```

Fortunately, you needn’t create this file manually; programs exist to do so automatically. In XFree86 4.3 and later and in X.org-X11, the simplest way to do the job is to use `mkfontscale` and `mkfontdir`:

```
mkfontscale
mkfontdir
```

The `mkfontscale` program reads all the fonts in the current directory and creates a `fonts.scale` file, which is just like a `fonts.dir` file but describes only outline fonts. The `mkfontdir` program combines the `fonts.scale` file with the `fonts.dir` file, creating it if it doesn't already exist.

Other programs to perform this task also exist. Most notably, `ttmkfdir` creates a `fonts.dir` file that describes TrueType fonts, and `type1inst` does the job for Type 1 fonts. The `mkfontscale` program is preferable because it handles both font types; but if you're using an older distribution that lacks this program, or if it's not doing a satisfactory job, you can try one of these alternative programs.

## Adding Fonts to X's Font Path

Once you've set up fonts in a directory and created a `fonts.dir` file describing them, you must add the fonts to the X font path. You do this by editing the `Files` section of the `XF86Config` or `xorg.conf` file:

```
Section "Files"
 FontPath "/usr/share/fonts/100dpi:unscaled"
 FontPath "/usr/share/fonts/Type1"
 FontPath "/usr/share/fonts/truetype"
 FontPath "/usr/share/fonts/URW"
 FontPath "/usr/share/fonts/Speedo"
 FontPath "/usr/share/fonts/100dpi"
EndSection
```



If your `Files` section contains `FontPath` lines that refer to `unix:/7100` or `unix:/-1` but that don't list conventional directories, read the section "Configuring a Font Server"; your system is configured to rely on an X font server for its core fonts. In this case, you may want to modify your font server configuration rather than change the X core fonts directly, although you can add font directories to have X both use the font server and directly handle your new fonts. If your X server configuration lacks a `Files` section, it uses a hard-coded default font path. You can add your own complete `Files` section to add new font paths.

To add your new font directory to the font path, duplicate one of the existing `FontPath` lines and change the directory specification to point to your new directory. The order of these directories is significant; when matching font names, X tries each directory in turn, so if two directories hold fonts of the same name, the first one takes precedence. Thus, if you want your new fonts to override any existing fonts, place the new directory at the top of the list; if you want existing fonts to take precedence, add your directory to the end of the list.



The `:unscaled` string in the first entry in the preceding example tells X to use bitmap fonts from this directory only if they exactly match the requested font size. Without this string, X will attempt to scale bitmap fonts from a font directory (with poor results). Typically, bitmap directories are listed twice: once near the top of the font path with the `:unscaled` specification and again near the bottom of the list without it. This produces quick display of matching bitmapped fonts, followed by any matching scalable fonts, followed by scaled bitmap fonts.

Once you've added your font directory to X's font path, you should test the configuration. The most reliable way to do this is to shut down X and restart it. (If your system boots directly into X, consult "Running an XDMCP Server" for information on doing this.) A quicker approach, but one that presents some opportunity for error, is to add the font path to a running system by using the `xset` program:

```
$ xset fp+ /your/font/directory
$ xset fp rehash
```

The first of these commands adds `/your/font/directory` to the end of the font path. (Substitute `+fp` for `fp+` to add the directory to the start of the existing font path.) The second command tells X to re-examine all the font directories to rebuild the list of available fonts. The result is that you should now be able to access the new fonts. (You'll need to restart any programs that should use the new fonts.) One program to quickly test the matter is `xfontsel`. This program enables you to select an X core font for display so you can check to be sure the fonts you've added are available and display as you expect.

## Configuring a Font Server

Prior to the release of XFree86 4.0, several Linux distributions began using TrueType-enabled font servers to provide TrueType font support. Some systems continue to use font servers, but most have now abandoned this practice.

Font servers are also handy ways to deliver fonts to many computers from a central location. This can be a great time-saver if you want to add fonts to many computers—set them up to use a font server and then tweak that server's font configuration. To use a font server, X must list that server in its font path:

```
Section "Files"
 FontPath "unix:/7100"
 FontPath "tcp/fount.pangaea.edu:7100"
EndSection
```

The first line in this example specifies a local font server. (Using `unix:/-1` rather than `unix:/7100` also works in some cases.) The second line specifies that the font server on the remote system `fount.pangaea.edu` is to be used. If your system is already configured to use a font server, you needn't change the X configuration to add or delete fonts; instead, you

can modify the font server's configuration. (You *can* still modify the X font configuration directly, but it may be cleaner to manage all the local fonts from one configuration file.)

To add fonts to a font server, you should first install the fonts on the system, as described earlier in “Preparing a Font Directory.” You should then modify the font server's configuration file, `/etc/X11/fs/config`. Rather than a series of `FontPath` lines, as in the main X configuration file, the font server's configuration lists the font path using the `catalogue` keyword as a comma-delimited list:

```
catalogue = /usr/share/fonts/100dpi:unscaled,
 /usr/share/fonts/Type1,
 /usr/share/fonts/truetype,
 /usr/share/fonts/URW,
 /usr/share/fonts/Speedo,
 /usr/share/fonts/100dpi
```

The `catalogue` list may span several lines or just one. In either event, all of the entries are separated by commas, but the final entry ends without a comma. You can add your new font directory anywhere in this list.

Once you've saved your changes, you must restart the font server. Typically, this is done via SysV startup scripts (described in more detail in Chapter 5):

```
/etc/init.d/xfs restart
```

At this point, you should restart X or type `xset fp rehash` to have X re-examine its font path, including the fonts delivered via the font server.

Although X core fonts and font servers were once very important, most modern X applications now emphasize an entirely different font system: Xft. You can add the same fonts as both X core fonts and as Xft fonts, but the Xft configuration requires doing things in a new way.

## Configuring Xft Fonts

X core fonts (including fonts delivered via a font server) have several important drawbacks:

- They aren't easy to integrate between the screen display and printed output. This makes them awkward from the point of view of word processing or other applications that produce printed output.
- They're server based. This means applications may not be able to directly access the font files because the fonts may be stored on a different computer than the application. This can exacerbate the printing integration problem.
- They provide limited or no support for kerning and other advanced typographic features. Again, this is a problem for word processing programs and other programs that must generate printed output.
- They don't support *font smoothing* (a.k.a. *anti-aliasing*). This technology employs gray pixels (rather than black or white pixels) along curves to create an illusion of greater resolution than the display can produce.

These problems are deeply embedded in the X core font system, so developers have decided to bypass that system. The result is the Xft font system, which is based in part on the FreeType library (<http://www.freetype.org>), an open-source library for rendering TrueType and Type 1 fonts. Xft is a client-based system, meaning that applications access font files on the computer on which they're running. Xft also supports font smoothing and other advanced font features. Overall, the result is greatly improved font support. The cost, though, is that Linux now has *two* font systems: X core fonts and Xft fonts.

Fortunately, you can share the same font directories through both systems. If you've prepared a font directory as described earlier, in "Preparing a Font Directory," you can add it to Xft. Load the `/etc/fonts/local.conf` file into a text editor. Look for any lines in this file that take the following form:

```
<dir>/font/directory</dir>
```

If such lines are present, duplicate one of them and change the duplicate to point to your new font directory. If such lines don't exist, create one just before the `</fontconfig>` line. Be sure not to embed your new font directory specification within a comment block, though. Comments begin with a line that reads `<!--` and end with a line that reads `-->`.



If you create a font directory that holds several subdirectories, you can add just the main directory to `local.conf`. For instance, if you created `/opt/fonts/tt` and `/opt/fonts/type1`, adding `/opt/fonts` to `local.conf` will be sufficient to access all the fonts you installed on the system.

Once you've made these changes, type **fc-cache** as root. This command causes Xft to run through its font directories and create index files. These files are similar to the `fonts.dir` file in principle, but the details differ. If you fail to take this step, you'll still be able to access these fonts, but each user's private Xft cache file will contain the lists of fonts. Generating these files can take some time, thus degrading performance.

To test your Xft fonts, use any Xft-enabled program. Most modern X-based Linux programs are so enabled, so loading a GUI text editor, word processor, Web browser, or other tool that enables you to adjust fonts should do the trick.

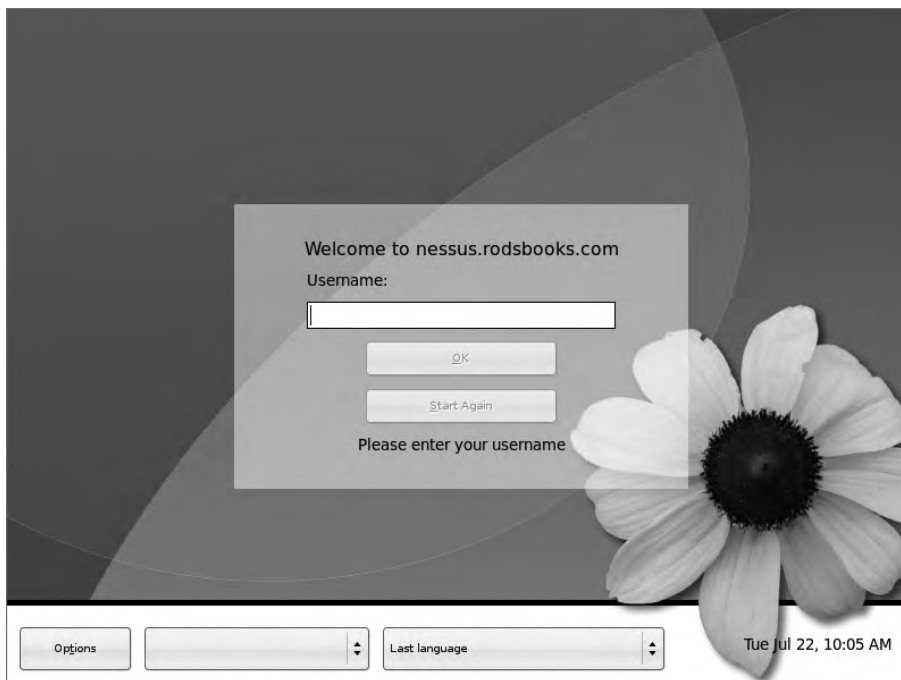
## Managing GUI Logins

Linux can boot into a purely text-based mode in which the console supports text-based logins and text-mode commands. This configuration is suitable for a system that runs as a server computer or for a desktop system for a user who dislikes GUIs. Most desktop users, though, expect their computers to boot into a friendly GUI. For such users, Linux supports a login system that starts X automatically and provides a GUI login screen. Configuring and managing this system requires you to understand a bit of how the system works, how to run it, and how to change the configuration.

## The X GUI Login System

As described later in this chapter, in “Using X for Remote Access,” X is a network-enabled GUI. This fact has many important consequences, and one of these relates to Linux’s GUI login system. This system employs a network login protocol, the *X Display Manager Control Protocol (XDMCP)*. To handle remote logins, an XDMCP server runs on a computer and listens for connections from remote computers’ X servers. To handle local logins, an XDMCP server runs on a computer and starts the local computer’s X server. The XDMCP server then manages the local X server’s display—that is, it puts up a login prompt like that shown in Figure 6.1.

**FIGURE 6.1** An XDMCP server manages local GUI logins to a Linux system.



Three XDMCP servers are common on Linux: the X Display Manager (XDM), the KDE Display Manager (KDM), and the GNOME Display Manager (GDM). A few more exotic XDMCP servers are also available, but these three are the most important. As you may guess by their names, KDM and GDM are associated with the KDE and GNOME projects, respectively, but neither limits your choice of desktop environment. Most Linux distributions run either GDM or KDM as the default XDMCP server, but you can change which one your system uses if you don’t like the default.

## Running an XDMCP Server

Several methods exist to start an XDMCP server. The two most common are to launch it more or less directly from `init`, via an entry in `/etc/inittab` or its ancillary configuration files; or to launch it as part of a runlevel's startup script set, via a SysV startup script. Chapter 5 describes both `init` and SysV startup scripts in general, so consult it for information about these processes.

Whichever method is used, many distributions configure themselves to run their chosen XDMCP server when they start in runlevel 5 but not when they start in runlevel 3. This is the only difference between these two runlevels in most cases. Thus, changing from runlevel 3 to runlevel 5 starts X and the XDMCP server on many distributions, and switching back to runlevel 3 stops X and the XDMCP server. As described in more detail in Chapter 5, you can change runlevels as root with the `telinit` command:

```
telinit 5
```

Permanently changing the runlevel requires editing the `/etc/inittab` file and, in particular, its `id` line:

```
id:5:initdefault:
```

Change the number (5 in this case) to the runlevel you want to use as the default.

A few distributions—most notably Gentoo, Debian, and Debian's derivatives (including the popular Ubuntu)—attempt to start an XDMCP server in all runlevels (or don't do so at all). This is done through the use of a SysV startup script called `xdm`, `kdm`, or `gdm`. Thus, you can temporarily start or stop the XDMCP server by running this script and passing it the `start` or `stop` option. To permanently enable or disable the XDMCP server, you should adjust your SysV startup scripts, as described in Chapter 5.

In addition to the question of whether to run an XDMCP server is the question of *which* XDMCP server to run. Most distributions set a default XDMCP server in one way or another. Two common methods exist:

**Selection via configuration file** Some distributions hide the XDMCP server choice in a configuration file, often in the `/etc/sysconfig` directory. In Fedora, the `/etc/sysconfig/desktop` file sets the `DISPLAYMANAGER` variable to `XDM`, `KDM`, or `GDM`. In openSUSE, `/etc/sysconfig/displaymanager` sets the `DISPLAYMANAGER` variable in a similar way, but using lowercase display manager names.

**Selection via SysV script** In Debian and derivative distributions, such as Ubuntu, the display manager is set via choice of SysV startup script—use the `gdm` script to use GDM, `kdm` to use KDM, and so on. By default, only one XDMCP server (and associated SysV startup script) is installed, so if you want to change your XDMCP server, you may need to install your desired server. Chapter 5 describes how to configure specific SysV startup scripts to run automatically.

Unfortunately, distribution maintainers have had a habit of changing the details of how XDMCP servers are launched from time to time, and the settings are often buried in poorly documented configuration files. Thus, you may need to go digging through the files in your

`/etc` directory to find the correct setting. If you can't find the setting, try using `grep` to search for strings such as `DISPLAYMANAGER` or the name of the XDMCP server that's currently running.

## Configuring an XDMCP Server

XDMCP servers, like most programs, can be configured. Unfortunately, this configuration varies from one server to another, although there are some commonalities.

### Configuring XDM

XDM is the simplest of the major XDMCP servers. It accepts usernames and passwords but doesn't enable users to perform other actions, such as choose which desktop environment to run. (This must be configured through user login files.)

XDM's main configuration file is `/etc/X11/xdm/xdm-config`. Most distributions ship with a basic `xdm-config` file that should work fine for a local workstation. If you want to enable the system to respond to remote login requests, or if you want to verify that the system is *not* so configured, you should pay attention to this line:

```
DisplayManager.requestPort: 0
```

This line tells XDM to not access a conventional server port. To activate XDM as a remote login server, you should change 0 to 177, the traditional XDMCP port. You must then restart XDM.

The `/etc/X11/xdm/Xaccess` file is another important XDM configuration file. If XDM is configured to permit remote access, this file controls who may access the XDM server, and in what ways. A wide-open system contains lines that use an asterisk (\*) to denote that anybody may access the system:

```
*
* CHOOSER BROADCAST
```

The first line tells XDM that anybody may connect, and the second line tells XDM that anybody may request a *chooser*—a display of local systems that accept XDMCP connections. To limit the choices, you should list individual computers or groups of computers instead of using the asterisk wildcard:

```
*.pangaea.edu
tux.example.com
*.pangaea.edu CHOOSER BROADCAST
```

This example lets any computer in the `pangaea.edu` domain connect or receive a chooser, and it also lets `tux.example.com` connect but not receive a chooser.

Many additional options are set in the `/etc/X11/xdm/Xresources` file; it hosts X *resources*, which are similar to environment variables but apply only to X-based programs. For instance, you can change the text displayed by XDM by altering the `xlogin*greeting` resource in this file.



## Configuring KDM

KDM is based partly on XDM and so shares many of its configuration options. Unfortunately, the location of the KDM configuration files is unpredictable; sometimes KDM uses the XDM configuration files, other times they're stored in `/etc/X11/kdm` or `/etc/kde/kdm`, and sometimes they're stored in a truly strange location such as `/usr/share/kde4/config/kdm/kdmrc`.



If you can't find the KDM configuration files, try using your package management tools, described in Chapter 2, "Managing Software." Try obtaining lists of files in the `kdebase` package or other likely candidates, and look for the KDM configuration files.

KDM expands on XDM by enabling users to select a session type when they log in, to shut down the computer from the main KDM prompt, and so on. Most of these extra options are set in the `kdmrc` file, which appears in the same directory as the other KDM configuration files. Some of these options override the more common XDM configuration options for the same features. In particular, the `[Xdmcp]` section provides options relating to network operation. The `Enable` option in that section should be set to `true` if you want to support network logins.

## Configuring GDM

GDM is more of a break from XDM than is KDM. GDM doesn't use the conventional XDM configuration files or similar files. Instead, it uses configuration files that are usually stored in `/etc/X11/gdm`. The most important of these files is `gdm.conf`, and it has a format similar to the `kdmrc` file. As with KDM, you should set the `enable` option to `yes` in the `[xdmcp]` section if you want to enable remote logins.



A GUI control tool for GDM exists on some systems but is missing from others. Type `gdmconfig` as root to launch this program, which enables you to set GDM options using a point-and-click interface.

Like KDM, GDM provides extra options over those of XDM. These options include the ability to choose your login environment and shut down the computer. GDM is a bit unusual in that it prompts for the username and only then presents a prompt for the password. (Figure 6.1 shows the GDM username prompt.) XDM and KDM both present fields for the username and password simultaneously.

# Using X for Remote Access

As noted earlier, in "The X GUI Login System," X is a network-enabled GUI. This fact enables you to run Linux programs remotely—you can set up a Linux system with X programs and run them from other Linux (or even non-Linux) computers. Similarly, you can

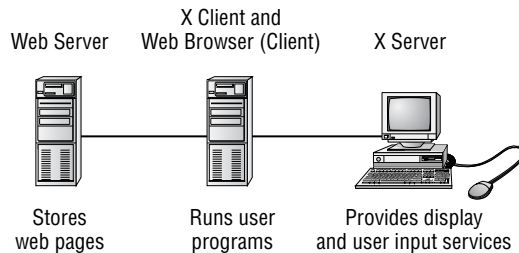
use a Linux computer as an access terminal for X programs that run on a non-Linux Unix computer, such as one running Solaris. To do this, you should first understand something of X's network model—where the client and server systems are located, how X controls access to itself, and so on. You can then proceed to perform the remote accesses.

## X Client/Server Principles

Most people think of servers as powerful computers hidden away in machine rooms and of clients as the desktop systems that ordinary people use. Although this characterization is often correct, it's very wrong when it comes to X. X is a server, meaning that the X server runs on the computer at which the user sits. X clients are the programs that users run—`xterm`, `xfontsel`, KMail, OpenOffice.org, and so on. In most cases, the X server and its clients reside on the same computer, so this peculiar terminology doesn't matter; but when you use X for remote access, you must remember that the X server runs on the user's computer while the X clients run on the remote system.

To make sense of this peculiarity, think of it from the program's point of view. For instance, consider a Web browser such as Firefox. This program accesses Web pages stored on a Web server computer. The Web server responds to requests to load files from Firefox. Just as Firefox loads files, it displays files on the screen and accepts input from its user. From the program's point of view, this activity is much like retrieving Web pages, but it's handled by an X server rather than a Web server. This relationship is illustrated in Figure 6.2.

**FIGURE 6.2** From a program's point of view, the X server works much like a conventional network server such as a Web server.



Ordinarily, Linux is configured in such a way that its X server responds only to local access requests as a security measure. Thus, if you want to run programs remotely, you must make some changes to have Linux lower its defenses—but not too far, lest you let anybody access the X server, which could result in security breaches.

## Using Remote X Clients

Suppose your local network contains two machines. The computer called `zeus` is a powerful machine that hosts important programs, like a word processor and data analysis utilities. The computer called `apollo` is a much less powerful system, but it has an adequate monitor and

keyboard. Therefore, you want to sit at `apollo` and run programs that are located on `zeus`. Both systems run Linux. To accomplish this task, follow these steps:

1. Log into `apollo` and, if it's not already running X, start it.
2. Open a terminal (such as an `xterm`) on `apollo`.
3. Type `xhost +zeus` in `apollo`'s terminal. This command tells `apollo` to accept for display in its X server data that originates on `zeus`.
4. Log into `zeus` from `apollo`. You might use Telnet or Secure Shell (SSH), for instance. The result should be the ability to type commands in a shell on `zeus`.
5. On `zeus`, type `export DISPLAY=apollo:0.0`. (This assumes you're using `bash`; if you're using `tcsh`, the command is `setenv DISPLAY apollo:0.0`.) This command tells `zeus` to use `apollo` for the display of X programs. (Chapter 9, "Writing Scripts, Configuring E-Mail, and Using Databases," describes environment variables, such as `DISPLAY`, in greater detail.)
6. Type whatever you need to type to run programs at the `zeus` command prompt. For instance, you could type `ooffice` to launch OpenOffice.org. You should see the programs open on `apollo`'s display, but they're running on `zeus`—their computations use `zeus`'s CPU, they can read files accessible on `zeus`, and so on.
7. After you're done, close the programs you've launched, log off `zeus`, and type `xhost -zeus` on `apollo`. This tightens security so that a miscreant on `zeus` won't be able to modify your display on `apollo`.



## Real World Scenario

### Encrypting X Connections with SSH

The SSH protocol is a useful remote-access tool. Although it's often considered a text-mode protocol, SSH also has the ability to *tunnel* network connections—that is, to carry another protocol through its own encrypted connection. This feature is most useful for handling remote X access. You can perform the steps described in "Using Remote X Clients" but omit steps 3 and 5 and the `xhost` command in step 7. This greatly simplifies the login process and adds the benefits of SSH's encryption, which X doesn't provide. On the other hand, SSH's encryption is likely to slow down X access, although if you enable SSH's compression features, this problem may be reduced in severity. Overall, tunneling X through SSH is the preferred method of remote X access, particularly when any network in the process isn't totally secure.

SSH tunneling does require that certain options be set. In particular, you must either use the `-X` option to the `ssh` client program or set the `ForwardX11` option to `yes` in `/etc/ssh_config` on the client system. You must also set the `X11Forwarding` option to `yes` in the `/etc/sshd_config` file on the SSH server system. These options enable SSH's X forwarding feature; without these options, SSH's X forwarding won't work.

Sometimes, you can skip some of these steps. For instance, depending on how it's configured, SSH can forward X connections, meaning that SSH intercepts attempts to display X information and passes those requests on to the system that initiated the connection. When this happens, you can skip steps 3 and 5, as well as the `xhost` command in step 7. (See the Real-World Scenario sidebar “Encrypting X Connections with SSH.”)

As an added security measure, many Linux distributions today configure X to ignore true network connections. If your distribution is so configured, the preceding steps won't work; when you try to launch an X program from the remote system, you'll get an error message. To work around this problem, you must make an additional change, depending on how X is launched:

**GDM** On older versions of GDM, check the GDM configuration file (typically `/etc/X11/gdm/gdm.conf`): look for the line `DisallowTCP=true`, and change it to read `DisallowTCP=false`. On newer versions of GDM, edit `/etc/gdm/gdm.schemas`, and look for the line that reads `<key>security/DisallowTCP</key>`. A couple of lines below this, change the key from `true` to `false`.

**KDM or XDM** These two XDMCP servers both rely on settings in the `Xservers` file (in `/etc/X11/xdm` for XDM, and in this location or some other highly variable location for KDM). Look for the line that begins with `:0`. This line contains the command that KDM or XDM uses to launch the X server. If this line contains the string `-noListen tcp`, remove that string from the line. Doing so eliminates the option that causes X to ignore conventional network connections.

**Special openSUSE configuration** In openSUSE, you must edit `/etc/sysconfig/displaymanager` and set the `DISPLAYMANAGER_XSERVER_TCP_PORT_6000_OPEN` option to `yes`.

**X launched from a text-mode login** If you log in using text mode and type `startx` to launch X, you may need to modify the `startx` script itself, which is usually stored in `/usr/bin`. Search this script for the string `-noListen tcp`. Chances are this string will appear in a variable assignment (such as `defaultserverargs`) or possibly in a direct call to the X server program. Remove the `-noListen tcp` option from this variable assignment or program call.

Once you've made these changes, you'll need to restart X as described earlier in “Running an XDMCP Server.” Thereafter, X should respond to remote access requests.



Distribution maintainers disable X's ability to respond to remote requests for a reason. If X responds to remote network requests, the risk of an intruder using a bug or misconfiguration to trick users by displaying bogus messages on the screen is greatly increased. Thus, you should disable this protection only if you're sure that doing so is necessary. You may be able to use an SSH link without disabling this protection. SSH has other benefits as well, as described shortly.

Another option for running X programs remotely is to use the Virtual Network Computing (VNC) system (<http://www.realvnc.com>). VNC runs a special X server on the computer that's to be used from a distance, and a special VNC client runs on the computer at which you sit. You use the client to directly contact the server. This reversal of client and server roles over the normal state of affairs with conventional X remote access is beneficial in some situations, such as when you're trying to access a distant system from behind certain types of firewall. VNC is also a cross-platform protocol; it's possible to control a Windows or Mac OS system from Linux using VNC, but this isn't possible with X. (X servers for Windows and Mac OS are available, allowing you to control a Linux system from these non-Linux OSs.)

## X Accessibility

Historically, most computers have been designed for individuals with normal physical capabilities. As computers have become everyday tools, though, the need for people with various disabilities to use computers has risen. Linux provides tools to help with this task. Some basic X settings (controlled in `xorg.conf` or `XF86Config`) can help in this respect—for instance, you can adjust the keyboard repeat rate to prevent spurious key repeats for individuals who may keep keys pressed longer than average. Other settings are unusual and may require the use of unique accessibility tools to set. Some options must be set in specific desktop environments (KDE or GNOME, for example).

### Keyboard and Mouse Accessibility Issues

You can set many keyboard and mouse options using ordinary desktop environment tools for personalizing keyboard and mouse responses. Other options are more exotic, such as onscreen keyboards.

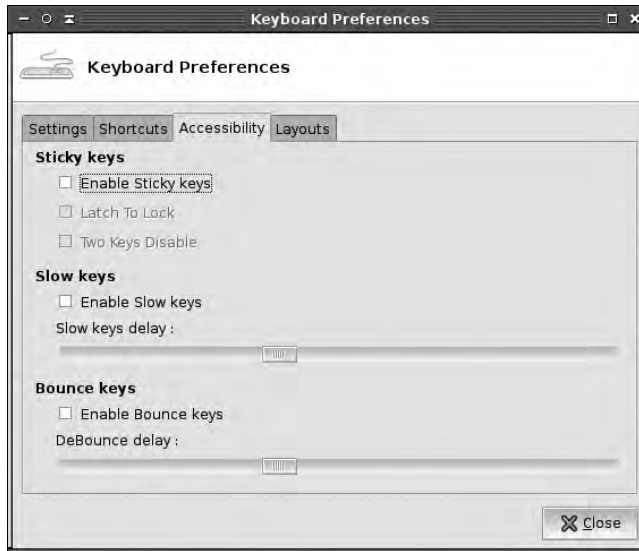


The LPI objectives mention `AccessX`; however, this package as such appears to be abandoned, and its functionality has been folded into the standard desktop environment control panels described in the following pages.

### Standard Keyboard and Mouse Options

Most Linux desktop environments include keyboard and mouse control panel options. For instance, in a standard Fedora 9 GNOME installation, you can find these options by selecting System > Preferences > Hardware > Mouse and System > Preferences > Hardware > Keyboard. Figure 6.3 shows the Keyboard Preferences control panel. Because the locations of such options can be customized from one distribution to another and can change from one release to another, you may need to hunt for the options in your menus.

**FIGURE 6.3** Linux desktop environments provide control panels with accessibility options.



You can find some accessibility settings, such as those for keyboard repeat options, on the main Settings tab. The Accessibility tab provides additional options.

Keyboard and mouse accessibility features include the following:

**Keyboard repeat rate** The repeat rate and delay can be set using sliders on the keyboard control panel's Settings tab. These settings override those set in the X configuration file; but if you use a bare window manager, you may need to set these options in the X configuration file. Disabling keyboard repeat or setting a very long delay may be necessary for some users.

**Sticky keys** When enabled, this option causes keyboard modifier keys (Ctrl, Alt, and Shift) to “stick” when pressed, affecting the next regular key to be pressed even after release of the sticky key. This can be useful for users who have difficulty pressing multiple keys simultaneously. The Toggle Keys option, available in some tools, sounds a beep when a sticky key toggles on or off.

**Slow keys** When activated, this option requires a key to be pressed for longer than a specified period of time before it registers as a keypress. This feature is useful for individuals who tend to accidentally press keys.

**Bounce/debounce keys** If a user tends to accidentally press a single key multiple times, the bounce keys option may be able to compensate for this tendency. (Aging keyboards also sometimes produce keybounce.)

**Mouse tracking and click options** The ordinary mouse tracking and click options can be adjusted to unusual values for those who have special needs.

**Simulated mouse clicks** Some environments let you configure the mouse to simulate a click whenever the mouse pointer stops moving or to simulate a double click whenever the mouse button is pressed for an extended period.

**Mouse emulation/mouse navigation** This option enables you to use the cursor keypad on your keyboard to emulate a mouse.

**Mouse gestures** Gestures are similar to keyboard shortcuts, but for mice; they permit you to activate program options by moving your mouse in particular ways.

## Using Onscreen Keyboards

If a user has difficulty using a regular keyboard but can use a mouse, that user can employ an onscreen keyboard. This is an application that displays an image of a keyboard. Using the mouse to press the keys on the keyboard image works much like using a real keyboard. Some other keyboards require the user to enter text into their own buffers and then cut-and-paste the text from the keyboard application into the target program.

Browse the menus for your desktop environment to locate the onscreen keyboards available on your system. If you can't find one, or if you don't like it, use your package manager to search for such programs—searching on “keyboard” should turn up some options.

The GNOME On-Screen Keyboard (GOK) deserves special mention as a particularly powerful tool in this category. This program provides not only an onscreen keyboard but also tools that provide shortcuts for various mouse, menu, and toolbar features of other programs, as well as tools to help users navigate the GNOME desktop. You can launch GOK from GNOME by selecting Applications > Accessibility > On-Screen Keyboard (the exact location may vary from one distribution or GNOME version to another) or by typing **gok** at a command prompt. You can learn more at the main GOK Web page, <http://www.gok.ca>.

## Screen Display Settings

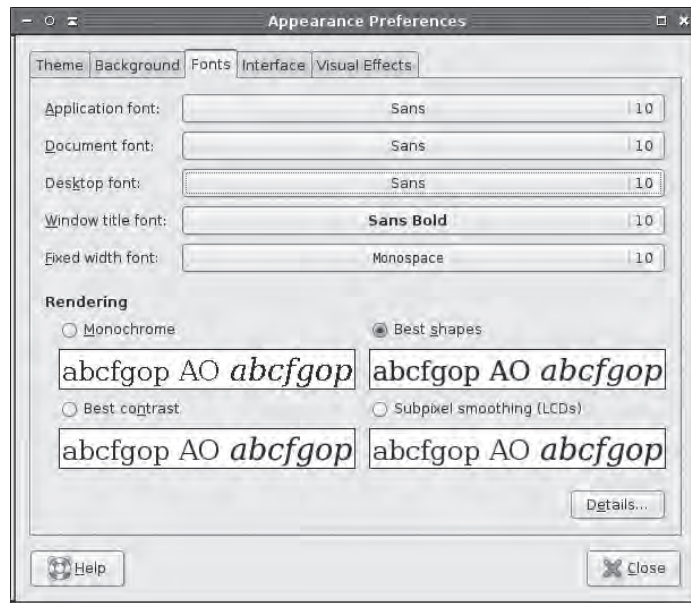
Users with poor eyesight can benefit from adjustments to screen settings and applications. These include font options, contrast settings, and screen magnification tools.

### Adjusting Default Fonts

Most desktop environments provide options to set the default fonts used on the screen. Figure 6.4 shows the Appearance Preferences dialog box provided with GNOME. You can access this by selecting the System > Preferences > Appearance menu on an Ubuntu 8.04 system. A similar tool is available in KDE, accessible from the Appearance item in its System Settings panel.

To adjust the fonts, click the font for each of the main categories, such as Application Font and Document Font in Figure 6.4. The result is a font selection dialog box, in which you can select the font (Sans, Times, and so on), the font style (normal, bold, and so on), and size in points. Adjust these options until you find a setting that works well. You'll have to adjust the font for each of the categories, or at least for those that are most important.

**FIGURE 6.4** Linux desktop environments provide control panels with accessibility options.



Unfortunately, although many applications take their cues on fonts from the GNOME and KDE settings, others don't. Thus, you may need to adjust options in at least some individual applications, as well as in the desktop environment as a whole.

## Adjusting Contrast

Desktop environments provide various themes—settings for colors, window manager decorations, and so on. Some themes are better than others in terms of legibility. For instance, some themes are very low in contrast, and others are high in contrast.



Monitors have their own contrast controls. You can adjust these for best legibility, of course, but the contrast adjustments afforded by desktop environment settings are independent of a monitor's contrast settings.

In GNOME, you can set themes in the same Appearance preferences dialog box in which you set the fonts (Figure 6.4); you click the Theme tab and select the theme you want to use. In KDE, the Appearance item in System Settings provides theme options.

## Using Magnifier Tools

A screen magnifier application enlarges part of the screen—typically the area immediately surrounding the mouse. One common screen magnifier is KMag, which is part of the KDE suite. (You can use KMag even in GNOME, XFce, or other desktop environments, though.)



To use it, type **kmag** or select it from your desktop menus. The result is the KMag window on the screen, which enlarges the area around the cursor by default.

## Using Additional Assistive Technologies

In addition to keyboard, mouse, and conventional display tools, some additional programs can help those with special needs. Most notably, screen readers and Braille displays can help those who can't read conventional displays.

### Configuring Linux to Speak

Computer speech synthesis has existed for decades. Today, several speech synthesis products are available for Linux, including these:

**Orca** This program, which is based at <http://live.gnome.org/Orca>, is a screen reader that's been integrated into GNOME 2.16 and later.

**Emacspeak** Similar to Orca in many respects, this program aims to enable those with visual impairments to use a Linux computer. You can learn more at <http://emacspeak.sourceforge.net>.

### Using Braille Displays

A Braille display is a special type of computer monitor. Rather than display data visually, it creates a tactile display of textual information in Braille. As such, a Braille display is an efficient way for those with visual impairments to access text-mode information, such as that displayed at a Linux text-mode console. Many Linux text-mode programs can manage a Braille display with no changes.

To use a Braille display, special Linux software is required. The BRLTTY (<http://www.mielke.cc/brlTTY/>) project provides a Linux daemon that redirects text-mode console output to a Braille display. It includes features that support scrollbar, multiple virtual terminals, and even speech synthesis.

The 2.6.26 Linux kernel adds some direct support for Braille displays. If you're familiar with Linux kernel compilation, you should check the Accessibility options in the Device Drivers area of the kernel configuration.

## Configuring Localization and Internationalization

Linux is an international OS. Its developers reside in many countries around the world, and its users are even more widespread. As such, Linux supports a wide variety of character sets, keyboards, date/time display formats, and other features that can vary from one region to another. Many of these features are set up when you answer questions during installation,

but knowing about them—and how to change them—can help you manage your system, particularly if you need to change these options for any reason.

## Setting Your Time Zone

Linux uses *Coordinated Universal Time* (UTC) internally. This is the time in Greenwich, England, uncorrected for Daylight Saving Time. When you write a file to disk on a Linux-native filesystem, the time stamp is stored in UTC. When you use tools such as `cron` (described in Chapter 7, “Administering the System”), they “think” in UTC. Chances are, though, that you use local time. Thus, a Linux computer must be able to translate between local time and UTC.

To perform this translation, Linux needs to know your time zone. Linux looks to the `/etc/localtime` file for information about its local time zone. This file is one of the rare configuration files that’s *not* a plain-text file, so you shouldn’t try editing it with a text editor. This file could be a file of its own, or it could be a symbolic or hard link to another file. If it’s a symbolic link, you should be able to determine your time zone by performing a long file listing to see the name of the file to which `localtime` links:

```
$ ls -l /etc/localtime
lrwxrwxrwx 1 root root 36 May 14 2008 /etc/localtime -> ➡
/usr/share/zoneinfo/America/New_York
```

If `/etc/localtime` is a regular file and not a symbolic link, or if you want further confirmation of your time zone, try using the `date` command by itself:

```
$ date
Mon Sep 1 12:50:58 EDT 2008
```

The result includes a standard three-letter time zone code (EDT in this example). Of course, you’ll need to know these codes, or at least the code for your area. For a list of time zone abbreviations, consult <http://www.timeanddate.com/library/abbreviations/timezones/>. Note that the time zone codes vary depending on whether Daylight Saving Time is active, but the Linux time zone files don’t change with this detail. Part of what these files do is describe when to change the clock for Daylight Saving Time. If you need to change your time zone, you should copy or link a sample file from a standard directory location to the `/etc/localtime` file:

1. Log in as `root` or acquire `root` privileges.
2. Change to the `/etc` directory.
3. View the contents of the `/usr/share/zoneinfo` directory. This directory contains files for certain time zones named after the zones or the regions to which they apply, such as GMT, Poland, and Japan. Most users will need to look in subdirectories, such as `/usr/share/zoneinfo/US` for the United States or `/usr/share/zoneinfo/America` for North and South America. These subdirectories contain zone files named after the regions or cities to which they apply, such as `Eastern` or `Los_Angeles`. (The `US` subdirectory contains files named after time zones or states, whereas the `America` subdirectory holds files

named after cities.) Identify the file for your time zone. Note that you might use a zone file named after a city other than the one in which you reside but that's in the same time zone as you. For instance, the `New_York` file works fine if you're in Boston, Philadelphia, Cincinnati, or any other city in the same (Eastern) time zone as New York.

4. If a `localtime` file exists in `/etc`, delete it or rename it. (For instance, type `rm localtime`.)
5. Create a symbolic link from your chosen time zone file to the `/etc/localtime` file. For instance, you can type `ln -s /usr/share/zoneinfo/US/Eastern localtime` to set up a computer in the U.S. Eastern time zone. Alternatively, you can copy a file (`cp`) rather than create a symbolic link (`ln -s`). If `/etc` and your target file are on the same filesystem, you can create a hard link rather than a symbolic link if you like.

At this point, your system should be configured to use the time zone you've selected. If you changed time zones, you should be able to see the difference by typing `date`, as described earlier. The time zone code on your system should change compared to issuing this command before you changed the `/etc/localtime` file or link. The time should also change by the number of hours between the time zones you've selected (give or take a bit for the time it took you to change the time zone files).

In addition to `/etc/localtime`, some distributions use a secondary file with text-mode time zone data. This file is called `/etc/timezone` on Debian and its derivatives. On Fedora and related distributions, it's `/etc/sysconfig/clock`. This file contains a line or two with the name of the time zone, sometimes in the form of a variable assignment. For instance, the `/etc/timezone` file on my Ubuntu system looks like this:

```
America/New_York
```

This file provides a quick way to check your time zone. It should also be updated when you change your time zone, lest higher-level configuration tools become confused.

Some distributions provide text-mode or GUI tools to help make time zone changes. Look for a program called `tzsetup`, `tzselect`, `tzconfig`, or something similar. Typically, these programs ask you for your location in several steps (starting with your continent, then your nation, and perhaps then your state or city) and create an appropriate symbolic link.

## Querying and Setting Your Locale

To localize your computer, you must first understand what a locale is in Linux parlance. Once you understand the basics, you can identify your current locale and other locales available to you. If necessary, you may need to install another locale's data. You can then set your computer to use that locale.

### What Is a Locale?

In Linux, a *locale* is a way of specifying the computer's (or user's) language, country, and related information for purposes of customizing displays. A single locale takes the following form:

```
[language[_territory]][.codeset][@modifier]
```

Each part of this string has a set of specific acceptable forms. For instance, *language* can be en (English), fr (French), ja (Japanese), and so on. These are two- or three-letter codes for languages.

The *territory* can be US (United States), FR (France), JP (Japan), and so on. These are codes for specific regions—generally nations.

The *codeset* can be ASCII, UTF-8, or other encoding names. The *American Standard Code for Information Interchange* (ASCII) is the oldest and most primitive encoding method; it supports 7-bit encodings (generally stored in 8-bit bytes) that can handle English, including common punctuation and symbols. ASCII can't handle characters used in many non-English languages, though, so it's awkward at best for international use. *ISO-8859* was an early attempt to extend ASCII; it employs an eighth bit to extend ASCII by 128 characters, giving room for the characters needed by a small number of non-Roman alphabets. *ISO-8859* is broken down into many substandards, each of which handles one language or small group of languages. *ISO-8859-1* covers Western European languages and *ISO-8859-5* provides Cyrillic support, for instance.

The latest language codeset is the *8-bit Unicode Transformation Format* (UTF-8). Like *ISO-8859*, UTF-8 starts with ASCII, but it extends it by supporting variable-byte extensions, so that a single character can take anywhere from one to four bytes to be encoded. This provides the ability to encode text in any language supported by *Unicode*, which is a character set designed to support as many languages as possible. The big advantage of UTF-8 over *ISO-8859* is that there's no need to specify a substandard, such as *ISO-8859-1* or *ISO-8859-5*; UTF-8 handles all of its writing systems automatically.

The *modifier* is a locale-specific code that modifies how it works. For instance, it may affect the sort order in a language-specific manner.

## What Is Your Locale?

A locale code can be assigned to one or more of several environment variables. To learn how these are set on your system, issue the `locale` command without any arguments:

### \$ locale

```
LANG=en_US.UTF-8
LC_CTYPE="en_US.UTF-8"
LC_NUMERIC="en_US.UTF-8"
LC_TIME="en_US.UTF-8"
LC_COLLATE="en_US.UTF-8"
LC_MONETARY="en_US.UTF-8"
LC_MESSAGES="en_US.UTF-8"
LC_PAPER="en_US.UTF-8"
LC_NAME="en_US.UTF-8"
LC_ADDRESS="en_US.UTF-8"
LC_TELEPHONE="en_US.UTF-8"
LC_MEASUREMENT="en_US.UTF-8"
LC_IDENTIFICATION="en_US.UTF-8"
LC_ALL=
```

As you can see, quite a few locale variables exist. When programs pay attention to these variables, they adjust themselves appropriately for your locale. For instance, a word processor may default to using common US paper sizes (such as 8.5 × 11 inches) when the *territory* code in LC\_PAPER is set to US, but European paper sizes (such as A4, 210 × 297 mm) when *territory* is set to a code for a country where these paper sizes are more common.

Most of the locale variables set specific and obvious features, such as LC\_PAPER (paper size), LC\_MEASUREMENT (measurement units), and so on. The LC\_ALL variable is a sort of master override—if it’s set, it overrides all the other LC\_\* variables.

A related environment variable is LANG. It takes the same type of locale specification as the LC\_\* variables. It sets the locale in case the LC\_\* variables aren’t set.

While you’re using the `locale` command, you should try it with the `-a` option, which identifies all the locales that are available to you:

```
$ locale -a
C
en_US.utf8
POSIX
```

In this example (from an Ubuntu system), very few locales are installed. Some systems may have many more; one of my computers has literally hundreds of locales available.

## Changing Your Locale

If you want to change your locale, you should first verify that an appropriate one is available to you by using `locale -a`, as just described. If you don’t see appropriate codes, you may need to install additional packages. Unfortunately, names for these packages aren’t standardized. Your best bet is to use a GUI package manager such as `yumex` or `Synaptic` (described in Chapter 2) to search on package names and descriptions that include `locale` or `language`. In the case of an Ubuntu system that provided just a few locales, many more could be installed from packages called `language-support-??`, where `??` is a two-character language code.

To temporarily change your locale, the simplest method is to set the LC\_ALL environment variable. For safety, you should also set LANG. For instance, to use the locale for Great Britain rather than the United States, you can type

```
$ export LANG=en_GB.UTF-8
$ export LC_ALL=en_GB.UTF-8
```

The result should be that all the locale variables change for that session. There will also be changes in the output of programs that honor locales. Note that this change only affects the current shell and the programs launched from it; you won’t see changes in programs that are already running or that you launch from another shell.

To permanently change your locale, you can adjust your bash startup script files, such as `~/.bashrc` or `/etc/profile`, as described in Chapter 1, “Exploring Linux Command-Line Tools.” (Shell scripting is described in more detail in Chapter 9, but setting or adjusting the LANG and LC\_ALL environment variables is fairly straightforward.)

X's configuration file (`x.org` or `XF86Config`) includes an option called `XkbLayout` in the keyboard's `InputDevice` section. This option takes a partial or complete locale specification, but converted to lowercase—for instance, `us` or `en_us.utf-8`. Adjusting this option can provide you with access to language- or country-specific keys. After changing this option, you'll have to restart X for the changes to take effect.

Some programs and sets of programs may require you to set the language independent of the overall system locale. Thus, you may need to adjust the language for certain specific programs. If a program doesn't seem to respond to the overall locale setting, check its documentation or browse through its menus to find a way to adjust its defaults.

One setting requires special mention: `LANG=C`. When you set `LANG` to `C`, programs that see this environment variable display output without passing it through locale translations. This can be helpful in some cases if a program's output is being corrupted by the locale—say by having conversions to UTF-8 change characters that need to be preserved as 8-bit entities. Thus, setting `LANG=C` can help to avoid some types of problems, particularly in pipelines and scripts that pass one program's data to another program in binary form.



Localization support is, to some extent or another, the responsibility of each program's author. It's entirely possible to write a program that supports just one language or a small subset of languages. Thus, you won't be able to get every program to support your desired language, particularly if it's an unusual one.

## Modifying Text-File Locales

Sometimes it's necessary to process textual data that originated on a system that used one encoding but process the data with a program that doesn't support that encoding. For instance, your preferred text editor might support UTF-8 but not ISO-8859. If you deal exclusively with English text files in ASCII, this isn't a problem; but if you receive an ISO-8859-1 text file with a few non-Roman characters, such as characters with umlauts, your editor might display those characters strangely.

To overcome this problem, the `iconv` utility converts between character sets. Its syntax is as follows:

```
iconv -f encoding [-t encoding] [inputfile]...
```

The `-f` and `-t` options specify the source and destination encodings. (You can obtain a list of encodings by typing `iconv --list`.) If you omit the target encoding, `iconv` uses your current locale for guidance. The program sends output to standard output, so if you want to store the data in a file, you must redirect it:

```
$ iconv -f iso-8859-1 -t UTF-8 umlautfile.txt > umlautfile-utf8.txt
```

# Configuring Printing

Most Linux desktop users work with X, but many also work with another output medium: printed pages. Printing in Linux is a cooperative effort involving several tools. Applications submit print jobs as PostScript documents. Because most Linux systems aren't connected directly to true PostScript printers, a program called Ghostscript converts the print job into a form that the system's printer can actually handle. The print queue, which is managed by software known as the Common Unix Printing System (CUPS), then sends the job to the printer. At various stages, administrators and users can examine the contents of a print queue and modify the queue. Understanding the tools used to create and manage print queues will help you to manage Linux printing.

## Conceptualizing the Linux Printing Architecture

Linux printing is built around the concept of a *print queue*. This is a sort of holding area where files wait to be printed. A single computer can support many distinct print queues. These frequently correspond to different physical printers, but it's also possible to configure several queues to print in different ways to the same printer. For instance, you might use one queue to print single-sided and another queue for double-sided printing on a printer that supports duplexing.

Users submit print jobs by using a program called `lpr`. Users can call this program directly, or they may let another program call it. In either case, `lpr` sends the print job into a specified queue. This queue corresponds to a directory on the hard disk, typically in a subdirectory of the `/var/spool/cups` directory. The CUPS daemon runs in the background, watching for print jobs to be submitted. The printing system accepts print jobs from `lpr` or from remote computers, monitors print queues, and serves as a sort of “traffic cop,” directing print jobs in an orderly fashion from print queues to printers.



The LPI exam emphasizes the CUPS printing system, which is the most common printing system on modern Linux systems. Older systems used the BSD Line Printer Daemon (LPD) or the similar LPRng printing systems. Many of the CUPS tools are workalikes of the LPD tools. If you ever use a system that runs LPD or LPRng, you'll find that user commands such as `lpr` work in the way you expect, but configuring the printer must be done in a very different way.

One important and unusual characteristic of Linux printing is that it's highly network oriented. As just noted, Linux printing tools can accept print jobs that originate from remote systems as well as from local ones. Even local print jobs are submitted via network protocols, although they don't normally use network hardware, so even a computer with no network connections can print. In addition to being a server for print jobs, CUPS can function as a client, passing print jobs to other computers that run the same protocols.

Applications can query CUPS about a printer's capabilities—its paper sizes, whether it supports color, and so on. The older LPD and LPRng printing systems didn't support such bidirectional communication. Thus, support for these features still isn't universal; some programs make assumptions about a printer's capabilities or must be told things that other programs can figure out by themselves.

## Understanding PostScript and Ghostscript

If you've configured printers under Windows, Mac OS, OS/2, or certain other OSs, you're probably familiar with the concept of a *printer driver*. In these OSs, the printer driver stands between the application and the printer queue. In Linux, the printer driver is part of Ghostscript (<http://www.cs.wisc.edu/~ghost/>), which exists as part of the printer queue, albeit a late part. This relationship can be confusing at times, particularly because not all applications or printers need Ghostscript. Ghostscript serves as a way to translate PostScript, a common printer language, into forms that can be understood by many different printers. Understanding Ghostscript's capabilities, and how it fits into a printer queue, can be important for configuring printers.

### PostScript: The De Facto Linux Printer Language

Laser printers began to become popular in the 1980s. The first laser printers were very expensive devices, and many of them supported what was at that time a new and powerful printer language: *PostScript*. PostScript printers became popular as accessories for the Unix systems of the day. Unix print queues weren't designed with Windows-style printer drivers in mind, so Unix programs that took advantage of laser printer features were typically written to produce PostScript output directly. As a result, PostScript developed into the de facto printing standard for Unix and, by inheritance, Linux. Where programs on Windows systems were built to interface with the Windows printer driver, similar programs on Linux generate PostScript and send the result to the Linux printer queue.

Some programs violate this standard. Most commonly, many programs can produce raw text output. Such output seldom poses a major problem for modern printers, although some PostScript-only models choke on raw text. Some other programs can produce either PostScript or *Printer Control Language (PCL)* output for Hewlett-Packard laser printers or their many imitators. A very few programs can generate output that's directly accepted by other types of printers.

The problem with PostScript as a standard is that it's uncommon on the low- and mid-priced printers with which Linux is often paired. Therefore, to print to such printers using traditional Unix programs that generate PostScript output, you need a translator and a way to fit that translator into the print queue. This is where Ghostscript fits into the picture.

### Ghostscript: A PostScript Translator

When it uses a traditional PostScript printer, a computer sends a PostScript file directly to the printer. PostScript is a programming language, albeit one that's oriented toward the goal of producing a printed page as output. Ghostscript is a PostScript interpreter that runs on a



computer. It takes PostScript input, parses it, and produces output in any of dozens of different bitmap formats, including formats that can be accepted by many non-PostScript printers. This makes Ghostscript a way to turn many inexpensive printers into Linux-compatible PostScript printers at very low cost. Ghostscript is available as open source software (GNU Ghostscript), with a more advanced variant (Aladdin Free Public License, or AFPL, Ghostscript) available for free. AFPL Ghostscript is not freely redistributable in any commercial package, though. Because all Linux distributions are available on CD-ROMs sold for a price, they ship with the older GNU Ghostscript, which works well enough for most users.

One of Ghostscript's drawbacks is that it produces large output files. A PostScript file that produces a page filled with text may be just a few kilobytes in size. If this page is to be printed on a 600 dots per inch (dpi) printer using Ghostscript, the resulting output file could be as large as 4MB—assuming it's black and white. If the page includes color, the size could be much larger. In some sense, this is unimportant because these big files will be stored on your hard disk only briefly. They do still have to get from the computer to the printer, though, and this process can be slow. Also, some printers (particularly laser printers) may require memory expansion to operate reliably under Linux.



## Real World Scenario

### Choosing an Appropriate Printer for Linux

If you want a speedy printer for Linux, choose a model with built-in PostScript. This is particularly true for textual and line-art output, which suffers the most in terms of size expansion going from PostScript to bitmap. In my experience, Ghostscript-driven printers work well enough for 600dpi black-and-white printers with speeds of up to about six pages per minute (ppm), although theoretically both the parallel port and USB 1.x port should be able to handle speeds of three to five times that value. If the printer's speed is greater than that, the parallel or USB 1.x port may not be able to deliver the necessary performance, although you may be able to tweak it to get somewhat better speed. USB 2.0 and Ethernet printers can handle higher speeds, which can be important for fast color printers.

Color ink-jet printers are generally limited more by the speed of the print head than by the speed of the data coming over their ports. Few such printers directly support PostScript, either. Some models come with Windows-based PostScript engines that are conceptually similar to Ghostscript, but such software is useless under Linux. There are a few PostScript ink-jets on the market, as well as color PostScript printers that use other printing technologies.

For information about what printers are supported by Ghostscript, check the Ghostscript Web page or the OpenPrinting database Web page ([http://www.linuxprinting.org/printer\\_list.cgi](http://www.linuxprinting.org/printer_list.cgi)).

## Squeezing Ghostscript into the Queue

Printing to a non-PostScript printer in Linux requires fitting Ghostscript into the print queue. This is generally done through the use of a *smart filter*. This is a program that's called as part of the printing process. The smart filter examines the file that's being printed, determines its type, and passes the file through one or more additional programs before the printing software sends it on to the printer. The smart filter can be configured to call Ghostscript with whatever parameters are appropriate to produce output for the queue's printer.

CUPS ships with its own set of smart filters, which it calls automatically when you tell the system what model printer you're using. CUPS provides a Web-based configuration tool, as described in the upcoming section "Using the Web-Based CUPS Utilities." This system, or distribution-specific GUI printer configuration tools, can make setting up a printer for CUPS fairly straightforward.

The end result of a typical Linux printer queue configuration is the ability to treat any supported printer as if it were a PostScript printer. Applications that produce PostScript output can print directly to the queue. The smart filter detects that the output is PostScript and runs it through Ghostscript. The smart filter can also detect other file types, such as plain-text and various graphics files, and it can send them through appropriate programs instead of or in addition to Ghostscript in order to create a reasonable printout.

If you have a printer that can process PostScript, the smart filter is usually still involved, but it doesn't pass PostScript through Ghostscript. In this case, the smart filter passes PostScript directly to the printer, but it still sends other file types through whatever processing is necessary to turn them into PostScript.

## Running a Printing System

Because Linux printing systems run as daemons, they must be started before they're useful. This task is normally handled automatically via startup scripts in `/etc/rc.d`, `/etc/init.d`, or `/etc/rc?.d` (where ? is a runlevel number). Look for startup scripts that contain the string `cups` (or `lpd` or `lpng` for older systems) in their names to learn what your system is running. If you're unsure if a printing system is currently active, use the `ps` utility to search for running processes by these names, as in:

```
$ ps ax | grep cups
1896 ? Ss 0:01 cupsd
```

This example shows that `cupsd`, the CUPS daemon, is running, so the system is using CUPS for printing. If you can't find any running printing system, consult your distribution's documentation to learn what is available and check that the appropriate package is installed. All major distributions include startup scripts that should start the appropriate printing daemon when the computer boots.

## Configuring CUPS

CUPS uses various configuration files in the `/etc/cups` directory and its subdirectories to manage its operation. You can edit these files directly, and you may need to do so if you want to share printers or use printers shared by other CUPS systems. The simplest way to add printers to CUPS, though, is to use the tool's Web-based configuration utility.

### Editing the CUPS Configuration Files

You can add or delete printers by editing the `/etc/cups/printers.conf` file, which consists of printer definitions. Each definition begins with the name of a printer, identified by the string `DefaultPrinter` (for the default printer) or `Printer` (for a nondefault printer) in angle brackets (`<>`), as in the following:

```
<DefaultPrinter okidata>
```

This line marks the beginning of a definition for a printer queue called `okidata`. The end of this definition is a line that reads `</Printer>`. Intervening lines set assorted printer options, such as identifying strings, the printer's location (its local hardware port or network location), its current status, and so on. Additional options are stored in a *PostScript Printer Definition (PPD)* file that's named after the queue and stored in the `/etc/cups/ppd` subdirectory. PPD files follow an industry-standard format. For PostScript printers, you can obtain a PPD file from the printer manufacturer, typically from a driver CD-ROM or from the manufacturer's Web site. CUPS and its add-on driver packs also ship with a large number of PPD files that are installed automatically when you use the Web-based configuration utilities.

As a general rule, you're better off using the CUPS Web-based configuration tools to add printers rather than adding printers by directly editing the configuration files. If you like, though, you can study the underlying files and tweak the configurations using a text editor to avoid having to go through the full Web-based tool to make a minor change.

One exception to this rule relates to configuring the CUPS Web-based interface tool itself and CUPS' ability to interface with other CUPS systems. One of the great advantages of CUPS is that it uses a new network printing protocol, known as the *Internet Printing Protocol (IPP)*, in addition to the older LPD protocol used by BSD LPD and LPRng. IPP supports a feature it calls *browsing*, which enables computers on a network to automatically exchange printer lists. This feature can greatly simplify configuring network printing. You may need to change some settings in the main CUPS configuration file, `/etc/cups/cupsd.conf`, to enable this support.

The `/etc/cups/cupsd.conf` file, which is structurally similar to the Apache Web server configuration file, contains a number of configuration blocks that specify which other systems should be able to access it. Each block controls access to a particular location on the server. These blocks look like this:

```
<Location /printers>
Order Deny,Allow
Deny from All
```

```

BrowseAllow from 127.0.0.1
BrowseAllow from 192.168.1.0/24
BrowseAllow from @LOCAL
Allow from 127.0.0.1
Allow from 192.168.1.0/24
Allow from @LOCAL
</Location>

```



If you're configuring a workstation with a local printer that you don't want to share, or if you want to configure a workstation to use printers shared via LPD or some other non-IPP printing protocol, you shouldn't need to adjust `/etc/cups/cupsd.conf`. If you want to access remote IPP printers, however, you should at least activate browsing by setting the directive `Browsing On`, as described shortly. You shouldn't have to modify your location definitions unless you want to share your local printers.

The `/printers` location, shown here, controls access to the printers themselves. The following list includes features of this example:

**Directive order** The `Order Deny,Allow` line tells CUPS in which order it should apply allow and deny directives—in this case, allow directives modify deny directives.

**Default policy** The `Deny from All` line tells the system to refuse all connections except those that are explicitly permitted.

**Browsing control lines** The `BrowseAllow` lines tell CUPS from which other systems it should accept browsing requests. In this case, it accepts connections from itself (127.0.0.1), from systems on the 192.168.1.0/24 network, and from systems connected to local subnets (@LOCAL).

**Access control lines** The `Allow` lines give the specified systems non-browse access to printers—that is, those systems can print to local printers. In most cases, the `Allow` lines are the same as the `BrowseAllow` lines.

You can also create a definition that uses `Allow from All` and then creates `BrowseDeny` and `Deny` lines to limit access. As a general rule, though, the approach shown in this example is safer. Locations other than the `/printers` location can also be important. For instance, there's a root (`/`) location that specifies default access permissions to all other locations and an `/admin` location that controls access to CUPS administrative functions.

Before the location definitions in `cupsd.conf` are a few parameters that enable or disable browsing and other network operations. You should look for the following options specifically:

**Enabling browsing** The `Browsing` directive accepts `On` and `Off` values. The CUPS default is to enable browsing (`Browsing On`), but some Linux distributions disable it by default.

**Browsing access control** The `BrowseAddress` directive specifies the broadcast address to which browsing information should be sent. For instance, to broadcast data on your printers to the 192.168.1.0/24 subnet, you'd specify `BrowseAddress 192.168.1.255`.

Once you've configured a CUPS server to give other systems access to its printers via appropriate location directions, and once you've configured the client systems to use browsing via `Browsing On`, all the systems on the network should auto-detect all the printers on the network. You don't need to configure the printer on any computer except the one to which it's directly connected. All printer characteristics, including their network locations and PPD files, are propagated automatically by CUPS. This feature is most important in configuring large networks with many printers or networks on which printers are frequently added and deleted.

## Obtaining CUPS Printer Definitions

Most Linux distributions ship with CUPS smart filter support for a variety of printers. If you can't find support for your printer, you can look for additional printer definitions. These definitions may consist of PPD files, appropriate behind-the-scenes "glue" to tell CUPS how to use them, and possibly Ghostscript driver files. You can obtain these printer definitions from several sources:

**Your Linux distribution** Many distributions ship extra printer definitions under various names, so check your distribution for such a package. Many distributions include some of the driver packages described next.

**Foomatic** The Linux Printing Web site hosts a set of utilities and printer definitions known collectively as Foomatic (<http://www.linuxfoundation.org/en/OpenPrinting/Database/Foomatic>). These provide many additional printer definitions for CUPS (as well as for other printing systems).

**Gutenprint** The Gutenprint drivers, originally known as GIMP Print, after the GNU Image Manipulation Program (GIMP), support a wide variety of printers. Check <http://gimp-print.sourceforge.net> for more information.

**CUPS DDK** The CUPS Driver Development Kit (DDK; <http://www.cups.org/ddk/>) is a set of tools designed to simplify CUPS driver development. It ships with a handful of drivers for Hewlett-Packard and Epson printers.

**Printer manufacturers** Some printer manufacturers offer CUPS drivers for their printers. These may be nothing more than Foomatic, Gutenprint, or other open source drivers; but a few provide proprietary drivers, some of which support advanced printer features that the open source drivers don't support.

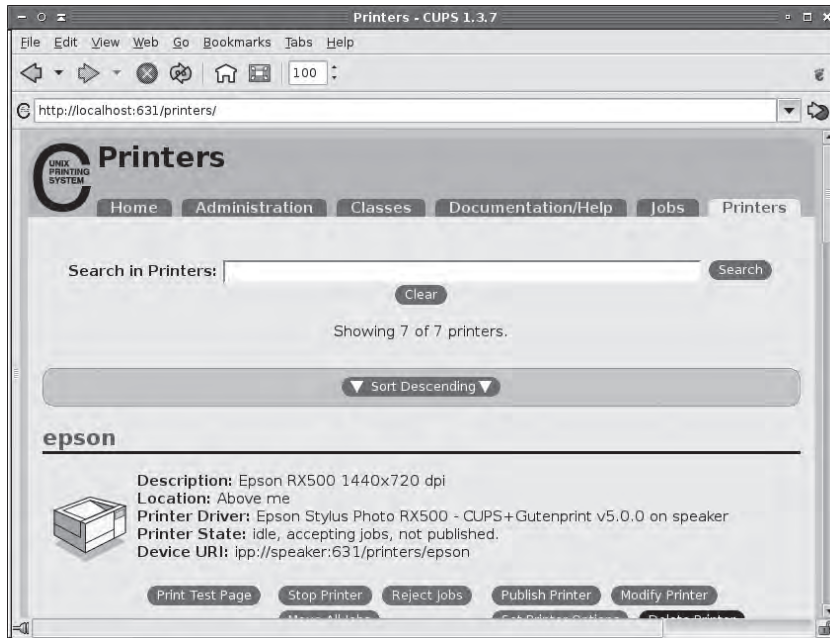
Chances are good that you'll find support for your printer in your standard installation, particularly if your distribution has installed the Foomatic or Gutenprint package. If you start configuring printers and can't find your model, though, you should look for an additional printer definition set from one of the preceding sources.

## Using the Web-Based CUPS Utilities

The CUPS IPP printing system is closely related to the Hypertext Transfer Protocol (HTTP) used on the Web. The protocol is so similar, in fact, that you can access a CUPS daemon by using a Web browser. You need only specify that you want to access the server

on port 631—the normal printer port. To do so, enter **http://localhost:631** in a Web browser on the computer running CUPS. (You may be able to substitute the hostname or access CUPS from another computer by using the other computer’s hostname, depending on your `cupsd.conf` settings.) This action brings up a list of administrative tasks you can perform. Click Printers or Manage Printers to open the printer management page, shown in Figure 6.5.

**FIGURE 6.5** CUPS provides its own Web-based configuration tool.



If you’re configuring a stand-alone computer or the only one on a network to use CUPS, the printer list will be empty, unlike the one shown in Figure 6.5. If other computers on your network use CUPS, you may see their printers in the printer list, depending on their security settings.

You can add, delete, or modify printer queues using the CUPS Web control system. To add a printer, follow these steps:

1. From the Home or Administration tab, click Add Printer.
2. The system displays a page asking for the printer’s name, location, and description. Enter appropriate information in the Name, Location, and Description fields. These fields are all entirely descriptive, so enter anything you like. (Users will use your entry in the Name field to access the printer, though.) When you click Continue, CUPS asks for the printer device.

3. The printer device may be a local hardware port (such as a parallel printer port or a USB port), a remote LPD printer, a remote SMB/CIFS (Samba) printer, or another device. The precise options available vary from one distribution to another. Select the appropriate one from the pop-up list, and click Continue.



USB printers must be turned on and connected to the computer when CUPS starts in order to be configured or used. If your printer was turned off or disconnected when your system booted, you may need to restart CUPS via its SysV startup script and then start over again to configure it.

4. If you entered a network printer, the result is a page in which you enter the complete path to the device. Type the path, such as **lpd://printserv/brother** to print to the brother queue on the printserv computer. Click Continue when you're done.
5. If you entered a local device in step 3 or after you've entered the complete path in step 4, you'll see a list of manufacturers. Select one, and click Continue. Alternatively, you can point directly to a PPD file if you have one handy. If you do this, you'll skip the next step.
6. CUPS now displays a complete list of printer models in the class you selected in step 5. Select an appropriate model, and click Continue. Alternatively, you can provide a PPD file if you have one.
7. If you haven't already logged in for other administrative tasks, CUPS asks for a username and password. Type **root** as the username and your root password as the password.



CUPS doesn't normally encrypt its data, so you shouldn't use it to administer printers remotely. Doing so would be a security risk, because the passwords would be exposed to sniffing.

8. CUPS informs you that the printer has been added.
9. If you wait a few seconds, the notification that the printer has been added is replaced by a page in which you can set printer-specific options, such as sheet feeder sources and print resolutions. Adjust any options you like, and then click Set Printer Options.

If you click the Printers item at the top of the page, you should be returned to the printers list (Figure 6.5), but your new printer should be listed among the existing queues. You can print a test page by clicking Print Test Page. If all goes well, a test page will emerge from your printer. If it doesn't, go back and review your configuration by clicking Modify Printer. This action takes you through the steps for adding a printer but with your previous selections already entered as the defaults. Try changing some settings until you get the printer to work.

From the printer queue list, you can also click Configure Printer to set various printer options. What options are available depends on the printer, but common options include the resolution, color dithering options, the paper size, whether to enable double-sided printing, and the presence of banner pages.



## Printing to Network Printers

If your network hosts many Windows computers, you may use the Server Message Block/Common Internet File System (SMB/CIFS) for file and printer sharing among Windows systems. Linux's Samba server also implements this protocol and so can be used for sharing printers from Linux.

On the flip side, you can print to an SMB/CIFS printer queue from a Linux system. To do so, you select an SMB/CIFS queue in the printer configuration tool. Under CUPS, it's called Windows Printer via SAMBA in step 3 in the preceding procedure. You must then provide your username, password, server name, and share name, but the format isn't obvious from the Web-based configuration tool:

```
smb://username:password@SERVER/SHARE
```

This is a uniform resource identifier (URI) for an SMB/CIFS share. You must substitute appropriate values for *username*, *password*, *SERVER*, and *SHARE*, of course. Once this is done and you've finished the configuration, you should be able to submit print jobs to the SMB/CIFS share.



SMB/CIFS printers hosted by Windows systems are usually non-PostScript models, so you must select a local Linux smart filter and Ghostscript driver, just as you would for a local printer. Printers hosted by Linux systems running Samba, by contrast, are frequently configured to act like PostScript printers, so you should select a PostScript driver when connecting to them.

If you want to print to a Unix or Linux server that uses the old LPD protocol, the URI format is similar but omits a username and password:

```
lpd://hostname/queue
```

You can use the same format, but substitute `ipp://` for `lpd://`, to print to a CUPS server if browsing is disabled on your network.

In practice, you may be faced with a decision: Should you use LPD, IPP, or SMB/CIFS for submitting print jobs? To be sure, not all print servers support all three protocols, but a Linux server might support them all. As a general rule, IPP is the simplest to configure because it supports browsing, which means that CUPS clients shouldn't need explicit configuration to handle specific printers. This makes IPP the best choice for Linux-to-Linux printing, assuming both systems run CUPS. When CUPS isn't in use, LPD is generally easier to configure than SMB/CIFS, and it has the advantage of not requiring the use of a username or password to control access. Because SMB/CIFS security is password-oriented, clients typically store passwords in an unencrypted form on the hard disk. This fact can become a security liability, particularly if you use the same account for printing as for other tasks. On the other hand, sometimes using a password on the server provides more of a security benefit than the risk of storing that password on the client. Generally speaking, if clients are few and well protected, whereas the server is exposed to the Internet at large, using passwords can be beneficial. If clients are numerous and exposed to the Internet,



whereas the print server is well protected, a password-free security system that relies on IP addresses may be preferable.

## Monitoring and Controlling the Print Queue

You can use several utilities to submit print jobs and to examine and manipulate a Linux print queue. These utilities are `lpr`, `lpq`, `lprm`, and `lpc`. All of these commands can take the `-P` parameter to specify that they operate on a specific print queue.

### Printing Files with `lpr`

Once you've configured the system to print, you probably want to start printing. As mentioned earlier, Linux uses the `lpr` program to submit print jobs. This program accepts many options that you can use to modify the program's action:

**Specify a queue name** The `-P $queue$ name` option enables you to specify a print queue. This is useful if you have several printers or if you've defined several queues for one printer. If you omit this option, the default printer is used.



In the original BSD version of `lpr`, there should be no space between the `-P` and the *queue*name. LPRng and CUPS are more flexible in this respect; you can insert a space or omit it as you see fit.

**Delete the original file** Normally, `lpr` sends a copy of the file you print into the queue, leaving the original unharmed. Specifying the `-r` option causes `lpr` to delete the original file after printing it.

**Suppress the banner** The `-h` option suppresses the banner for a single print job. Early versions of CUPS didn't support this option, but recent versions do.

**Specify a job name** Print jobs have names to help identify them, both while they're in the queue and once they're printed (if the queue is configured to print banner pages). The name is normally the name of the first file in the print job, but you can change it by including the `-J  $job$ name` option. The `-C` and `-T` options are synonymous with `-J`.

**Notify a user by e-mail** The `-m  $username$`  option causes `lpd` to send e-mail to *username* when the print job is complete. This option was unavailable in early versions of CUPS but is available in recent versions.

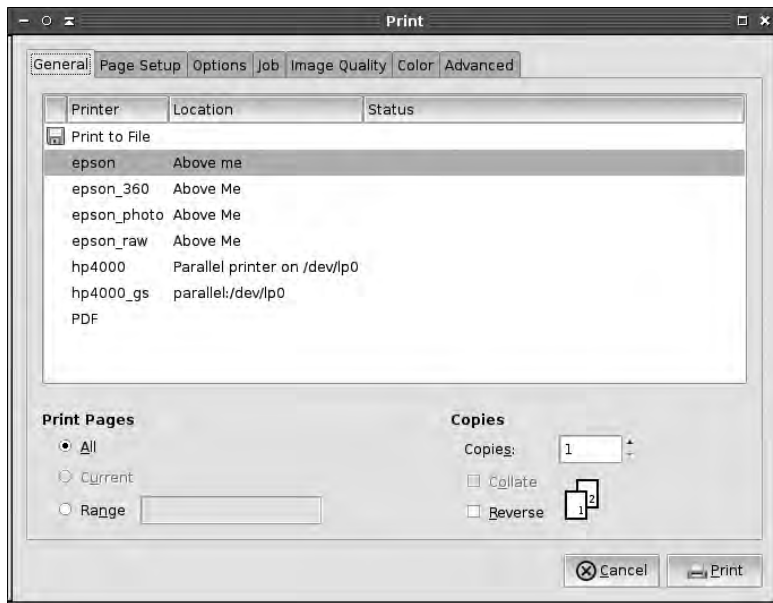
**Specify the number of copies** You can specify the number of copies of a print job by using the `-#  $number$`  option, as in `-# 3` to print three copies of a job.

Suppose you have a file called `report.txt` that you want to print to the printer attached to the `lexmark` queue. This queue is often busy, so you want the system to send e-mail to your account, `ljones`, when it's finished so you know when to pick up the printout. You can use the following command to accomplish this task:

```
$ lpr -Plexmark -m ljones report.txt
```

The `lpr` command is accessible to ordinary users as well as to `root`, so anybody may print using this command. It's also called from many programs that need to print directly, such as graphics programs and word processors. These programs typically give you some way to adjust the print command so that you can enter parameters such as the printer name. For instance, Figure 6.6 shows Firefox's Print dialog box, which features a list of available print queues and a Copies field so that you can print multiple copies. Additional tabs enable you to set more options. Some programs provide a text entry field in which you type some or all of an `lpr` command instead of selecting from a list of available queues and options. Consult the program's documentation if you're not sure how it works.

**FIGURE 6.6** Most Linux programs that can print do so by using `lpr`, but many hide the details of the `lpr` command behind a dialog box.



Sometimes you want to process a file in some way prior to sending it to the printer. Chapter 1 covers some commands that can do this, such as `fmt` and `pr`. Another handy program is `mpage`, which reads plain-text or PostScript files and reformats them so that each printed sheet contains several reduced-size pages from the original document. This can be a good way to save paper if you don't mind a reduction in the document size. In the simplest case, you can use `mpage` much as you'd use `lpr`:

```
$ mpage -Plexmark report.ps
```

This command prints the `report.ps` file reduced to fit four pages per sheet. You can change the number of source pages to fit on each printed page with the `-1`, `-2`, `-4`, and `-8` options, which specify one, two, four, or eight input pages per output page, respectively. Additional `mpage` options exist to control features such as the paper size, the font to be used

for plain-text input files, and the range of input file pages to be printed. Consult the man page for `mpage` for more details.

## Displaying Print Queue Information with `lpq`

The `lpq` utility displays information about the print queue—how many files it contains, how large they are, who their owners are, and so on. By entering the user's name as an argument, you can also use this command to check on any print jobs owned by a particular user. To use `lpq` to examine a queue, you can issue a command like the following:

```
$ lpq -Php4000
```

```
hp4000 is ready and printing
```

Rank	Owner	Job	File(s)	Total Size
active	rodsmit	1630	file:///	90112 bytes

Of particular interest is the job number—1630 in this example. You can use this number to delete a job from the queue or reorder it so that it prints before other jobs. Any user may use the `lpq` command.

## Removing Print Jobs with `lprm`

The `lprm` command removes one or more jobs from the print queue. You can issue this command a couple of ways:

- If `lprm` is used with a number, that number is understood to be the job ID (as shown in `lpq`'s output) of the job that's to be deleted.
- If a user runs the BSD `lprm` and passes a dash (-) to the program, it removes all the jobs belonging to the user.

This program may be run by `root` or by an ordinary user; but as just noted, its capabilities vary depending on who runs it. Ordinary users may remove only their own jobs from the queue, but `root` may remove anybody's print jobs.

## Controlling the Print Queue

In the original BSD LPD system, the `lpc` utility starts, stops, and reorders jobs within print queues. Although CUPS provides an `lpc` command, it has few features. Instead of using `lpc`, you should use the CUPS Web interface, which provides point-and-click print queue management:

- You can disable a queue by clicking the Stop Printer link for the printer on the CUPS Web interface (Figure 6.5). When you do so, this link changes to read Start Printer, which reverses the effect when clicked. The Jobs link also provides a way to cancel and otherwise manage specific jobs.
- You can use a series of commands, such as `cupsenable`, `cupsdisable`, and `lpmove`, to control the queue. These commands enable a queue, disable a queue, or move a job from one queue to another. Moving a job can be handy if you must shut down a queue for maintenance and want to redirect the queue's existing jobs to another printer.

## Summary

X is Linux's GUI system. In part because of Linux's modular nature, X isn't a single program; you have your choice of X servers to run on Linux. Fortunately, most Linux distributions use the same X server as all others (X.org-X11). Both X.org-X11 and its main competitor, XFree86, are configured in much the same way, using the `xorg.conf` (for X.org-X11) or `XFree86Config` configuration file. Whatever its name, this file consists of several sections, each of which controls one X subsystem, such as the mouse, the keyboard, or the video card. This file also controls X's core fonts system, but you can use a font server in addition to this system; and most modern programs are now emphasizing an entirely new font system, Xft, instead of X core fonts. For this reason, Linux font configuration can be complex.

X's GUI login system uses an XDMCP server, which starts X and manages the X display. Three XDMCP servers are in common use in Linux: XDM, KDM, and GDM. They all perform the same basic tasks, but configuration details differ. (XDM is also less sophisticated than KDM or GDM.) X is a network-enabled GUI, which means you can use an X server to access programs running on another computer. Doing so requires performing a few steps for each login session. You can also tunnel X accesses through SSH, which greatly improves the security of the connection.

An assortment of tools can help make Linux more accessible to users with visual or motor impairments. You can adjust font size, screen contrast, and other display features to improve legibility; use screen magnifiers to help users read part of a larger screen; or even bypass a visual display entirely and use a screen reader for auditory output or a Braille display for tactile output. On the input side, you can adjust keyboard repeat rates, use sticky keys, or modify the mouse tracking speed and click sensitivity to improve users' ability to input data accurately. You can even have a mouse stand in for a keyboard or vice-versa by using appropriate software.

The second main visual output tool on computers is a printer, and Linux provides sophisticated printer support. The CUPS package manages printers in Linux by accepting local or remote print jobs, passing them through a smart filter for processing, and queuing the jobs so that they print in a reasonable order. Most CUPS configuration is best handled via its own Web interface, but some options (particularly security features) can be set via text configuration files.

## Exam Essentials

**Name the major X servers for Linux.** XFree86 has been the traditional standard Linux X server, but in 2004 X.org-X11 (which was based on XFree86) rapidly gained prominence as the new standard Linux X server. Accelerated-X is a commercial X server that sometimes supports video cards that aren't supported by XFree86 or X.org-X11.

**Describe the X configuration file format.** The XFree86 and X.org-X11 configuration file is broken into multiple sections, each of which begins with the keyword `Section` and ends with `EndSection`. Each section sets options related to a single X feature, such as loading modules, specifying the mouse type, or describing the screen resolution and color depth.

**Summarize the differences between X core fonts, a font server, and Xft fonts.** X core fonts are managed directly by X, and they lack modern font features such as font smoothing. Font servers integrate with the X core fonts but run as separate programs and may optionally deliver fonts to multiple computers on a network. Xft fonts bypass the X core font system to provide client-side fonts in a way that supports modern features such as font smoothing.

**Explain the role of an XDMCP server.** An XDMCP server, such as XDM, KDM, or GDM, launches X and controls access to X via a login prompt—that is, it serves as Linux’s GUI login system. XDMCP servers are also network enabled, providing a way to log in remotely from another X server.

**Summarize X’s client/server model.** An X server runs on the user’s computer to control the display and accept input from the keyboard and mouse. Client programs run on the same computer or on a remote computer to do the bulk of the computational work. These client programs treat the X server much as they treat other servers, requesting input from and sending output to them.

**Explain the benefits of using SSH for remote X access.** SSH can simplify remote X-based network access by reducing the number of steps required to run X programs from a remote computer. More important, SSH encrypts data, which keeps information sent between the X client and X server secure from prying eyes.

**Summarize X accessibility features.** You can adjust keyboard and mouse options to help those with motor impairments to use keyboards and mice or to substitute one device for the other. Font size, contrast, and magnification tools can help those with visual impairments. Finally, text readers and Braille displays can enable blind individuals to use a Linux system.

**Describe how to set a time zone in Linux.** Linux uses a binary file, `/etc/localtime`, to describe the features of the time zone. This file is copied or linked from a repository of such files at system installation, but you can replace the file at any time.

**Explain the role of Ghostscript in Linux printing.** PostScript is the standard Linux printing language, and Ghostscript converts PostScript into bitmap formats that are acceptable to non-PostScript printers. Thus, Ghostscript is a critical translation step in most Linux print queues.

**Summarize how print jobs are submitted and managed under Linux.** You use `lpr` to submit a print job for printing, or an application program may call `lpr` itself or implement its functionality directly. The `lpq` utility summarizes jobs in a queue, and `lprm` can remove print jobs from a queue.

## Review Questions

1. When you configure an X server, you need to make changes to configuration files and then start or restart the X server. Which of the following can help streamline this process?
  - A. Shut down X by switching to a runlevel in which X doesn't run automatically, and then reconfigure it and use `startx` to test X startup.
  - B. Shut down X by booting into single-user mode, and then reconfigure X and use `telinit` to start X running again.
  - C. Reconfigure X, and then unplug the computer to avoid the lengthy shutdown process before restarting the system and X along with it.
  - D. Use the `startx` utility to check the X configuration file for errors before restarting the X server.
2. Which of the following summarizes the organization of the X configuration file?
  - A. The file contains multiple sections, one for each screen. Each section includes subsections for individual components (keyboard, video card, and so on).
  - B. Configuration options are entered in any order desired. Options relating to specific components (keyboard, video card, and so on) may be interspersed.
  - C. The file begins with a summary of individual screens. Configuration options are preceded by a code word indicating the screen to which they apply.
  - D. The file is broken into sections, one or more for each component (keyboard, video card, and so on). The file also has one or more sections that define how to combine the main sections.
3. A monitor's manual lists its range of acceptable synchronization values as 27–96kHz horizontal and 50–160Hz vertical. What implications does this have for the resolutions and refresh rates the monitor can handle?
  - A. The monitor can run at up to 160Hz vertical refresh rate in all resolutions.
  - B. The monitor can handle up to 160Hz vertical refresh rate depending on the color depth.
  - C. The monitor can handle up to 160Hz vertical refresh rate depending on the resolution.
  - D. The monitor can handle vertical resolutions of up to 600 lines ( $96,000 \div 160$ ), but no more.
4. In what section of `XF86Config` or `xorg.conf` do you specify the resolution that you want to run?
  - A. In the `Screen` section, subsection `Display`, using the `Modes` option
  - B. In the `Monitor` section, using the `Modeline` option
  - C. In the `Device` section, using the `Modeline` option
  - D. In the `DefaultResolution` section, using the `Define` option

5. What is an advantage of a font server?
  - A. It provides faster font displays than are otherwise possible.
  - B. It can simplify font maintenance on a network with many X servers.
  - C. It's the only means of providing TrueType support for XFree86 4.x.
  - D. It enables the computer to turn a bitmapped display into an ASCII text file.
6. What methods do Linux distributions use to start X automatically when the system boots? (Select all that apply.)
  - A. Start an XDMCP server from the `Start` folder
  - B. Start an XDMCP server from an `~/xinitrc` script
  - C. Start an XDMCP server via a SysV startup script
  - D. Start an XDMCP server from `init`
7. How would you change the text displayed by XDM as a greeting?
  - A. Click `Configure` ➤ `Greeting` from the XDM main menu, and edit the text in the resulting dialog box.
  - B. Edit the `/etc/X11/xdm/Xresources` file, and change the text in the `xlogin*greeting` line.
  - C. Edit the `/etc/X11/xorg.conf` file, and change the `Greeting` option in the `xdm` area.
  - D. Run `xdmconfig`, and change the greeting on the `Login` tab.
8. Which of the following features do KDM and GDM provide that XDM doesn't?
  - A. An encrypted remote X-based access ability, improving network security
  - B. The ability to accept logins from remote computers, once properly configured
  - C. The ability to select the login environment from a menu on the main login screen
  - D. A login screen that shows the username and password simultaneously rather than sequentially
9. Which of the following commands tells the X server to accept connections from `penguin.example.com`?
  - A. `xhost +penguin.example.com`
  - B. `export DISPLAY=penguin.example.com:0`
  - C. `telnet penguin.example.com`
  - D. `xaccess penguin.example.com`

10. To assist an employee who has trouble with keyboard repeat features, you've disabled this function in `/etc/X11/xorg.conf`. Why might this step not be sufficient to the goal of disabling keyboard repeat?
  - A. GNOME, KDE, or other desktop environment settings for keyboard repeat may override those set in `xorg.conf`.
  - B. The `xorg.conf` file has been deprecated; you should instead adjust the `/etc/X11/XF86Config` file.
  - C. Keyboard settings in `xorg.conf` apply only to PS/2 keyboards; you must use `usbkbrate` to adjust keyboard repeat for USB keyboards.
  - D. You must also locate and reset the DIP switch on the keyboard to disable keyboard repeat.
11. Which of the following programs may be used to provide computer-generated speech for users who have trouble reading computer displays? (Select all that apply.)
  - A. SoX
  - B. Emacspeak
  - C. Orca
  - D. talk
12. You manage a computer that's located in Los Angeles, California, but the time zone is misconfigured as being in Tokyo, Japan. What procedure can you follow to fix this problem? (Select all that apply.)
  - A. Run `hwclock --systohc` to update the clock to the correct time zone.
  - B. Delete `/etc/localtime`, and replace it with an appropriate file from `/usr/share/zoneinfo`.
  - C. Edit the `/etc/tzconfig` file so that it specifies `North_America/Los_Angeles` as the time zone.
  - D. Use the `tzselect` program to select a new (Los Angeles) time zone.
13. You're configuring a Linux system that doesn't boot any other OS. What is the recommended time to which the computer's hardware clock should be set?
  - A. Helsinki time
  - B. Local time
  - C. US Pacific time
  - D. UTC



14. You've developed a script that uses several Linux commands and edits their output. You want to be sure that the script runs correctly on a computer in Great Britain, although you're located elsewhere. What might you do to test this?
- A. Enter the BIOS, locate and change the location code, reboot into Linux, and run the script.
  - B. Edit `/etc/locale.conf`, change all the `LC_*` variables to `en_GB.UTF-8`, and then reboot and run the script.
  - C. Type **`export LC_ALL=en_GB.UTF-8`**, and run the script from the same shell you used to type this command.
  - D. Type **`locale_set Great_Britain`**, and run the script from the same shell you used to type this command.
15. Which character set encoding is the preferred method on modern Linux systems?
- A. UTF-8
  - B. ASCII
  - C. ISO-8859-1
  - D. ISO-8859-8
16. Which of the following describes the function of a smart filter?
- A. It detects the type of a file and passes it through programs to make it printable on a given model of printer.
  - B. It detects information in print jobs that may be confidential as a measure against industrial espionage.
  - C. It sends e-mail to the person who submitted the print job, obviating the need to wait around the printer for a printout.
  - D. It detects and deletes prank print jobs that are likely to have been created by miscreants trying to waste your paper and ink.
17. What information about print jobs does the `lpq` command display? (Select all that apply.)
- A. The name of the application that submitted the job
  - B. A numerical job ID that can be used to manipulate the job
  - C. The amount of ink or toner left in the printer
  - D. The username of the person who submitted the job
18. You've submitted several print jobs, but you've just realized that you mistakenly submitted a huge document that you didn't want to print. Assuming you can identify which job this was, that it's not yet printing, and that its job ID number is 749, what command would you type to delete it from the `okidata` print queue?
- A. The answer depends on whether you're using BSD LPD, LPRng, or CUPS.
  - B. **`lpdel -Pokidata 749`**
  - C. **`lprm -Pokidata 749`**
  - D. None of the above; the task is impossible.

19. Which of the following is generally true of Linux programs that print?
- A. They send data directly to the printer port.
  - B. They produce PostScript output for printing.
  - C. They include extensive collections of printer drivers.
  - D. They can print only with the help of add-on commercial programs.
20. What tool might you use to print a four-page PostScript file on a single sheet of paper?
- A. PAM
  - B. mpage
  - C. 4Front
  - D. route

# Answers to Review Questions

1. A. On most Linux systems, some runlevels don't run X by default, so using one of them along with the `startx` program (which starts X running) can be an effective way to quickly test changes to an X configuration. The `telinit` program changes runlevels, which is a lengthy process compared to using `startx`. Unplugging the computer to avoid the shutdown process is self-defeating because you'll have to suffer through a long startup (if you use a non-journaling filesystem), and it can also result in data loss. The `startx` utility doesn't check the veracity of an X configuration file; it starts X running from a text-mode login.
2. D. The `XF86Config` and `xorg.conf` file design enables you to define variants or multiple components and easily combine or recombine them as necessary.
3. C. The vertical refresh rate range includes a maximum value, but that value may be reduced when the resolution and vertical refresh rate would demand a higher horizontal refresh rate than the monitor can handle. In practice, the horizontal limit is usually most important, at least when running at typical resolutions. The color depth is irrelevant to the computation.
4. A. Option A describes the correct location for this option. The `Modeline` option in the `Monitor` section (as described in option B) defines *one* possible resolution, but there are usually several `Modeline` entries defining many resolutions. The `Modeline` option doesn't exist in the `Device` section (as suggested by option C), nor is that section where the resolution is set. There is no `DefaultResolution` section (as referenced in option D).
5. B. By maintaining fonts on one font server and pointing other X servers to that font server, you can reduce the administrative cost of maintaining the fonts on all the systems. Font servers don't produce faster font displays than X's local font handling; if anything, the opposite is true. XFree86 4.x supports TrueType fonts directly, but XFree86 3.3.6 and earlier didn't include this support by default. Converting a bitmapped display into ASCII text is a function of optical character recognition (OCR) software, not a font server.
6. C, D. XDMCP servers are typically launched either from a SysV startup script or by `init` (as specified in `/etc/inittab`), as described in options C and D. The XDMCP server then starts X. The `Start` folder mentioned in option A is a Windows construct, not a Linux construct. The `~/xinitrc` script mentioned in option B is an X login script used when starting X from the command line via `startx`; it's not used to automatically start X when the system boots.
7. B. The XDM greeting is a resource set in the `/etc/X11/xdm/Xresources` file, so option B is correct. XDM doesn't offer many options on its main screen and certainly not one to change its greeting, as described in option A. Although the `xorg.conf` file mentioned in option C is real, this file provides no XDM configuration options because XDM is a separate program from the X server. There is no standard `xdmconfig` program, as mentioned in option D.

8. C. KDM and GDM add many features, one of which is a menu that enables users to select their desktop environment or window manager when they log in rather than specifying it in a configuration file, as option C states. Option A describes one of the advantages of the Secure Shell (SSH) as a remote-access protocol. Option B describes a feature common to all three XDMCP servers. Option D describes the way both KDM and XDM function; GDM is the one that presents username and password fields in series rather than simultaneously.
9. A. The `xhost` command controls various aspects of the local X server, including the remote computers from which it will accept connections. Option B sets the `DISPLAY` environment variable, which doesn't directly affect the X server (it does tell X clients which X server to use). Option C initiates a text-mode remote login session with `penguin.example.com`. Option D's `xaccess` is a fictitious program.
10. A. As stated in option A, GNOME, KDE, and other user programs often override the keyboard repeat settings in the X configuration file. Option B has it almost backward; most Linux distributions have abandoned XFree86, and therefore its `XF86Config` file, in favor of X.org-X11 and its `xorg.conf` file. Option C is pure fiction; `xorg.conf` settings apply to all varieties of keyboards, and there is no standard `usbkbrate` program. Although some keyboards do have hardware switches, these don't affect X's ability to control the keyboard repeat rate, contrary to option D.
11. B, C. The Emacspeak and Orca programs both provide text-to-speech conversion facilities. SoX is an audio format converter, but it won't convert from text to speech. The `talk` program is an early Unix online text-mode "chat" program, but it has no built-in speech synthesis capabilities.
12. B, D. Time zones are determined by the `/etc/localtime` file, so replacing that one with the correct file (a selection is stored in `/usr/share/zoneinfo`) will fix the problem. (You may also need to edit `/etc/timezone` or some other file to keep automatic utilities from becoming confused.) Utilities such as `tzselect` will make these changes for you after prompting you for your location. The `hwclock` program mentioned in option A reads and writes data from the system's hardware clock. Although it relies on time zone data, it can't adjust your system's time zone itself. There is no standard `/etc/tzconfig` file, although the `tzconfig` program, like `tzselect`, can help you set the time zone.
13. D. Linux, like Unix, maintains its time internally in Coordinated Universal Time (UTC), so setting the computer's hardware clock to UTC is the recommended procedure for computers that run only Linux. Although Linus Torvalds spent time at the University of Helsinki, Helsinki time (as in option A) has no special place in Linux. Local time (as in option B) is appropriate if the computer dual-boots to an OS, such as Windows, that requires the hardware clock to be set to local time, but this is the second-best option for a Linux-only system. Option C's US Pacific time, like Helsinki time, has no special significance in Linux.
14. C. The `LC_ALL` environment variable, when set, adjusts all the locale (`LC_*`) variables, so setting this and then running the script will make the programs that your script uses work as if on a British computer. The BIOS has no location code data. There is no standard `/etc/locale.conf` file. There is no standard `locale_set` utility.

15. A. The Unicode Transformation Format 8 (UTF-8) standard can encode characters for just about any language on Earth, while looking just like ordinary ASCII to programs that only understand ASCII. Thus, UTF-8 is the preferred method for character encoding when a choice is possible. ASCII is an old standard that's adequate for English and a few other languages, but it lacks some or all characters needed by most languages. ISO-8859 is a standard that extends ASCII, but it requires separate encodings for different languages and so is awkward when a computer must process data from multiple languages.
16. A. The smart filter makes a print queue "smart" in that it can accept different file types (plain text, PostScript, graphics, and so on) and print them all correctly. It doesn't detect confidential information or prank print jobs. The `lpr` program can be given a parameter to e-mail a user when the job finishes, but the smart filter doesn't do this.
17. B, D. The job ID and job owner are both displayed by `lpq`. Unless the application embeds its own name in the filename, that information won't be present. Most printers lack Linux utilities to query ink or toner status; certainly `lpq` can't do this.
18. C. The `lprm` command deletes a job from the print queue. It can take the `-Pqueue` option to specify the queue and a print job number or various other parameters to specify which jobs to delete. BSD LPD, LPRng, and CUPS all implement the `lprm` command, so you can use it with any of these systems. Option B presents the correct syntax but the wrong command name; there is no standard `lpdel` command.
19. B. PostScript is the de facto printing standard for Unix and Linux programs. Linux programs generally *do not* send data directly to the printer port; on a multi-tasking, multi-user system, this would produce chaos because of competing print jobs. Although a few programs include printer driver collections, most forgo this in favor of generating PostScript. Printing utilities come standard with Linux; add-on commercial utilities aren't required.
20. B. The `mpage` utility prints multiple input pages on a single output page, so it's ideally suited to the specified task. PAM is the Pluggable Authentication Modules, a tool for helping to authenticate users. 4Front is the name of a company that produces commercial sound drivers for Linux. The `route` command is used to display or configure a Linux routing table.



# Chapter 7

# Administering the System

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**THE FOLLOWING LINUX PROFESSIONAL INSTITUTE OBJECTIVES ARE COVERED IN THIS CHAPTER:**

- ✓ 1.107.1 Manage user and group accounts and related system files (weight: 5)
- ✓ 1.107.2 Automate system administration tasks by scheduling jobs (weight: 4)
- ✓ 1.108.1 Maintain system time (weight: 3)
- ✓ 1.108.2 System logging (weight: 2)





Much of Linux system administration deals with handling mundane day-to-day tasks. Many of these tasks relate to users and groups: adding them, deleting them, configuring their environments, and so on. On a small system, you might perform such tasks infrequently, but on a busy system, you might adjust accounts frequently. In any event, you must know how to do these things. Another class of day-to-day tasks involves managing and reviewing *log files*. These are files that record details of system operations, such as remote logins. Log files can be invaluable debugging resources, but even if you aren't experiencing a problem, you should review them periodically to be sure everything's working as it should.

Many Linux tasks relate to time. Linux keeps time somewhat differently than some other OSs, and understanding how Linux treats time is important. So are the skills needed to set the time in Linux. (Some automated tools can be very helpful, but you must know how to configure them.) You can also tell Linux to run particular jobs at specific times in the future. This can be handy to help automate repetitive tasks, such as synchronizing data with other systems on a regular basis.

## Managing Users and Groups

Linux is a multi-user system that relies on *accounts*—data structures and procedures used to identify individual users of a computer. Managing these accounts is a basic but important system administration skill. Before delving into the details, I describe a few basic concepts you should understand about user and group administration. With that out of the way, I describe the tools and configuration files that you employ to manage users and groups.

### Understanding Users and Groups

Chances are you have a good basic understanding of accounts already. Fundamentally, Linux accounts are like accounts on Windows, Mac OS, and other OSs. Some Web sites use accounts, too. Nonetheless, a few details deserve explanation. These include Linux username conventions, the nature of Linux groups, and the way Linux maps the numbers it uses internally to the usernames and group names that people generally use.

### Understanding Linux Usernames

Linux is fairly flexible about its usernames. Most versions of Linux support usernames consisting of any combination of upper- and lowercase letters, numbers, and many punctuation



symbols, including periods and spaces. Some punctuation symbols, however, such as spaces, cause problems for certain Linux utilities, so it's generally best to avoid using punctuation in Linux usernames. Underscores (`_`) and periods (`.`) are relatively unlikely to cause problems and so are occasionally used. Also, usernames must begin with a letter, so a username such as `45u` is invalid, but `u45` is fine. Although usernames may consist of up to 32 characters, many utilities truncate usernames longer than 8 characters or so in their displays; for this reason, many administrators try to limit username length to 8 characters.

Linux treats usernames in a case-sensitive way. Therefore, a single computer can support both `e11en` and `E11en` as separate users. This practice can lead to a great deal of confusion, so it's best to avoid creating accounts whose usernames differ only in case. The traditional practice is to use entirely lowercase letters in Linux usernames, such as `sally`, `sam`, `e11en`, and `george`. Usernames don't need to be based on first names, of course—you could use `sam_jones`, `s.jones`, `sJones`, `jones`, `jones17`, or `d76`, to name just a few possibilities. Most sites develop a standard method of creating usernames, such as using the first initial and the last name. Creating and following such a standard practice can help you locate an account that belongs to a particular individual. If your computer has many users, though, you may find a naming convention produces duplicates, particularly if your standard is to use initials to shorten usernames. You may be forced to deviate from the standard or incorporate numbers to distinguish between all the Davids or Smiths of the world, because each account requires a unique username.

## Linking Users Together for Productivity via Groups

Linux uses *groups* as a means of organizing users. In many ways, groups parallel users. In particular, they're defined in similar configuration files, have names similar to usernames, and are represented internally by numbers (as are accounts).

Groups are *not* accounts, however. Rather, groups are a means of organizing collections of accounts, largely as a security measure. Every file on a Linux system is associated with a specific group, and various permissions can be assigned to members of that group. For instance, group members (such as faculty at a university) may be allowed to read a file, but others (such as students) may be disallowed such access. Because Linux provides access to most hardware devices (such as serial ports and tape backup units) through files, you can also use this same mechanism to control access to hardware.

Every group has anywhere from no members to as many members as there are users on the computer. Group membership is controlled through the `/etc/group` file. This file contains a list of groups and the members belonging to each group. The details of this file's contents are described in the section “Configuring Groups.”

In addition to membership defined in `/etc/group`, each user has a default or *primary* group. The user's primary group is set in the user's configuration in `/etc/passwd` (the file that defines accounts). When users log onto the computer, their group membership is set to their primary group. When users create files or launch programs, those files and running programs are associated with a single group—the current group membership. A user can access files belonging to other groups as long as the user belongs to that group and the group access permissions permit the access. To run programs or create files with a group

other than the primary one, however, the user must run the `newgrp` command to switch current group membership. For instance, to change to the `project2` group, you might type the following:

```
$ newgrp project2
```

If the user typing this command is listed as a member of the `project2` group in `/etc/group`, the user's current group membership changes. Thereafter, files created by that user will be associated with the `project2` group. Alternatively, users can change the group associated with an existing file by using the `chgrp` or `chown` command, as described in Chapter 4, "Managing Files."

This group structure enables you to design a security system that permits different collections of users to easily work on the same files while simultaneously keeping other users of the same computer from prying into files they should not be able to access. In a simple case, you may create groups for different projects, classes, or workgroups, with each user restricted to one of these groups. A user who needs access to multiple groups can be a member of each of these groups—for instance, a student who takes two classes can belong to the groups associated with each class, or a supervisor may belong to all the supervised groups.

## Mapping UIDs and GIDs to Users and Groups

As mentioned earlier, Linux defines users and groups by numbers, referred to as *user IDs (UIDs)* and *group IDs (GIDs)*, respectively. Internally, Linux tracks users and groups by these numbers, not by name. For instance, the user `sam` may be tied to UID 523, and `e11en` may be UID 609. Similarly, the group `project1` may be GID 512, and `project2` may be GID 523. For the most part, these details take care of themselves—you use names, and Linux uses `/etc/passwd` or `/etc/group` to locate the number associated with the name. You may occasionally need to know how Linux assigns numbers when you tell it to do something, though. This is particularly true when you're troubleshooting or if you have cause to manually edit `/etc/passwd` or `/etc/group`.

Linux distributions reserve the first hundred user and group IDs (0–99) for system use. The most important of these is 0, which corresponds to `root` (both the user and the group). Subsequent low numbers are used by accounts and groups that are associated with specific Linux utilities and functions. For instance, UID 2 and GID 2 may be the `daemon` account and group, respectively, which are used by various servers; and UID 8 and GID 12 might be the `mail` account and group, which can be used by mail-related servers and utilities. Not all account and group numbers from 0 to 99 are in use; usually, only one or two dozen accounts and a dozen or so groups are used in this way. You can check your `/etc/passwd` and `/etc/group` files to determine which user and group IDs are so used.



Aside from UID 0 and GID 0, UID and GID numbers aren't fully standardized. For instance, although UID 2 and GID 2 map to the `daemon` account and `daemon` group on Red Hat and SUSE, on Debian UID 2 and GID 2 map to the `bin` account and `bin` group; the `daemon` account and group correspond to UID 1 and GID 1. If you need to refer to a particular user or group, use the name rather than the number.

Beyond 100, user and group IDs are available for use by ordinary users and groups. Many distributions, however, reserve up to 500 or even 1000 for special purposes. Frequently, therefore, the first normal user account is assigned a UID of 500 or 1000. When you create additional accounts, the system typically locates the next-highest unused number, so the second user you create is UID 501, the third is 502, and so on. When you remove an account, that account's ID number may be reused, but the automatic account-creation tools typically don't do so if subsequent numbers are in use, leaving a gap in the sequence. This gap causes no harm unless you have so many users that you run out of ID numbers. (The limit is 65,536 users with the 2.2.x kernels and over 4.2 billion with the 2.4.x and later kernels, including root and other system accounts. The limit can be set lower in configuration files or because of limits in support programs.) In fact, reusing an ID number can cause problems if you don't clear away the old user's files—the new user will become the owner of the old user's files, which can lead to confusion.

Typically, GID 100 is users—the default group for some distributions. On any but a very small system with few users, you'll probably want to create your own groups. Because different distributions have different default ways of assigning users to groups, it's best that you familiarize yourself with your distribution's way of doing this and plan your own group-creation policies with this in mind. For instance, you may want to create your own groups within certain ranges of IDs to avoid conflicts with the distribution's default user- and group-creation processes.

It's possible to create multiple usernames that use the same UID or multiple group names that use the same GID. In some sense, these are different accounts or groups; they have different entries in `/etc/passwd` or `/etc/group`, so they can have different home directories, different passwords, and so on. Because these users or groups share IDs with other users or groups, though, they're treated identically in terms of file permissions. Unless you have a compelling reason to do so, you should avoid creating multiple users or groups that share an ID.



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Intruders sometimes create accounts with UID 0 to give themselves root privileges on the systems they invade. *Any* account with a UID of 0 is effectively the root account, with all the power of the superuser. If you spot a suspicious account in your `/etc/passwd` file with a UID of 0, your system has probably been compromised.

## Configuring User Accounts

How frequently you'll do user maintenance depends on the nature of the system you administer. Some systems, such as small personal workstations, need changes very rarely. Others, such as large systems in environments in which users are constantly coming and going, may require daily maintenance. The latter situation would seem to require more knowledge of user account configuration tools; but even in a seldom-changing system, it's useful to know how to do these things so that you can do them quickly and correctly when you do need to add, modify, or delete user accounts.



Some security-related account issues are covered in Chapter 10, “Securing Your System.”

This chapter describes the traditional text-based tools for account creation and maintenance. Most modern Linux distributions ship with GUI tools that accomplish the same goals. These tools vary from one distribution or environment to another, so they’re hard to summarize for Linux as a whole. The LPI exam also emphasizes the text-based tools. Overall, the text-based tools provide the greatest flexibility and are most broadly applicable, but you can certainly use the GUI tools if you like.

## Adding Users

Adding users can be accomplished through the `useradd` utility. (This program is called `adduser` on some distributions.) Its basic syntax is as follows:

```
useradd [-c comment] [-d home-dir] [-e expire-date] [-f inactive-days] ➤
 [-g default-group] [-G group[,...]] [-m [-k skeleton-dir] | -M] ➤
 [-p password] [-s shell] [-u UID [-o]] [-r] [-n] username
```



Some of these parameters modify settings that are valid only when the system uses shadow passwords. This is the standard configuration for most distributions today.

In its simplest form, you may type just `useradd username`, where *username* is the username you want to create. The rest of the parameters are used to modify the default values for the system, which are stored in the file `/etc/login.defs`.

The parameters for the `useradd` command modify the program’s operation in various ways:

**Comment** The `-c comment` parameter passes the comment field for the user. Some administrators store public information like a user’s office or telephone number in this field. Others store just the user’s real name or no information at all.

**Home directory** You specify the account’s home directory with the `-d home-dir` parameter. This defaults to `/home/username` on most systems.

**Account expiration date** Set the date on which the account will be disabled, expressed in the form `YYYY-MM-DD`, with the `-e expire-date` option. (Many systems accept alternative forms, such as `MM-DD-YYYY`, as well.) The default is for an account that doesn’t expire.

**Inactive days** An account becomes completely disabled a certain number of days after a password expires. The `-f inactive-days` parameter sets the number of days. A value of `-1` disables this feature and is the default.

**Default group** You set the name or GID of the user’s default group with the `-g default-group` option. The default for this value varies from one distribution to another.

**Additional groups** The `-G group[,...]` parameter sets the names or GIDs of one or more groups to which the user belongs. These groups need not be the default group, and you can specify more than one by separating them with commas.

**Home directory options** The system automatically creates the user's home directory if `-m` is specified. Normally, default configuration files are copied from `/etc/skel`, but you may specify another template directory with the `-k skeleton-dir` option. Many distributions use `-m` as the default when running `useradd`.

**No home directory creation** The `-M` option forces the system to *not* automatically create a home directory, even if `/etc/login.defs` specifies that this action is the default.

**Encrypted password specification** The `-p encrypted-password` parameter passes the *pre-encrypted* password for the user to the system. The *encrypted-password* value is added, *unchanged*, to the `/etc/passwd` or `/etc/shadow` file. This means that if you type an unencrypted password, it won't work as you probably expect. In practice, this parameter is most useful in scripts, which can encrypt a password (using `crypt`) and then send the encrypted result through `useradd`. The default value disables the account, so you must run `passwd` to change the user's password.

**Default shell** Set the name of the user's default login shell with the `-s shell` option. On most systems, this defaults to `/bin/bash`, but you can specify another shell or even a program that's not traditionally a shell. For instance, some systems include a `shutdown` account that calls `/sbin/shutdown`. Logging into this account immediately shuts down the computer.

**UID** The `-u UID` parameter creates an account with the specified user ID value (*UID*). This value must be a positive integer, and it's normally greater than 500 for user accounts. System accounts typically have numbers less than 100. The `-o` option allows the number to be reused so that two usernames are associated with a single UID.

**System account creation** The `-r` parameter specifies the creation of a system account—an account with a value less than `UID_MIN`, as defined in `/etc/login.defs`. (This is normally 100, 500, or 1000.) `useradd` doesn't create a home directory for system accounts.

**No user group** In some distributions, such as Red Hat, the system creates a group with the same name as the specified username. The `-n` parameter disables this behavior.

Suppose you've added a hard disk and mounted it as `/home2`. You want to create an account for a user named Sally in this directory and place her home directory on the new disk. You want to make the new user a member of the `project1` and `project4` groups, with default membership in `project4`. The user has also requested `tcsh` as her default shell. The following commands accomplish this goal:

```
useradd -d /home2/sally -g project4 -G project1,project4 -s /bin/tcsh sally
passwd sally
Changing password for user sally
New UNIX password:
Retype new UNIX password:
passwd: all authentication tokens updated successfully
```



The `passwd` command asks for the password twice, but it does not echo what you type. This prevents somebody who sees your screen from reading the password. `passwd` is described in more detail shortly, in “Setting a Password.”

## Modifying User Accounts

User accounts may be modified in many ways: You can directly edit critical files such as `/etc/passwd`, modify user-specific configuration files in the account’s home directory, or use system utilities like those used to create accounts. You usually modify an existing user’s account at the user’s request or to implement some new policy or system change, such as moving home directories to a new hard disk. Sometimes, though, you must modify an account immediately after its creation in order to customize it in ways that aren’t easily handled through the account-creation tools or because you realize you forgot a parameter to `useradd`.

### Setting a Password

Although `useradd` provides the `-p` parameter to set a password, this tool isn’t very useful when directly adding a user because it requires a pre-encrypted password. Therefore, it’s usually easiest to create an account in disabled form (by not using `-p` with `useradd`) and set the password after creating the account. You can do this with the `passwd` command, which has the following syntax:

```
passwd [-k] [-l] [-u [-f]] [-d] [-S] [username]
```



Although `passwd` is frequently used to set or change passwords, some of its actions don’t prompt you for a password. Instead, they modify the password in predictable ways, as described shortly. Other uses produce a password prompt at which you must type a new password (twice, to guard against typos).

The parameters to this command enable you to modify its behavior:

**Update expired accounts** The `-k` parameter indicates that the system should update an expired account.

**Lock accounts** The `-l` parameter locks an account by prefixing the encrypted password with an exclamation mark (!). The result is that the user can no longer log into the account, but the files are still available and the change can be easily undone. This parameter is particularly handy if you want to temporarily suspend user access to an account—say, because you’ve spotted some suspicious activity involving the account or because you know a user won’t be using the account for a while and you want to minimize the chance of it being abused in the interim.

**Unlock accounts** The `-u` parameter unlocks an account by removing a leading exclamation mark. `useradd` creates accounts that are locked and have no password, so using this command on a fresh account results in an account with no password. Normally, `passwd` doesn't allow this—it returns an error if you attempt it. Adding `-f` forces `passwd` to turn the account into one with no password.

**Remove an account's password** The `-d` parameter removes the password from an account, rendering it password-less.

**Display account information** The `-S` option displays information about the password for an account—whether it's set, and what type of encryption it uses.

Ordinary users may use `passwd` to change their passwords, but many `passwd` parameters may only be used by root. Specifically, `-l`, `-u`, `-f`, `-d` are all off-limits to ordinary users. Similarly, only root may specify a username to `passwd`. When ordinary users run the program, they should omit their usernames; `passwd` will change the password for the user who ran the program. As a security measure, `passwd` asks for a user's old password before changing the password when an ordinary user runs the program. This precaution is *not* taken when root runs the program, so that the superuser may change a user's password without knowing the original password. This is necessary because the administrator normally doesn't know the user's password. It also provides a way for the system administrator to help a user who's forgotten a password—the administrator can type `passwd username` and then enter a new password for the user.

Linux passwords may consist of letters, numbers, and punctuation. Linux distinguishes between upper- and lowercase letters in passwords, which means you can use mixed-case passwords, numbers, and punctuation to improve security.



Chapter 10 provides information about selecting good passwords.

Exercise 7.1 provides you with practice in creating accounts on a Linux system.

## EXERCISE 7.1

### Creating User Accounts

This exercise explores the process of creating user accounts. After performing this exercise, you should be familiar with the text-mode Linux account-creation tools and be able to create new accounts, including preparing new users' home directories. To add and test a new account, follow these steps:

1. Log into the Linux system as a normal user.
2. Launch an `xterm` from the desktop environment's menu system, if you used a GUI login method.

**EXERCISE 7.1 (continued)**

3. Acquire root privileges. You can do this by typing **su** in an xterm, by selecting Session > New Root Console from a Konsole, or by using **sudo** (if it's configured) to run the commands in the following steps.
4. Type **useradd -m username**, where *username* is the name you want to be associated with the account. This command creates an account. The **-m** parameter tells Linux to create a home directory for the user and fill it with default account configuration files.
5. Type **passwd username**. You'll be asked to enter a password for the user and to type it a second time. Enter a random string or select a password as described in "Setting a Password."
6. Press **Ctrl+Alt+F2** to go to a fresh text-mode login screen. (If you're already using multiple virtual terminals, you may need to use a function key number greater than F2.)
7. Try logging in as the new user to verify that the account works properly.

In practice, creating accounts on a production system may require variations on this procedure. You may need to use additional options in step 4, for instance; consult the section "Adding Users" or the **useradd** man page for details on these options. Furthermore, setting the password may require changes. On a small system with few users, you may be able to create accounts in the presence of their future users, in which case the user can type the password in step 5. On other systems, you may need to generate passwords yourself and then give them to users in some way.

---

**Using *usermod***

The **usermod** program closely parallels **useradd** in its features and parameters. This utility changes an existing account instead of creating a new one, though. The major differences between **useradd** and **usermod** are as follows:

- **usermod** allows the addition of a **-m** parameter when used with **-d**. The **-d** parameter alone changes the user's home directory, but it doesn't move any files. Adding **-m** causes **usermod** to move the user's files to the new location.
- **usermod** supports a **-l** parameter, which changes the user's login name to the specified value. For instance, typing **usermod sally -l sjones** changes the username from **sally** to **sjones**.
- You may lock and unlock a user's password with the **-L** and **-U** options, respectively. These options duplicate functionality provided by **passwd**.

The **usermod** program changes the contents of **/etc/passwd** or **/etc/shadow**, depending on the option used. If **-m** is used, **usermod** also moves the user's files, as already noted.





Changing an account’s characteristics while the owner is logged in can have undesirable consequences. This is particularly true of the `-d -m` combination, which can cause the files a user is working on to move. Most other changes, such as changes to the account’s default shell, don’t take effect until the user has logged out and back in again.

If you change the account’s UID, this action does *not* change the UIDs stored with a user’s files. Because of this, the user may lose access to these files. You can manually update the UIDs on all files by using the `chown` command, as described in Chapter 4. Specifically, a command like the following, issued after changing the UID on the account `sally`, restores proper ownership on the files in `sally`’s home directory:

```
chown -R sally /home/sally
```

This action does *not* change the ownership of files that aren’t in `sally`’s home directory. If you believe such files exist, you may need to track them down with the `find` command, as you’ll see in the upcoming section “Deleting Accounts.” Also, this command blindly changes ownership of *all* files in the `/home/sally` directory. This is probably OK, but it’s conceivable that some files in that directory *should* be owned by somebody else—say, because `sally` and another user are collaborating on a project.

When using the `-G` option to add a user to new groups, be aware that any groups *not* listed will be removed. The `gpasswd` command, described in the upcoming section “Using `gpasswd`,” provides a way to add a user to one or more specific groups without affecting existing group memberships, and so it’s generally preferable for this purpose.

### Using `chage`

The `chage` command allows you to modify account settings relating to account expiration. It’s possible to configure Linux accounts so that they automatically expire if either of two conditions is true:

- The password hasn’t been changed in a specified period of time.
- The system date is past a predetermined time.

These settings are controlled through the `chage` utility, which has the following syntax:

```
chage [-l] [-m mindays] [-M maxdays] [-d lastday] [-I inactivedays]
[-E expiredate] [-W warndays] username
```

The program’s parameters modify the command’s actions:

**Display information** The `-l` option causes `chage` to display account expiration and password aging information for a particular user.

**Set the minimum time between password changes** The `-m mindays` parameter sets the minimum number of days between password changes. 0 indicates that a user can change a password multiple times in a day; 1 means that a user can change a password once a day; 2 means that a user may change a password once every two days; and so on.

**Set the maximum time between password changes** The `-M maxdays` parameter sets the maximum number of days that may pass between password changes. For instance, 30 requires a password change approximately once a month.



If the user changes a password before the deadline, the counter is reset from the password-change date.

**Set the last password change date** The `-d lastday` parameter sets the last day a password was changed. This value is normally maintained automatically by Linux, but you can use this parameter to artificially alter the password change count. *lastday* is expressed in the format `YYYY/MM/DD` or as the number of days since January 1, 1970.

**Set the maximum inactive days** The `-I inactivedays` parameter sets the number of days between password expiration and account disablement. An expired account may not be used or may force the user to change the password immediately upon logging in, depending on the distribution. A disabled account is completely disabled.

**Set the expiration date** You can set an absolute expiration date with the `-E expiredate` option. For instance, you might use `-E 2010/05/21` to have an account expire on May 21, 2010. The date may also be expressed as the number of days since January 1, 1970. A value of `-1` represents no expiration date.

**Set the number of warning days** The `-W warnndays` option sets the number of days before account expiration that the system will warn the user of the impending expiration. It's generally a good idea to use this feature to alert users of their situation, particularly if you make heavy use of password-change expirations. Note that these warnings are usually only shown to text-mode login users; GUI login users, file-share users, and so on usually don't see these messages.

The `chage` command can normally be used only by `root`. The one exception to this rule is if the `-l` option is used; this feature allows ordinary users to check their account-expiration information.

### Directly Modifying Account Configuration Files

User configuration files can be modified directly. The `/etc/passwd` and `/etc/shadow` files control most aspects of an account's basic features. Both files consist of a set of lines, one line per account. Each line begins with a username and continues with a set of fields, delimited by colons (`:`). Many of these items may be modified with `usermod` or `passwd`. A typical `/etc/passwd` entry resembles the following:

```
sally:x:529:100:Sally Jones:/home/sally:/bin/bash
```

Each field has a specific meaning, as follows:

**Username** The first field in each `/etc/passwd` line is the username (`sally` in this example).

**Password** The second field has traditionally been reserved for the password. Most Linux systems, however, use a shadow password system in which the password is stored in `/etc/shadow`. The `x` in the example's password field is an indication that shadow passwords are in use. In a system that doesn't use shadow passwords, an encrypted password appears here instead.

**UID** Following the password is the account's user ID (529 in this example).

**Primary GID** The default login group ID is next in the `/etc/passwd` line for an account. The example uses a primary GID of 100.

**Comment** The comment field may have different contents on different systems. In the preceding example, it's the user's full name. Some systems place additional information here, in a comma-separated list. Such information may include the user's telephone number, office number, title, and so on.

**Home directory** The user's home directory is next up in the list.

**Default shell** The default shell is the final item on each line in `/etc/passwd`. This is normally `/bin/bash`, `/bin/tcsh`, or some other common command shell. It's possible to use something unusual here, though. For instance, many systems include a shutdown account with `/bin/shutdown` as the shell. If you log into this account, the computer immediately shuts down. You can create user accounts with a shell of `/bin/false`, which prevents users from logging in as ordinary users but leaves other utilities intact. Users can still receive mail and retrieve it via a remote mail retrieval protocol like POP or IMAP, for instance. A variant on this scheme uses `/bin/passwd` so that users may change their passwords remotely but can't log in using a command shell.

You can directly modify any of these fields, although in a shadow password system, you probably do *not* want to modify the password field; you should make password-related changes via `passwd` so that they can be properly encrypted and stored in `/etc/shadow`. As with changes initiated via `usermod`, it's best to change `/etc/passwd` directly only when the user in question isn't logged in, to prevent a change from disrupting an ongoing session.

Like `/etc/passwd`, `/etc/shadow` may be edited directly. An `/etc/shadow` line resembles the following:

```
sally:E/moFkeT5UnTQ:14069:0:-1:7:-1:-1:
```

Most of these fields correspond to options set with the `chage` utility, although some are set with `passwd`, `useradd`, or `usermod`. The meaning of each colon-delimited field on this line is as follows:

**Username** Each line begins with the username. Note that the UID is *not* used in `/etc/shadow`; the username links entries in this file to those in `/etc/passwd`.

**Password** The password is stored in encrypted form, so it bears no obvious resemblance to the actual password. An asterisk (\*) or exclamation mark (!) denotes an account with no password (that is, the account doesn't accept logins—it's locked). This is common for accounts used by the system itself.



If you've forgotten the root password for a system, you can boot with an emergency recovery system and copy the contents of a password field for an account whose password you do remember. You can then boot normally, log in as root, and change the password. In a real pinch, you can delete the contents of the password field, which results in a root account with *no* password (that is, none is required to log in). If you do this, be *sure* to *immediately* change the root password after rebooting!

**Last password change** The next field (14069 in this example) is the date of the last password change. This date is stored as the number of days since January 1, 1970.

**Days until a change is allowed** The next field (0 in this example) is the number of days before a password change is allowed.

**Days before a change is required** This field is the number of days after the last password change before another password change is required.

**Days of warning before password expiration** If your system is configured to expire passwords, you may set it to warn the user when an expiration date is approaching. A value of 7, as in the preceding example, is typical.

**Days between expiration and deactivation** Linux allows for a gap between the expiration of an account and its complete deactivation. An expired account either can't be used or requires that the user change the password immediately after logging in. In either case, its password remains intact. A deactivated account's password is erased, and the account can't be used until it's reactivated by the system administrator.

**Expiration date** This field shows the date on which the account will expire. As with the last password change date, the date is expressed as the number of days since January 1, 1970.

**Special flag** This field is reserved for future use and normally isn't used or contains a meaningless value. This field is empty in the preceding example.

For fields relating to day counts, a value of -1 or 99999 typically indicates that the relevant feature has been disabled. The `/etc/shadow` values are generally best left to modification through the `usermod` and `chage` commands because they can be tricky to set manually—for instance, it's easy to forget a leap year or the like when computing a date as the number of days since January 1, 1970. Similarly, because of its encrypted nature, the password field can't be edited effectively except through `passwd` or similar utilities. You can cut and paste a value from a compatible file or use `crypt`, but it's generally easier to use `passwd`. Copying encrypted passwords from other systems is also somewhat risky because it means that the users will have the same passwords on both systems, and this fact will be obvious to anybody who's acquired both encrypted password lists.



The `/etc/shadow` file is normally stored with very restrictive permissions, such as `rw-----` (600), with ownership by `root`. (Precise permissions vary from one distribution to another, though.) This fact is critical to the shadow password system's utility because it keeps non-`root` users from reading the file and obtaining the password list, even in an encrypted form. By contrast, `/etc/passwd` must be readable by ordinary users and usually has `rw-r--r--` (644) permissions. If you manually modify `/etc/shadow`, be sure it has the correct permissions when you're done.



## Real World Scenario

### Network Account Databases

Many networks employ network account databases. Such systems include the Network Information System (NIS), an update to this system called NIS+, the Lightweight Directory Access Protocol (LDAP), Kerberos realms, Windows NT 4.0 domains, and Active Directory (AD) domains. All of these systems move account database management onto a single centralized computer (often with one or more backup systems). The advantage of this approach to account maintenance is that users and administrators need not deal with maintaining accounts independently on multiple computers. A single account database can handle accounts on dozens (or even hundreds or thousands) of different computers, greatly simplifying day-to-day administrative tasks and simplifying users' lives. Using such a system, though, means that most user accounts won't appear in `/etc/passwd` and `/etc/shadow`, and groups may not appear in `/etc/group`. (These files will still hold information on local system accounts and groups, though.)

Linux can participate in these systems. In fact, some distributions provide options to enable such support at OS installation time. Typically, you must know the name or IP address of the server that hosts the network account database, and you must know what protocol that system uses. You may also need a password or some other protocol-specific information, and the server may need to be configured to accept accesses from the Linux system you're configuring.

Activating use of such network account databases after installing Linux is a complex topic. It involves installing appropriate software, modifying the `/etc/nsswitch.conf` file, and modifying the Pluggable Authentication Module (PAM) configuration files in `/etc/pam.d`. Such systems often alter the behavior of tools such as `passwd` and `usermod` in subtle or not-so-subtle ways. If you need to use such a system, you'll have to consult documentation specific to the service you intend to use. My book *Linux in a Windows World* (O'Reilly, 2005) covers this topic for Windows NT 4.0 domains, LDAP, and Kerberos; and Mark Minasi and Dan York's *Linux for Windows Administrators* (Sybex, 2002) covers this topic for Windows NT 4.0 domains and NIS.

## Deleting Accounts

On the surface, deleting user accounts is easy. You may use the `userdel` command to do the job of removing a user's entries from `/etc/passwd` and, if the system uses shadow passwords, `/etc/shadow`. The `userdel` command takes just three parameters:

**Remove user files** The `-r` or `--remove` parameter causes the system to remove all files from the user's mail spool and home directory, as well as the home directory.

**Force deletion** You can force deletion of the account while a user is logged in by using the `-f` or `--force` option in conjunction with `-r`. This option also forces removal of the mail spool even if it's owned by another user and forces removal of the home directory even if another user uses the same home directory.

**Get help** The `-h` or `--help` option summarizes `userdel` options.

Thus, removing a user account such as `sally` is easily accomplished with the following command:

```
userdel -r sally
```

You may omit the `-r` parameter if you want to preserve the user's files. Be aware of one potential complication: Users may create files *outside* their home directories. For instance, many programs use the `/tmp` directory as “scratch space,” so user files often wind up there. These files are deleted automatically after a certain period, but you may have other directories in which users may store files. To locate all such files, you can use the `find` command with its `-uid` parameter (or `-user`, if you use `find` before deleting the account). For instance, if `sally` was UID 529, you can use the following command to locate all her files:

```
find / -uid 529
```

The result is a list of files owned by UID 529 (formerly `sally`). You can then go through this list and decide what to do with the files—change their ownership to somebody else, delete them, back them up to CD-R, or what have you. It's wise to do *something* with these files, or they may be assigned ownership to another user if Sally's UID is reused. This can become awkward if the files exceed the new user's disk quota or if they contain information that the new user should not have—such a person may mistakenly be accused of indiscretions or even crimes.

A few servers—most notably Samba—keep their own list of users. If you run such a server, it's best to remove the user's entry from that server's user list when you remove the user's main account. In the case of Samba, this is normally done by manually editing the `smbpasswd` file (usually located in `/etc`, `/etc/samba`, or `/etc/samba.d`) and deleting the line corresponding to the user in question, or using the `smbpasswd` command and its `-x` option, as in `smbpasswd -x sally`, to delete the `sally` account from Samba's database.

## Configuring Groups

Linux provides group configuration tools that parallel those for user accounts in many ways. Groups are not accounts, however, so many features of these tools differ. Likewise,

you can create or modify groups by directly editing the configuration files in question. Their layout is similar to that for account control files, but the details differ.

## Adding Groups

Linux provides the `groupadd` command to add a new group. This utility is similar to `useradd` but has fewer options. The `groupadd` syntax is as follows:

```
groupadd [-g GID [-o]] [-r] [-f] groupname
```

The parameters to this command enable you to adjust its operation:

**Specify a GID** You can provide a specific GID with the `-g GID` parameter. If you omit this parameter, `groupadd` uses the next available GID. Normally, the GID you specify must be unused by other groups, but the `-o` parameter overrides this behavior, allowing you to create multiple groups that share one GID.

**Create a sub-500 GID** The `-r` parameter instructs `groupadd` to create a group with a GID of less than 500. Not all distributions support this option; it was added by Red Hat and has been used on some related distributions. Red Hat uses GIDs of 500 and above for user private groups (that is, groups named after individual users), hence the `-r` parameter.

**Force creation** Normally, if you try to create a group that already exists, `groupadd` returns an error message. The `-f` parameter suppresses that error message. Not all versions of `groupadd` support this parameter.

In most cases, you'll create groups without specifying any parameters except for the group name itself:

```
groupadd project3
```

This command creates the `project3` group, giving it whatever GID the system finds convenient—usually the highest existing GID plus 1. Once you've done this, you can add users to the group, as described in the next section. When you add new users, you can add them directly to the new group with the `-g` and `-G` parameters to `useradd`, described earlier.

## Modifying Group Information

Group information, like user account information, may be modified either using utility programs or by directly editing the underlying configuration file, `/etc/group`. There are fewer options for modifying groups than for modifying accounts, and the utilities and configuration files are similar. In fact, `usermod` is one of the tools that's used to modify groups.

### Using `groupmod` and `usermod`

The `groupmod` command modifies an existing group's settings. Its syntax is as follows:

```
groupmod [-g GID [-o]] [-n newgroupname] oldgroupname
```

The options to this command modify its operation:

**Specify a GID** Specify the new group ID using the `-g GID` option. `groupmod` returns an error if you specify a new group ID that's already in use, unless you include the `-o` parameter, in which case you can create two groups that share a single GID.

**Specify a group name** Specify a new group name with the `-n newgroupname` option.

One of the most common group manipulations you'll perform is not handled through `groupmod`; it's done with `usermod`. Specifically, `usermod` allows you to add a user to a group with its `-G` parameter. For instance, the following command sets `sally` to be a member of the `users`, `project1`, and `project4` groups, and it removes her from all other groups:

```
usermod -G users,project1,project4 sally
```



Be sure to list all the user's current groups in addition to any groups to which you want to add the user. Omitting any of the user's current groups will remove the user from those groups. You can discover the groups to which a user currently belongs with the `groups` command, as in **groups sally**. To avoid accidentally omitting a group, many system administrators prefer to modify the `/etc/group` file in a text editor or use `gpasswd`. Both options allow you to add users to groups without specifying a user's existing group memberships.

### Using `gpasswd`

The `gpasswd` command is the group equivalent to `passwd`. The `gpasswd` command also enables you to modify other group features and to assign *group administrators*—users who may perform some group-related administrative functions for their groups. The basic syntax for this command is:

```
gpasswd [-a user] [-d user] [-R] [-r] [-A user[,...]] [-M user[,...]] group
```

The options for this command modify its actions:

**Add a user** The `-a user` option adds the specified user to the specified group.

**Delete a user** The `-d user` option deletes the specified user from the specified group.

**Disallow newgrp additions** The `-R` option configures the group to not allow anybody to become a member through `newgrp`.

**Remove password** The `-r` option removes the password from a group.

**Add group administrators** The root user may use the `-A user[,...]` parameter to specify group administrators. Group administrators may add members to and remove members from a group and change the group password. Using this parameter completely overwrites the list of administrators, so if you want to add an administrator to an existing set of group administrators, you must specify *all* of their usernames.



**Add users** The `-M user[, ...]` option works like `-A`, but it also adds the specified user(s) to the list of group members.

If entered without any parameters except a group name, `gpasswd` changes the password for the group. Group passwords enable you to control temporary membership in a group, as granted by `newgrp`. Ordinarily, members of a group may use `newgrp` to change their current group membership (affecting the group of files they create). If a password is set, even those who aren't members of a group may become temporary group members; `newgrp` prompts for a password that, if entered correctly, gives the user temporary group membership.

Unfortunately, some of these features aren't implemented correctly in all distributions. In particular, password entry by non-group members sometimes does *not* give group membership—the system responds with an `access denied` error message. The `-R` option also sometimes doesn't work correctly—group members whose primary group membership is with another group may still use `newgrp` to set their primary group membership.

### Directly Modifying Group Configuration Files

Group information is stored primarily in the `/etc/group` file. Like account configuration files, the `/etc/group` file is organized as a set of lines, one line per group. A typical line in this file resembles the following:

```
project1:x:501:sally,sam,ellen,george
```

Each field is separated from the others by a colon. The meanings of the four fields are as follows:

**Group name** The first field (`project1` in the preceding example) is the name of the group.

**Password** The second field (`x` in the preceding example) is the group password. Distributions that use shadow passwords typically place an `x` in this field; others place the encrypted password directly in this field.

**GID** The group ID number (in this example's case, `501`) goes in this field.

**User list** The final field is a comma-separated list of group members.

Users may also be members of a group based on their own `/etc/passwd` file primary group specification. For instance, if user `george` has `project1` listed as his primary group, he need not be listed in the `project1` line in `/etc/group`. If user `george` uses `newgrp` to change to another group, though, he won't be able to change back to `project1` unless he's listed in the `project1` line in `/etc/group`.

Systems with shadow passwords also use another file, `/etc/gshadow`, to store shadow password information about groups. This file stores the shadow password and information for group administrators, as described earlier in “Using `gpasswd`.”



If you configure Linux to use a network account database, the `/etc/group` file is present and may define groups important for the system's basic operation. As with `/etc/passwd` and `/etc/shadow`, though, important user groups are likely to be defined only on the network account server, not in `/etc/group`.

## Deleting Groups

Deleting groups is done via the `groupdel` command, which takes a single parameter: a group name. For instance, `groupdel project3` removes the `project3` group. You can also delete a group by editing the `/etc/group` file (and `/etc/gshadow`, if present) and removing the relevant line for the group. It's generally better to use `groupdel`, because `groupdel` checks to see if the group is any user's primary group. If it is, `groupdel` refuses to remove the group; you must change the user's primary group or delete the user account first.

As with deleting users, deleting groups can leave orphaned files on the computer. You can locate them with the `find` command, which is described in more detail in Chapter 4. For instance, if a deleted group used a GID of 503, you can find all the files on the computer with that GID by using the following command:

```
find / -gid 503
```

Once you've found any files with the deleted group's ownership, you must decide what to do with them. In some cases, leaving them alone won't cause any immediate problems; but if the GID is ever reused, it can lead to confusion and even security breaches. Therefore, it's usually best to delete the files or assign them other group ownership using the `chown` or `chgrp` command.

# Tuning User and System Environments

Text-mode user environments are controlled through shell configuration files. For `bash`, these files include `/etc/profile`, `/etc/bash.bashrc`, `~/.profile`, `~/.bashrc`, `~/.bash_profile`, and `~/.profile`. The files in `/etc` are global configuration files, which affect all users; those in users' home directories (which are usually copied from the skeleton directory at account creation, as described earlier) affect individual users' accounts and can be customized by individual users. These files control the various `bash` options, including environment variables—named variables that hold data for the benefit of many programs. For instance, you might set the `$EDITOR` environment variable to the name of your favorite text editor. Some (but not all) programs that launch editors pay attention to this environment variable and launch the editor you specify.

As a system administrator, you can change the system-wide `bash` configuration files to add, remove, or change the environment variables that all users receive. Generally speaking, you should do so because the documentation for a specific program indicates that it uses particular environment variables. You can also see all your current environment variables by typing `env`. (The list is rather long, so you may want to pipe it through `less`, as in `env | less`.)

In addition to setting default environment variables and otherwise modifying users' text-mode login environment by adjusting their `bash` configuration files, you can adjust the default set of files created by `useradd`. As described earlier, in "Adding Users," `useradd` copies files from the *skeleton directory* (`/etc/skel` by default) into a newly created home directory. Typically, `/etc/skel` contains a handful of user configuration files, such as `.bashrc`. You can add files (and even directories) to this directory, including user configuration files, a starting directory tree, a `README` file for new users, and anything else you like. Because these files are

copied into users' home directories and users are given ownership of the copies, the users can read, change, and even delete their copies of these files. Thus, you shouldn't place any options in these files that are sensitive from a security point of view or that users should not be able to change. (In truth, entries you place in global bash configuration files can easily be overridden by individual users, as well.) Also, be aware that any changes you make to the global files won't automatically be moved into existing users' copies of these files; changes will affect only the files received by new users. This fact makes the global files (such as `/etc/profile`) preferable to `/etc/skel` for any changes to system defaults you want to implement system-wide, particularly if you expect you'll ever want to modify your changes.



Various programs set environment variables themselves, and some are maintained automatically by bash. For instance, bash maintains the `PWD` environment variable, so you shouldn't try to set it in a configuration script. Also, be aware that adjusting the bash configuration files only affects bash. If a user's default shell is something else, or if a user doesn't use a text-mode shell (say, if the user logs into X and launches programs from a GUI menu), setting environment variables in the bash configuration files will do no good.

## Using System Log Files

Linux maintains log files that record various key details about system operation. You may be able to begin using log files immediately, but knowing how to change the log file configuration can also be important. You do this by configuring the `syslogd` daemon (a daemon is a program that runs continuously in the background waiting for an event to trigger it to perform some action). Some servers and other programs perform their own logging and so must be configured independently of `syslogd`. You may even want to configure one computer to send its log files to another system as a security measure. You should also be aware of issues surrounding log file rotation; if your computer doesn't properly manage existing log files, they can grow to consume all your available disk space, at least on the partition on which they're stored. In addition to configuring logging, you must be able to use the log files that the system generates.

### Understanding *syslogd*

Most Linux systems employ a special daemon to handle log maintenance in a unified way. The traditional Linux system logger is `syslogd`, which is often installed from a package called `sysklogd`. The `syslogd` daemon handles messages from servers and other user-mode programs. It's usually paired with a daemon called `klogd`, which is generally installed from the same `sysklogd` package as `syslogd`. The `klogd` daemon manages logging of kernel messages.



Other choices for system loggers exist. For instance, `syslog-ng` is a replacement that supports advanced filtering options, and `metalog` is another option. Recent versions of Fedora use `rsyslogd`. This chapter describes the traditional `syslogd` logger. Others are similar in principle, and even in some specific features, but differ in many details.

The basic idea behind a system logger is to provide a unified means of handling log files. The daemon runs in the background and accepts data delivered from servers and other programs that are configured to use the log daemon. The daemon can then use information provided by the server to classify the message and direct it to an appropriate log file. This configuration enables you to consolidate messages from various servers in a handful of standard log files, which can be much easier to use and manage than potentially dozens of log files from the various servers running on the system.

In order to work, of course, the log daemon must be configured. In the case of `syslogd`, this is done through the `/etc/syslog.conf` file. (The `rsyslogd` configuration file is `/etc/rsyslog.conf` and is similar to `syslog.conf`.) The next section describes the `syslog.conf` file's format in more detail.

## Setting Logging Options

The format of the `/etc/syslog.conf` file is conceptually simple but provides a great deal of power. Comment lines, as in many Linux configuration files, are denoted by a hash mark (#). Non-comment lines take the following form:

```
facility.priority action
```

In this line, the *facility* is a code word for the type of program or tool that generated the message to be logged; the *priority* is a code word for the importance of this message; and the *action* is a file, remote computer, or other location that's to accept the message. The *facility* and *priority* are often referred to collectively as the *selector*.

Valid codes for the *facility* are `auth`, `authpriv`, `cron`, `daemon`, `kern`, `lpr`, `mail`, `mark`, `news`, `security`, `syslog`, `user`, `uucp`, and `local0` through `local7`. Many of these names refer to specific servers or program classes. For instance, mail servers and other mail-processing tools typically log using the `mail` facility. Most servers that aren't covered by more specific codes use the `daemon` facility. The `security` facility is identical to `auth`, but `auth` is the preferred name. The `mark` facility is reserved for internal use. An asterisk (\*) refers to all facilities. You can specify multiple facilities in one selector by separating the facilities with commas (,).

Valid codes for the *priority* are `debug`, `info`, `notice`, `warning`, `warn`, `error`, `err`, `crit`, `alert`, `emerg`, and `panic`. The `warning` priority is identical to `warn`, `error` is identical to `err`, and `emerg` is identical to `panic`. The `error`, `warn`, and `panic` priority names are deprecated; you should use their equivalents instead. Other than these identical pairs, these priorities represent ascending levels of importance. The `debug` level logs the most information; it's intended, as the name implies, for debugging programs that are misbehaving. The `emerg` priority logs the most important messages, which indicate very serious problems.

When a program sends a message to the system logger, it includes a priority code; the logger logs the message to a file if you've configured it to log messages of that level or higher. Thus, if you specify a *priority* code of `alert`, the system will log messages that are classified as `alert` or `emerg` but not messages of `crit` or below. An exception to this rule is if you precede the priority code by an equal sign (=), as in `=crit`, which describes what to do with messages of `crit` priority *only*. An exclamation mark (!) reverses the meaning of a match. For instance, `!crit` causes messages *below* `crit` priority to be logged. A *priority* of `*` refers to all priorities.

You can specify multiple selectors for a single action by separating the selectors by a semicolon (;). Note that commas are used to separate multiple facilities within a single selector, whereas semicolons are used to separate multiple selectors as a whole. Examples of complete selectors appear shortly.

Most commonly, the *action* is a filename, typically in the `/var/log` directory tree. The messages, `syslog`, and `secure` files in this directory are three common and important log files, although not all distributions use all of these files. Other possible logging locations include a device filename for a console (such as `/dev/console`) to display data on the screen, a remote machine name preceded by an at sign (@) to log data to the specified system, and a list of usernames of individuals who should see the message if they're logged in. For the last of these options, an asterisk (\*) means all logged-in users.

Some examples should help clarify these rules. First is a fairly ordinary and simple entry:

```
mail.* /var/log/mail
```

This line sends all log entries identified by the originating program as related to mail to the `/var/log/mail` file. Most of the entries in a default `/etc/syslog.conf` file resemble this one. Together, they typically cover all of the facilities mentioned earlier. Some messages may be handled by multiple rules. For instance, another rule might look like this one:

```
*.emerg *
```

This line sends all `emerg`-level messages to the consoles of all users who are logged into the computer using text-mode tools. If this line and the earlier `mail.*` selector are both present, `emerg`-level messages related to mail will be logged to `/var/log/mail` *and* displayed on users' consoles.

A more complex example logs kernel messages in various ways, depending on their priorities:

```
kern.* /var/log/kernel
kern.crit @logger.pangaea.edu
kern.crit /dev/console
kern.info;kern.!err /var/log/kernel-info
```

The first of these rules logs all kernel messages to `/var/log/kernel`. The second line sends critical messages to `logger.pangaea.edu`. (This system must be configured to accept remote logs, which is a topic not covered in this book.) The third line sends a copy of critical messages to `/dev/console`, which causes them to be displayed on the computer's main text-mode

console display. Finally, the last line sends messages that are between `info` and `err` in priority to `/var/log/kernel-info`. Because `err` is the priority immediately above `crit`, and because `info` is the lowest priority, these four lines cause all kernel messages to be logged two or three times: once to `/var/log/kernel` as well as to either the remote system and the console *or* to `/var/log/kernel-info`.

Most distributions ship with reasonable system logger settings, but you may want to examine these settings and perhaps adjust them. If you change them, be aware that you may need to change some other tools. For instance, all major distributions ship with tools that help rotate log files. If you change the files to which `syslogd` logs messages, you may need to change your log file rotation scripts as well. This topic is covered in the next section.

In addition to the system logger's options, you may be able to set logging options in individual programs. For instance, you may tell programs to record more or less information or to log routine information at varying priorities. Some programs also provide the means to log via the system log daemon or via their own mechanisms. Details vary greatly from one program to another, so you should consult the program's documentation for details.



Most programs that use the system log daemons are servers and other system tools. Programs that individuals run locally seldom log data via the system log daemon, although there are some exceptions to this rule, such as the Fetchmail program for retrieving e-mail from remote servers.

## Manually Logging Data

For the most part, the system logger accepts log entries from system tools, such as servers. Occasionally, though, you may want to manually create a log entry or have a script do so. The tool for this job is known as `logger`, and it has the following syntax:

```
logger [-isd] [-f file] [-p pri] [-t tag] [-u socket] [message ...]
```

Options to `logger` permit changing its default function:

**Record logger PID** The `-i` option records the process ID (PID) of the `logger` process along with other data.

**Output to standard error** You can echo data to standard error, as well as to the log file, by using the `-s` option. An interactive script might use this feature to alert users to problems.

**Log using datagrams** The `-d` option causes `logger` to use datagrams rather than a stream connection to the system log socket. This is an advanced feature that you should only

use if you're instructed to do so in documentation or if you understand the networking issues involved.

**Log a file** You can log the contents of a file by using the `-f file` option. Be cautious with this option; if *file* is big, your system log file can grow to ridiculous size!

**Identify a priority** The `-p pri` option specifies a priority, as described earlier.

**Log tags** By default, `logger` includes its name in the log file as a tag. You can change this tag with the `-t tag` option. This is useful if you want to identify a script or other program that created the log entry and don't care to record the fact that `logger` was involved in the process.

**Specify a socket** Ordinarily, `logger` calls the default system log tools to do its job. You can log directly to a network socket using the `-u socket` option, if you prefer.

**Specify a message** If you don't specify a file using `-f file`, `logger` will log whatever you type after other options as the message to be logged. If you don't provide a message on the command line, `logger` accepts input you type on subsequent lines as information to be logged. You should terminate such input by pressing Ctrl+D.

As an example, suppose you want to log the message “shutting down for system maintenance” to the system log. You can do so by typing the following command:

```
$ logger shutting down for system maintenance
```

The result will be an entry like the following, probably in `/var/log/messages`:

```
Jul 29 14:09:50 nessus logger: shutting down for system maintenance
```

Adding parameters changes the details of what's logged, as just described. You can place a call to `logger` in a script as a way of documenting the script's activities. For instance, a system backup script might use `logger` to record details such as its start and stop times and the number and size of the files it has backed up.

## Rotating Log Files

Log files are intended to retain information about system activities for a reasonable period of time; but system logging daemons provide no means to control the size of log files. Left unchecked, log files can therefore grow to consume all the available space on the partition on which they reside. To avoid this problem, Linux systems employ *log file rotation* tools. These tools rename and optionally compress the current log files, delete old log files, and force the logging system to begin using new log files.

The most common log rotation tool is a package called `logrotate`. This program is typically called on a regular basis via a cron job. (The upcoming section “Running Jobs in the Future” describes cron jobs in more detail.) The `logrotate` program consults a configuration file called `/etc/logrotate.conf`, which includes several default settings and typically refers to files in `/etc/logrotate.d` to handle specific log files. A typical `/etc/logrotate.conf` file includes several comment lines, denoted by hash marks (`#`), as well as lines to set various options, as illustrated by Listing 7.1.

**Listing 7.1:** Sample /etc/logrotate.conf File

```
Rotate logs weekly
weekly

Keep 4 weeks of old logs
rotate 4

Create new log files after rotation
create

Compress old log files
compress

Refer to files for individual packages
include /etc/logrotate.d

Set miscellaneous options
notifempty
nomainl
noolddir

Rotate wtmp, which isn't handled by a specific program
/var/log/wtmp {
 monthly
 create 0664 root utmp
 rotate 1
}
```

Most of the lines in Listing 7.1 set options that are fairly self-explanatory or that are well explained by the comments that immediately precede them—for instance, the `weekly` line sets the default log rotation interval to once a week. If you see an option in your file that you don't understand, consult the man page for `logrotate`.



Because log file rotation is handled by cron jobs that typically run late at night, it won't happen if a computer is routinely turned off at the end of the day. This practice is common with Windows workstations but is uncommon with servers. Either Linux workstations should be left running overnight as a general practice or some explicit steps should be taken to ensure that log rotation occurs despite routine shutdowns. The `anacron` utility, described in the upcoming section "Using *anacron*," is particularly well suited to this task.



The last few lines of Listing 7.1 demonstrate the format for the definition of a specific log file. These definitions begin with the filename for the file (multiple filenames may be listed, separated by spaces), followed by an open curly brace (`{`). They end in a close curly brace (`}`). Intervening lines set options that may override the defaults. For instance, the `/var/log/wtmp` definition in Listing 7.1 sets the `monthly` option, which tells the system to rotate this log file once a month, overriding the default `weekly` option. Such definitions are common in the individual files in `/etc/logrotate.d`, which are typically owned by the packages whose log files they rotate. Examples of features that are often set in these definitions include:

**Rotated file naming** Ordinarily, rotated log files acquire numbers, such as `messages.1` for the first rotation of the `messages` log file. Using the `dateext` option causes the rotated log file to obtain a date code instead, as in `messages-20091005` for the rotation performed on October 5, 2009.

**Compression options** As already noted, `compress` causes `logrotate` to compress log files to save space. This is done using `gzip` by default, but you can specify another program with the `compresscmd` keyword, as in `compresscmd bzip2` to use `bzip2`. The `compressoptions` keyword enables you to pass options to the compression command (say, to improve the compression ratio).

**Creation of new log files** The `create` option causes `logrotate` to create a new log file for use by the system logger or program. This option takes a file mode, an owner, and a group as additional options. Some programs don't work well with this option, though. Most of them use the `copytruncate` option instead, which tells `logrotate` to copy the old log file to a new name and then clear all the data out of the original file.

**Time options** The `daily`, `weekly`, and `monthly` options tell the system to rotate the log files at the specified intervals. These options aren't always used; some configurations use a size threshold rather than a time threshold for when to rotate log files.

**Size options** The `size` keyword sets a maximum size for a log file. It takes a size in bytes as an argument (adding `k` or `M` to the size changes it to kilobytes or megabytes, respectively). For instance, `size 100k` causes `logrotate` to rotate the file when it reaches 100KB in size.

**Rotation options** The `rotate x` option causes `x` copies of old log files to be maintained. For instance, if you set `rotate 2` for the `/var/log/messages` file, `logrotate` will maintain `/var/log/messages.1` and `/var/log/messages.2` in addition to the active `/var/log/messages` file. When that file is rotated, `/var/log/messages.2` is deleted, `/var/log/messages.1` is renamed to `/var/log/messages.2`, `/var/log/messages` becomes `/var/log/messages.1`, and a new `/var/log/messages` is created.

**Mail options** If you use `mail address`, `logrotate` will e-mail a log file to the specified address when it's rotated out of existence. Using `nomail` causes the system to not send any e-mail; the log is quietly deleted.

**Scripts** The `prerotate` and `postrotate` keywords both begin a series of lines that are treated as scripts to be run immediately before or after log file rotation, respectively. In both cases, these scripts end with the `endscript` keyword. These commands are frequently used to force `syslogd` or a server to begin using a new log file.

In most cases, servers and other programs that log data either do so via the system logging daemon or ship with a configuration file that goes in `/etc/logrotate.d` to handle the server's log files. These files usually do a reasonable job, but you may want to double-check them. For instance, you might discover that your system is configured to keep too many or too few old log files for your taste, in which case adjusting the `rotate` option is in order. You should also check the `/var/log` directory and its subdirectories every now and then. If you see huge numbers of files accumulating, or if files are growing to unacceptable size, you may want to check the corresponding `logrotate` configuration files. If an appropriate file doesn't exist, create one. Use a working file as a template, modifying it for the new file. Pay particular attention to the `prerotate` and `postrotate` scripts; you may need to consult the documentation for the program that's creating the log file to learn how to force that program to begin using a new log file.

In most cases, log files remain on the computer that recorded them. Sometimes, though, you may want to copy such files off-site. The easiest way to do this may be to reconfigure the log daemon to send the messages you want to archive to another system, as described in “Setting Logging Options.” Another possibility is to create a cron job (as described later, in “Running Jobs in the Future”) to copy files to another system using a network share, `ssh`, or some other network tool. You can also manually copy log files onto removable disks, if you like. There are few technical reasons to archive log files for more than a few weeks—only if a problem escapes your notice for a long time will they be useful. Managers or lawyers may want to keep them around for the long term for business or legal reasons, though.

## Reviewing Log File Contents

Log files do no good if they simply accumulate on the system. Their purpose is to be used as a means of identifying problems or documenting normal activity. When a server isn't responding as you expect, when a computer refuses logins it should be accepting (or accepting logins it should be refusing), or when a system's network interface isn't coming up (to name just three types of problems), you should check your log files as part of your troubleshooting procedures. Log files can also be useful in less troublesome situations, such as helping you to identify the load on a server so as to plan upgrades. Several procedures, many of which involve tools described elsewhere in this book, can help you access your log files:

**Paging through whole log files** You can use a pager program, such as `less` (described in Chapter 1, “Exploring Linux Command-Line Tools”), to view the entire contents of a log file. A text editor can fill the same role.

**Searching for keywords** You can use `grep` (described in Chapter 1) to pull lines that contain keywords out of log files. This can be particularly handy when you don't know which log file is likely to hold an entry. For instance, typing `grep eth0 /var/log/*` locates all lines in all files in the `/var/log` directory that contain the string `eth0`.

**Examining the start or end of a file** You can use the `head` or `tail` command (described in Chapter 1) to examine the first or last several lines of a log file. The `tail` command is particularly handy; you can use it to look at the last few entries just after you take some action that you expect to produce some diagnostic log file entries.

**Monitoring log files** In addition to checking the last few lines of a log file, `tail` can monitor a file on an ongoing basis, echoing lines to the screen as they're added to the file. You do this with the `-f` option to `tail`, as in `tail -f /var/log/messages`.

**Using advanced log analysis tools** Various packages exist expressly for the purpose of analyzing log files. For instance, there's Logcheck, which is part of the Sentry Tools package (<http://sourceforge.net/projects/sentrytools/>). This package comes with some distributions, such as Mandriva and Debian. Unfortunately, it requires a fair amount of customization for your own system, so it's most easily implemented if it comes with your distribution, preconfigured for its log file format.

Log file analysis is a skill that's best learned through experience. Many log file messages are cryptic, and they can be cryptic in different ways for different programs. For instance, consider these entries:

```
Apr 14 23:17:00 speaker /USR/SBIN/CRON[6026]: (george) CMD➤
 (/usr/bin/fetchmail -f /home/george/.fetchmailrc > /dev/null)
Apr 14 23:17:52 speaker sshd[6031]: Accepted publickey for george from➤
 ::ffff:192.168.1.3 port 48139 ssh2
```

These two lines relate to two entirely different events, but they have a similar format. Both entries begin with a time stamp and the name of the computer on which the activity occurred (speaker in this example). Next on each line is an identifier for the program that logged the activity, including its PID number: `/USR/SBIN/CRON[6026]` and `sshd[6031]` in this example. Note that these names are generated by the programs that create the activity, so they aren't necessarily consistent or even fully accurate. For instance, there is no `/USR/SBIN/CRON` program, although there *is* a `/usr/sbin/cron` program. (Recall that Linux has a case-sensitive filesystem.)

All of this information helps you identify what program logged the entry and when it did so. The rest of the log entry contains the actual logged data. The first entry in this example is from the cron utility, and it identifies a program run on behalf of `george`—specifically, cron ran the `fetchmail` program, passed it the name of a configuration file via the `-f` option, and redirected the output to `/dev/null`. The second entry (for `sshd`) identifies a login from 192.168.1.3 on port 48139, again involving the user `george`.

You can use entries like these to help identify malfunctioning servers, spot security breaches, and otherwise debug your system. Doing so, though, requires at least some familiarity with the normal log file contents as well as other system details. For instance, in the preceding example, if your system has no `george` account, these entries should both be suspicious; but you must be familiar enough with the format of the entries to spot that `george` is a username (or be able to work it out). You must also know that your system should have no `george` account.

Overall, you should probably examine your log files from time to time to become familiar with their contents. This will help you spot abnormalities when the system begins misbehaving or when you want to use log files to help track down an unwelcome visitor.



Log file entries can be conspicuous by their absence as well as by suspicious content within them. Intruders often try to cover their tracks by editing log files to remove the entries that betray their unauthorized accesses. Sometimes, though, they're sloppy about this and just delete all the log entries from the time in question. If you notice unusual gaps in your log files, such as a space of an hour with no entries on a system that normally logs a couple dozen entries in that period, you may want to investigate further.

## Maintaining the System Time

Linux depends on its system clock more than many OSs. Tools such as `cron` and `at` (described later, in “Running Jobs in the Future”) run programs at specified times, the `make` development tool uses files' time stamps to determine which ones need attention, and so on. Thus, you should be familiar with how Linux deals with time, how to set the time zone, how to set the time, and how to keep the clock accurate.

### Linux Time Concepts

The *x86* computers that most often run Linux, as well as most other computers of this general class, have two built-in clocks. The first of these clocks, sometimes called the *hardware clock*, maintains the time while the computer is turned off. When you boot Linux, it reads the hardware clock and sets the *software clock* to the value it retrieves. The software clock is what Linux uses for most purposes while it's running.

Most desktop OSs, such as Windows and pre-X versions of Mac OS, set their clocks to the local time. This approach is simple and convenient for people who are used to dealing mainly with local time, but for purposes of networking, it's inadequate. When it's 4:00 in New York, it's 1:00 in Los Angeles, so network protocols that rely even partly on time can become confused (or at the very least, create confusing log entries) when they operate across time zones. Linux, like other Unix-like OSs, sets its clock to *Coordinated Universal Time (UTC)*, which for most purposes is identical to *Greenwich Mean Time (GMT)*—the time in Greenwich, England, unadjusted for Daylight Saving Time. This approach means that Linux systems in New York and Los Angeles (and London and Moscow and Beijing) should have identical times, assuming all are set correctly. For communicating with users, though, these systems need to know their time zones. For instance, when you type `ls -l` to see a file listing complete with time stamps, Linux reads the time stamp in UTC and then adds or subtracts the appropriate amount of time so that the time stamp appears in your local time. Of course, all of this means that you must be able to set the computer's time zone. On most systems, this is done at system installation; the distribution's installer asks you for your time zone and sets things up correctly. If you erred during installation or if you need to change the time zone for any reason, Chapter 6, “Configuring the X Window System, Localization, and Printing,” describes how to set your time zone.



LPI objective 108.1 includes the files `/usr/share/zoneinfo`, `/etc/timezone`, and `/etc/localtime`. These files are also included under LPI objective 107.3 and are described in Chapter 6, which covers that objective.

Linux’s internal use of UTC can complicate setting the hardware clock. Ideally, the hardware clock should be set to UTC; but if your system multi-boots between Linux and an OS that expects the hardware clock to be in local time, you’ll have to set the hardware clock to local time and configure Linux to deal with this fact. For the most part, this configuration works well, but you may have to watch the clock the first time you reboot in the spring or fall after changing your clocks because of a Daylight Saving Time adjustment. Depending on your Linux and other OS’s settings, your hardware clock may be reset in a way one OS or the other doesn’t expect.

Both the hardware clock and the software clock are notoriously unreliable on standard *x86* hardware; both clocks tend to drift, so your clock can easily end up being several minutes off the correct time within a month or two of being set. To deal with this problem, Linux supports various network protocols for setting the time. The most popular of these is the *Network Time Protocol (NTP)*, which is described in the upcoming section “Using NTP.”

## Manually Setting the Time

You can manually set your system’s clock—or more precisely, its *clocks*, because as noted earlier, Linux maintains two clocks: the hardware clock and the software clock. The main tool to set the software clock is `date`, which has the following syntax when setting the clock:

```
date [-u|--utc|--universal] [MMDDhhmm][[CC]YY][.ss]
```

Used without any options, this command displays the current date. If you pass a time to the program, it sets the software clock to that time. This format contains a month, a day, an hour, and a minute at a minimum, all in two-digit codes (*MMDDhhmm*). You can optionally add a 2- or 4-digit year and the seconds within a minute if you like. You should specify the time in a 24-hour format. For instance, to set the time to 3:02 pm on October 27, 2009, you’d type the following command:

```
date 102715022009
```

By default, `date` assumes you’re specifying the time in local time. If you want to set the clock in UTC, include the `-u`, `--utc`, or `--universal` option.

Because *x86* hardware maintains both software and hardware clocks, Linux provides tools to synchronize the two. Specifically, the `hwclock` utility enables you to set the hardware clock from the software clock or vice versa, as well as do a few other things. Its syntax is fairly straightforward:

```
hwclock [options]
```

You can specify options to accomplish several goals:

**Show the hardware clock** To view the hardware clock, pass the `-r` or `--show` option. The time is displayed in local time, even if the hardware clock is set to UTC.

**Set the hardware clock manually** To set the hardware clock to a date you specify, you need two options: `--set` and `--date=newdate`. The *newdate* is in the date format that the date program accepts.

**Set the hardware clock based on the software clock** If you've set the software clock, you can synchronize the hardware clock to the same value with the `--systohc` option.

**Set the software clock based on the hardware clock** If your hardware clock is accurate but your software clock isn't, you can use the `--hctosys` option to set the software clock to the hardware clock's value. This option is often used in a SysV startup script to set the system clock when the computer first boots.

**Specify UTC or local time** You can tell Linux to treat the hardware clock as storing UTC by using the `--utc` option or to treat it as holding local time by using the `--localtime` option. The default is whichever was last used when the hardware clock was set.

Ordinarily, you won't use `hwclock` directly very often. You may need to use it after a Daylight Saving Time shift if you maintain your hardware clock in local time, but some distributions include scripts that manage this task automatically. You may also want to use it once in a while to keep the hardware clock from drifting too far from an accurate time; but again, some distributions do this automatically as part of the system shutdown procedure.



You can also set the hardware clock via your computer's BIOS setup utility. Consult your motherboard or computer hardware manual for details. You must reboot the system to do this, typically pressing the Delete or some other key at a critical time early in the boot process (before your boot loader takes over). You must then find the time option and set it appropriately. If Linux is using UTC, remember to set the clock to UTC rather than local time.

## Using NTP

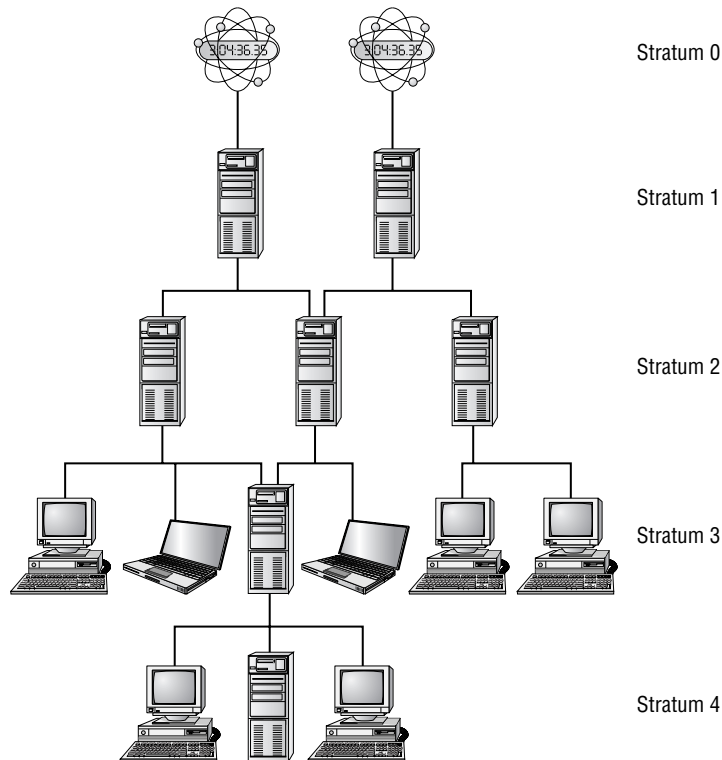
Typically, a clock on an isolated computer needn't be set with any great precision. It doesn't really matter if the time is off by a few seconds, or even a few minutes, so long as the time is reasonably consistent on that one computer for the purpose of `cron`, other scheduling tools, and time stamps. Sometimes, though, maintaining a truly accurate system time is important. This is true for a few scientific, business, and industrial applications (such as astronomical measurements or a system that determines the start and stop times for television broadcasts). In a networked environment, maintaining the correct time can be more important. Time stamps on files may become confused if a file server and its clients have different times, for instance. Worse, a few protocols, such as the Kerberos security suite,

embed time stamps in their packets and rely on those time stamps for normal system functioning. If two systems using Kerberos have wildly different times, they may not be able to communicate. For these reasons, several protocols exist to synchronize the clocks of multiple systems. Of these, NTP is the most popular and flexible, so I describe it. You should first understand the basic principles of NTP operation. You can then go on to configuring an NTP server for your network and setting up other systems as NTP clients.

### Understanding NTP Basics

One of the most popular, flexible, and accurate network time tools is NTP. This protocol creates a tiered hierarchy of time sources, as illustrated in Figure 7.1. At the top of the structure are one or more highly accurate time sources—typically atomic clocks or radio receivers that pull their times from broadcast time signals based on atomic clocks. These are referred to as *stratum 0* time servers, but they aren't directly accessible to any but the *stratum 1* time servers to which they're connected. These stratum 1 computers run NTP servers that deliver the time to *stratum 2* servers, which deliver the time to *stratum 3* servers, and so on for an arbitrary number of strata.

**FIGURE 7.1** NTP enables an expanding pyramid of computers to set their clocks to a highly accurate source signal.





Other time-setting protocols include one built into the Server Message Block/Common Internet File System (SMB/CIFS) used for Windows file sharing and implemented in Linux by Samba and a protocol used by the `rdate` utility in Linux.

The key to NTP is the fact that each server can deliver time to an expanding number of clients. For instance, if a stratum 1 server has 1,000 clients, each of which has 1,000 clients, and so on, stratum 3 will consist of 1,000,000 systems and stratum 4 will contain 1,000,000,000 systems. Each increase in the stratum number slightly decreases the accuracy of the time signal, but not by much; even a stratum 4 system's clock should be accurate to well under a second, which is accurate enough for almost all purposes. More important, if you run a network, you can set aside one computer as an NTP server and set all your other computers' clocks from that one server. Even if your primary NTP server's clock is off by a second, all the clocks on your network should be set to within a tiny fraction of each other, which is the most important consideration for time-dependent network protocols such as Kerberos.

NTP works by measuring the round-trip time for packets between the server and the client. The two systems exchange packets with embedded time stamps; the client then adjusts its time so that it is synchronized with the source's time stamp but adds a bit to the time reported by the source to account for this round-trip delay. For this reason, when you select an NTP source (as described next, in "Locating a Time Source"), you should pick one with the shortest possible network time delay, all other things being equal. (In truth, several measures of reliability exist, and the NTP programs try to take them all into account.)

The main Linux NTP server program functions as both a server and a client; it sets its clock based on the time of the server to which it's pointed, and it enables other systems to set their clocks based on its own. Even the end points in the NTP hierarchy (the stratum 4 and some stratum 3 servers in Figure 7.1) often run the full NTP server package. The reason is that this software runs constantly and can monitor for and adjust the clock drift that's common in *x86* and other computers' clocks, resulting in much more consistent timekeeping than is possible with a program that simply sets the clock and then ignores it until the next time the program is run. In other words, NTP doesn't just reset the system clock periodically; the server improves the accuracy of the system clock. In part, this is done through the `ntp.drift` file, which is usually buried in `/var/lib/ntp` but is sometimes stored in `/etc`. This file holds information about the software clock's inaccuracies and so can be used to correct for them. A full NTP server, even when it's functioning only as an NTP client, periodically checks with its source systems to keep the system time set correctly and to update the `ntp.drift` file.

## Locating a Time Source

You may think that locating an NTP server with a low stratum number (such as stratum 1) is ideal. Although it's true that your own system will have a minutely more accurate clock when using such a source, the best approach in most cases is to synchronize with a stratum 2 or lower system. The reason is that this practice will help keep the load on the stratum 1 servers



low, thus improving the overall performance of the NTP network as a whole. An exception might be if you're configuring an NTP server that will itself deliver the time to hundreds or more computers.

To locate an NTP server, you should consult one or more of several sources:

**Your ISP** Many Internet service providers (ISPs), including business networks and universities, operate NTP servers for the benefit of their users. These servers are usually very close to your own in a network sense, making them good choices for NTP. You should consult your ISP or the networking department at your organization to learn if such a system is available.

**Your distribution's NTP server** Some Linux distributions operate NTP servers for their users. If you happen to be close to these servers in a network sense, they can be good choices; however, chances are this isn't the case, so you may want to look elsewhere.

**Public NTP server lists** Lists of public NTP servers are maintained at <http://support.ntp.org/bin/view/Servers/WebHome>. These servers can be good choices, but you'll need to locate the one closest to you in a network sense, and perhaps contact the site you choose to obtain permission to use it.

**Public NTP server pool** The `pool.ntp.org` subdomain is dedicated to servers that have volunteered to function as public NTP servers. These servers are accessed in a round-robin fashion by hostname, so you can end up using different servers each time you launch NTP. Thus, using the public NTP server pool can be a bit of a gamble, but the results are usually good enough for casual users or if you don't want to spend time checking and maintaining your NTP configuration. To use the pool, you can configure your NTP server to use either the `pool.ntp.org` subdomain name or a numbered host within that domain, such as `0.pool.ntp.org`. Consult <http://support.ntp.org/bin/view/Servers/NTPPoolServers> for details.



The closest server in a network sense may not be the closest computer in a geographic sense. For instance, a national ISP may route all traffic through just one or two hub sites. The result can be that traffic from, say, Atlanta, Georgia to Tampa, Florida may go through Chicago, Illinois. Such a detour is likely to increase round-trip time and decrease the accuracy of NTP. In such a situation, a user in Atlanta may be better off using a Chicago NTP server than one in Tampa, even though Tampa is much closer geographically.

Once you've located a few possible time servers, try using `ping` to determine the round-trip time for packets to this system. If any systems have very high `ping` times, you may want to remove them from consideration.

## Configuring NTP Servers

When you're setting up a network to use NTP, select one system (or perhaps two for a network with several dozen or more computers) to function as the primary NTP server. This

computer needn't be very powerful, but it must have always-up access to the network. You can then install the NTP server and configure it.

Most Linux distributions ship the NTP software in a package called `ntp`, `xntp`, `ntpd`, or `xntpd`. Look for this package and, if it's not already installed, install it. If you can't find this package, check <http://www.ntp.org/downloads.html>. This site hosts NTP source code, which you can compile and install. Alternatively, you can look for a binary package for another distribution. Either way, if you don't install your distribution's own NTP package, you'll need to create your own SysV startup script or start the NTP daemon in some other way.

Once NTP is installed, look for its configuration file, `/etc/ntp.conf`. This file contains various NTP options, but the most important are the server lines:

```
server clock.example.com
server ntp.pangaea.edu
server time.luna.edu
```

Each of these lines points to a single NTP server. When your local NTP daemon starts up, it contacts all the servers specified in `/etc/ntp.conf`, measures their accuracy against each other, and settles on one as its primary time source. Typically, you list about three upstream time servers for a system that's to serve many other computers. This practice enables your server to weed out any servers that deliver a bad time signal, and it also gives automatic fallback in case an upstream server becomes temporarily or permanently unavailable. If your NTP server won't be serving many computers itself, you may want to configure it for three servers initially and then drop the ones your system isn't using as its primary time source after a day or two. This will reduce the load on these servers.

You may want to peruse your configuration file for entries to remove. For instance, the configuration file may contain references to servers you'd rather not use or other odd options with associated comments that make you think they're inappropriate. Generally speaking, you shouldn't adjust entries in the `ntp.conf` file other than the reference server lines, but special circumstances or odd starting files may require you to make changes.

Once you've made your changes, start or restart your NTP daemon. Typically, this is done via a SysV startup script:

```
/etc/init.d/ntpd restart
```

You may need to change the path to the file, the SysV script filename, or the option (change `restart` to `start` if you're starting NTP for the first time). Most distributions configure NTP to start whenever the system boots once you install the server. Consult Chapter 5, "Booting Linux and Editing Files," for details of changing this configuration.

To verify that NTP is working, you can use `ntpq`, which is an interactive program that accepts various commands. Figure 7.2 shows it in operation, displaying the output of the `peers` command, which displays the servers to which your NTP server is connected. In Figure 7.2, three external servers are listed, plus `LOCAL(0)`, which is the last-resort reference source of the computer's own clock. The `refid` column shows the server to which each system is synchronized, the `st` column shows the stratum of the server, and additional columns show more technical information. The server to which yours is synchronized is

denoted by an asterisk (\*), other servers with good times are indicated by plus signs (+), and most other symbols (such as x and -) denote servers that have been discarded from consideration for various reasons. Consult `ntpq`'s man page for more information about its operation.

**FIGURE 7.2** The `ntpq` program enables you to verify that an NTP server is functioning correctly.

```

rodsmith@speaker:~ - Shell - Konsole
Session Edit View Bookmarks Settings Help
$ ntpq
ntpq> peers
=====
remote refid st t when poll reach delay offset jitter
=====
+clock.example.c 128.227.205.3 2 u 186 1024 377 23.016 -0.624 10.787
*ntp.pangaea.edu 172.17.1.243 2 u 269 1024 377 41.464 4.139 2.553
+time.luna.edu 18.145.0.30 2 u 186 1024 377 20.183 -0.293 0.366
LOCAL(0) LOCAL(0) 10 1 23 64 377 0.000 0.000 0.001
ntpq>

```



You won't see a server selected as the source until a few minutes after you restart the NTP daemon. The reason is that your local NTP process takes a while to determine which of the sources is providing the best signal.

## Configuring NTP Clients

Once you've configured one or more NTP servers, you can configure the rest of your systems to point to them. Their configuration is done just like the NTP server configuration, with a couple of exceptions:

- You set your NTP clients to refer to the NTP server (or servers) you've just configured rather than to an outside NTP source. This way, your local systems won't put an additional burden on the outside NTP server you've selected.
- You may want to ensure that your NTP clients can't be accessed as servers. This is a security measure. You can do this with an `iptables` firewall rule or by using the `restrict default ignore` line in `ntp.conf`. This line tells the server to ignore all incoming NTP requests. Ideally, you should use both methods.

Once you've configured a client, restart its NTP daemon. You can then use `ntpq` to check its status. You should see that it refers only to your network's own NTP server or servers. These systems should be listed as belonging to a stratum with a number one higher than the servers to which they refer.

In some cases, a simpler way to set the time on a client is to use `ntpdate`. This program is part of the NTP suite, and it performs a one-time clock setting. To use it, type the command name followed by the hostname or IP address of an NTP server:

```
ntpdate clock.example.com
```

Some NTP packages include a call to `ntpdate` in their NTP daemon startup scripts in order to ensure that the system is set to the correct time when it starts. The `ntpdate` command, however, has been deprecated and could disappear from the NTP package at any time. Instead, you can start `ntpd` with its `-g` option, which enables it to perform a one-time clock setting to a value that's wildly divergent from the current time. (Ordinarily, `ntpd` exits if the time server's time differs from the local time by more than a few minutes.)



### Real World Scenario

#### Serving Time to Windows Systems

If your network hosts both Linux and Windows systems, you may want to use a Linux system as a time source for Windows clients or conceivably even use a Windows server as a time source for Linux clients. One way to do this is to run NTP on Windows. Consult <http://geodsoft.com/howto/timesync/wininstall.htm> or perform a Web search to locate NTP software for Windows systems. For Windows NT/200x/XP/Vista, you can type **NET TIME /SETSNTP:time.server**, where *time.server* is the name of your local NTP time server. This command performs a one-time setting of the clock but doesn't run in the background as the full NTP package does on Linux. Running this command in a Windows login script may be adequate for your purposes.

For older Windows 9x/Me systems, you can type **NET TIME \\SERVER /SET /YES** to have the system set the time to the time maintained by *SERVER*, which must be a Windows or Samba file or print server. This command doesn't use NTP, but if you've got a Linux system that runs both NTP and Samba, it can be a good way to get the job done.

## Running Jobs in the Future

Some system maintenance tasks should be performed at regular intervals and are highly automated. For instance, the `/tmp` directory (which holds temporary files created by many users) tends to collect useless data files. Linux provides a means of scheduling tasks to run at specified times to handle such issues. This tool is the `cron` program, which runs what are known as *cron* jobs. A related tool is `at`, which enables you to run a command on a one-time basis at a specified point in the future as opposed to doing so on a regular basis, as `cron` does.

### Understanding the Role of *cron*

The `cron` program is a daemon, so it runs continuously, looking for events that cause it to spring into action. Unlike most daemons, which are network servers, `cron` responds to temporal events. Specifically, it “wakes up” once a minute, examines configuration files in the

`/var/spool/cron` and `/etc/cron.d` directories and the `/etc/crontab` file, and executes commands specified by these configuration files if the time matches the time listed in the files.

There are two types of cron jobs: *system cron jobs* and *user cron jobs*. System cron jobs are run as `root` and perform system-wide maintenance tasks. By default, most Linux distributions include system cron jobs that clean out old files from `/tmp`, perform log rotation (as described earlier, in “Rotating Log Files”), and so on. You can add to this repertoire, as described shortly. Ordinary users can create user cron jobs, which might run some user program on a regular basis. You can also create a user cron job as `root`, which might be handy if you need to perform some task at a time not supported by the system cron jobs, which are scheduled rather rigidly.

One of the critical points to remember about cron jobs is that they run unsupervised. Therefore, you shouldn’t call any program in a cron job if that program requires user input. For instance, you wouldn’t run a text editor in a cron job; but you might run a script that automatically manipulates text files, such as log files.

## Creating System *cron* Jobs

The `/etc/crontab` file controls system cron jobs. This file normally begins with several lines that set environment variables, such as `$PATH` and `$MAILTO` (the former sets the path, and the latter is the address to which programs’ output is mailed). The file then contains several lines that resemble the following:

```
02 4 * * * root run-parts /etc/cron.daily
```

This line begins with five fields that specify the time. The fields are, in order, the minute (0–59), the hour (0–23), the day of the month (1–31), the month (1–12), and the day of the week (0–7; both 0 and 7 correspond to Sunday). For the month and day of the week values, you can use the first three letters of the name rather than a number, if you like.

In all cases, you can specify multiple values in several ways:

- An asterisk (\*) matches all possible values.
- A list separated by commas (such as 0,6,12,18) matches any of the specified values.
- Two values separated by a dash (-) indicate a range, inclusive of the end points. For instance, 9-17 in the hour field specifies a time of from 9:00 a.m. to 5:00 p.m.
- A slash, when used in conjunction with some other multi-value option, specifies stepped values—a range in which some members are skipped. For instance, \*/10 in the minute field indicates a job that’s run every 10 minutes.

After the first five fields, `/etc/crontab` entries continue with the account name to be used when executing the program (`root` in the preceding example) and the command to be run (`run-parts /etc/cron.daily` in this example). The default `/etc/crontab` entries generally use `run-parts`, `cronloop`, or a similar utility that runs any executable scripts within a directory. Thus, the preceding example runs all the scripts in `/etc/cron.daily` at 4:02 a.m. every day. Most distributions include monthly, daily, weekly, and hourly system cron jobs, each corresponding to scripts in a directory called `/etc/cron.interval`, where

*interval* is a word associated with the run frequency. Others place these scripts in `/etc/cron.d/interval` directories.



The exact times chosen for system cron jobs to execute vary from one distribution to another. Normally, though, daily and longer-interval cron jobs run early in the morning—between midnight and 6:00 a.m. Check your `/etc/crontab` file to determine when your system cron jobs run.

To create a new system cron job, you may create a script to perform the task you want performed (as described in Chapter 9, “Writing Scripts, Configuring E-Mail, and Using Databases”) and copy that script to the appropriate `/etc/cron.interval` directory. When the runtime next rolls around, cron will run the script.



Before submitting a script as a cron job, test it thoroughly. This is particularly important if the cron job will run when you’re not around. You don’t want a bug in your cron job script to cause problems by filling the hard disk with useless files or producing thousands of e-mail messages when you’re not present to quickly correct the problem.

If you need to run a cron job at a time or interval that’s not supported by the standard `/etc/crontab`, you can either modify that file to change or add the cron job runtime or create a user cron job, as described shortly. If you choose to modify the system cron job facility, model your changes after an existing entry, changing the times and script storage directory as required.



System cron job storage directories should be owned by root, and only root should be able to write to them. If ordinary users can write to a system cron directory, unscrupulous users can write scripts to give themselves superuser privileges and place them in the system cron directory. The next time cron runs those scripts, the users will have full administrative access to the system.

## Creating User *cron* Jobs

To create a user cron job, you use the `crontab` utility, not to be confused with the `/etc/crontab` configuration file. The syntax for `crontab` is as follows:

```
crontab [-u user] [-l | -e | -r] [file]
```

If given without the `-u user` parameter, `crontab` modifies the cron job associated with the current user. (User cron jobs are often called *crontabs*; but because the word is already used in reference to the system-wide configuration file and the utility itself, this usage can be perplexing.) The `crontab` utility can become confused by the use of `su` to change the

current user identity, so if you use this command, it's safest to also use `-u user`, even when you're modifying your own cron job.

If you want to work directly on a cron job, use the `-l`, `-r`, or `-e` option. The `-l` option causes `crontab` to display the current cron job; `-r` removes the current cron job; and `-e` opens an editor so that you can edit the current cron job. (Vi is the default editor, but you can change this by setting the `VISUAL` or `EDITOR` environment variable, as described in Chapter 1.)

Alternatively, you can create a cron job configuration file and pass the filename to `crontab` using the `file` parameter. For instance, `crontab -u tbaker my-cron` causes `crontab` to use `my-cron` for `tbaker`'s cron jobs.

Whether you create the cron job and submit it via the `file` parameter or edit it via `-e`, the format of the cron file is similar to that described earlier. You can set environment variables by using the form `VARIABLE=value`, or you can specify a command preceded by five numbers or wildcards to indicate when the job is to run. In a user cron job, you do *not* specify the username used to execute the job, as you do with system cron jobs. That information is derived from the owner of the cron job. Listing 7.2 shows a sample cron job file. This file runs two programs at different intervals: The `fetchmail` program runs every 30 minutes (on the hour and half hour), and `clean-adouble` runs on Mondays at 2:00 a.m. Both programs are specified via complete paths, but you can include a `PATH` environment variable and omit the complete path specifications.

**Listing 7.2:** A Sample User cron Job File

```
SHELL=/bin/bash
MAILTO=tbaker
HOME=/home/tbaker
0,30 * * * * /usr/bin/fetchmail -s
0 2 * * mon /usr/local/bin/clean-adouble $HOME
```

Ultimately, user cron job files are stored in the `/var/spool/cron`, `/var/spool/cron/tabs`, or `/var/spool/cron/crontabs` directory. Each file in this directory is named after the user under whose name it runs; for example, `tbaker`'s file might be called `/var/spool/cron/tabs/tbaker`. You shouldn't directly edit the files in this directory; instead, use `crontab` to make changes.

Access to the cron facility may be restricted in several ways:

**Executable permissions** The permissions on the `cron` and `crontab` programs may be restricted using standard Linux permissions mechanisms, as described in Chapter 4. Not all distributions configure themselves in this way, but for those that do, users who should be able to schedule jobs using `cron` should be added to the appropriate group. This group is often called `cron`, but you should check the group owner and permissions on the `/usr/sbin/cron` and `/usr/bin/crontab` program files to be sure.

**Allowed users list** The `/etc/cron.allow` file contains a list of users who should be permitted access to `cron`. If this file is present, only users whose names appear in the file may use `cron`; all others are denied access. If this file isn't present, anybody may use `cron`, assuming access isn't restricted by executable permissions or a disallowed users list.

**Disallowed users list** The `/etc/cron.deny` file contains a list of users who should be denied access to cron. If this file is present, any user whose name appears in the file is denied access to cron, but all others may use it, assuming executable permissions and the allowed users list don't restrict access.

Exercise 7.2 guides you through the process of creating user cron jobs.

## EXERCISE 7.2

### Creating User *cron* Jobs

cron jobs can be a useful way to run programs at regular times. In this exercise, you'll create a simple user cron job that will mail you the output of an `ifconfig` command on a daily basis. This exercise assumes that you're authorized to use cron as an ordinary user. To configure your cron job, follow these steps:

1. Log into the Linux system as a normal user.
2. Launch an `xterm` from the desktop environment's menu system, if you used a GUI login method.
3. Create and edit a file called `cronjob` in your home directory. Use your favorite text editor for this purpose. The file should contain the following lines:

```
SHELL=/bin/bash
MAILTO=yourusername
00 12 * * * /sbin/ifconfig
```

Be sure to type these lines exactly; a typo will cause problems. One exception: Substitute your e-mail address on the Linux system or elsewhere for *yourusername*; cron uses the `MAILTO` environment variable to determine to whom to e-mail the output of cron jobs.

4. Type `crontab cronjob` to install the `cronjob` file as a cron job. Note that this command replaces any existing user cron jobs that may exist. If you've already defined user cron jobs for your account, you should edit your existing `cronjob` file to add the line calling `ifconfig` rather than create a new file.
5. Wait for 12:00 noon (00 12 in the cron time format). When this time rolls around, you should have a new e-mail waiting for you with the contents of the `ifconfig` output.

Instead of waiting for 12:00 noon, you can substitute a time that's a couple of minutes in the future. Remember that cron specifies minutes first, followed by the hour in a 24-hour format. For instance, if you create the file at 3:52 p.m., you might enter 54 15 as the first two numbers on the final line of the file; this will cause the cron job to execute at 15:54 on a 24-hour clock, or 3:54 p.m.

---



## Using *anacron*

Although *cron* is a great tool for performing certain tasks, such as rotating log files, on systems that are up most or all of the time, it's a much less useful tool on systems that are frequently shut down, such as notebook computers or even many desktop systems. Frequently, late-night *cron* jobs are never executed on such systems, which can lead to bloated log files, cluttered `/tmp` directories, and other problems.

One solution to such problems is *anacron* (<http://anacron.sourceforge.net>). This program is designed as a supplement to *cron* to ensure that regular maintenance jobs are executed at reasonable intervals. It works by keeping a record of programs it should execute and how frequently it should do so, in days. Whenever *anacron* is run, it checks to see when it last executed each of the programs it's configured to manage. If a period greater than the program's execution interval has passed, *anacron* runs the program. Typically, *anacron* itself is run from a system startup script, and perhaps from a *cron* job. You can then reconfigure your regular system *cron* jobs as *anacron* jobs and be sure they'll execute even on systems that are regularly shut down for long stretches of time.

Like *cron*, *anacron* is controlled through a configuration file named after itself: `/etc/anacrontab`. This file consists of three main types of lines: comment lines (denoted by a leading hash mark, #), environment variable assignments (as in `SHELL=/bin/bash`), and job definition lines. This last type of line contains four fields:

```
period delay identifier command
```

The *period* is how frequently, in days, the command should be run. The *delay* is a delay period, in minutes, between the time *anacron* starts and the time the command is run, if it should be run. This feature is intended to help keep the system from being overloaded if *anacron* determines it needs to run many commands when it starts up. The *identifier* is a string that identifies the command. You can pass it to *anacron* on the command line to have *anacron* check and, if necessary, run only that one command. Finally, *command* is the command to be run. This is a single command or script name, optionally followed by any parameters it may take.

Listing 7.3 shows a sample `/etc/anacrontab` file. This file sets a couple of environment variables; `PATH` is particularly important if any scripts call programs without specifying their complete paths. The three job definition lines tell *anacron* to run the `run-parts` command, passing it the name of a different directory for each line. This command is used on some distributions to run *cron* jobs, so the effect of calling it from *anacron* is to take over *cron*'s duties. The first line, run once a day, causes *anacron* to run (via `run-parts`) the scripts in `/etc/cron.daily`; the second line causes the scripts in `/etc/cron.weekly` to be run once a week; and the third, run once every 30 days, runs the scripts in `/etc/cron.monthly`.

### Listing 7.3

#### **SAMPLE /etc/anacrontab FILE**

```
SHELL=/bin/bash
PATH=/usr/local/sbin:/usr/local/bin:/sbin:/bin:/usr/sbin:/usr/bin
```

```
format: period delay job-identifier command
1 5 cron.daily run-parts /etc/cron.daily
7 10 cron.weekly run-parts /etc/cron.weekly
30 15 cron.monthly run-parts /etc/cron.monthly
```

Of course, to do any good, `anacron` must be called itself. This is typically done in one of two ways:

**Via a startup script** You can create a startup script to run `anacron`. A simple SysV startup script that takes no options but that runs `anacron` should do the job if configured to run from your regular runlevel. Alternatively, you can place a call to `anacron` in a local startup script, such as Fedora and Red Hat's `/etc/rc.d/rc.local` or SUSE's `/etc/boot.d/boot.local`.

**Via a cron job** You can create a cron job to run `anacron`. Typically, this call will replace your regular system cron job entries (in `/etc/crontab`), and you'll probably want to call `anacron` on a daily basis or more frequently.

The startup script approach is best employed on systems that are shut down and started up frequently, such as laptops or desktop systems that are regularly shut down at the end of the day. One drawback to this approach is that it can cause sluggish performance when the system is booted if `anacron` needs to run a time-consuming task. Calling `anacron` via a cron job can shift the burden to off hours, but if `cron` can reliably run `anacron`, `cron` can as easily and reliably run the jobs that `anacron` runs. Typically, you use a cron job if the system is sometimes, but not always, left running overnight. This ensures that `anacron` and the jobs it handles are run fairly frequently, if not on a completely regular basis. Alternatively, you can call `anacron` more frequently than once a day. For instance, if it's called once every six hours, it will almost certainly be called during a typical eight-hour workday.



For a desktop system, you might try calling `anacron` via a cron job at the user's typical lunch break. This will help minimize the disruption caused by any resource-intensive programs that `anacron` must run.

No matter how you run `anacron`, you should be sure to disable any cron jobs that `anacron` now handles. If you don't do so, those tasks will be performed twice, which may needlessly burden your system. Because `anacron` measures its run intervals in days, it's not a useful utility for running hourly cron jobs. Thus, you shouldn't eliminate any hourly system cron jobs when you edit your cron configuration for `anacron`.

## Using `at`

Sometimes `cron` and `anacron` are overkill. You may simply want to run a single command at a specific point in the future on a one-time basis rather than on an ongoing basis. For this task, Linux provides another command: `at`. In ordinary use, this command takes a single option (although options to fine-tune its behavior are also available): a time. This time can take any of several forms:

**Time of day** You can specify the time of day as *HH:MM*, optionally followed by AM or PM if you use a 12-hour format. If the specified time has already passed, the operation is scheduled for the next occurrence of that time—that is, for the next day.

noon, midnight, or teatime These three keywords stand for what you'd expect (teatime is 4:00 p.m.).

**Day specification** To schedule an at job more than 24 hours in advance, you must add a day specification after the time-of-day specification. This can be done in numeric form, using the format *MMDDYY*, *MM/DD/YY* or *DD.MM.YY*. Alternatively, you can specify the date as *month-name day* or *month-name day year*.

**A specified period in the future** You can specify a time using the keyword now, a plus sign (+), and a time period, as in `now + 2 hours` to run a job in two hours.



The at command relies on a daemon, atd, to be running. If your system doesn't start atd automatically, you may need to configure a SysV startup script to do so.

When you run at and give it a time specification, the program responds with its own prompt, at>, which you can treat much like your normal bash or other command shell prompt. When you're done typing commands, press Ctrl+D to terminate input. Alternatively, you can pass a file with commands by using the -f parameter to at, as in `at -f commands.sh noon` to use the contents of `commands.sh` as the commands you want to run at noon.

The at command has several support tools. The most important of these is atd, the at daemon. This program must be running for at to do its work. If it's not, check for its presence using ps. If it's not running, look for a SysV startup script and ensure that it's enabled, as described in Chapter 5.

Other at support programs include atq, which lists pending at jobs; atrm, which removes an at job from the queue; and batch, which works much like at but executes jobs when the system load level drops below 0.8. These utilities are all fairly simple. To use atq, simply type its name. (The program does support a couple of options, but chances are you won't need them; consult atq's man page for details.) To use atrm, type the program name and the number of the at job, as returned by atq. For instance, you might type `atrm 12` to remove at job number 12.

The at facility supports access restrictions similar to those of cron. Specifically, the `/etc/at.allow` and `/etc/at.deny` files work analogously to the `/etc/cron.allow` and `/etc/cron.deny` files. There are a few wrinkles with at, though. Specifically, if neither `at.allow` nor `at.deny` exists, only root may use at. If `at.allow` exists, the users it lists are granted access to at; if `at.deny` exists, everybody *except* those mentioned in this file is granted access to at. This differs from cron, in which everybody is granted access if neither access-control file is present. This tighter default security on at means that the program is seldom installed with restrictive execute permissions, but of course you can use program file permissions to deny ordinary users the ability to run at if you want an extra layer of security.

# Summary

Routine system administration involves a variety of tasks, many of which center around user management. Adding, deleting, and modifying user accounts and groups are critical tasks that all system administrators must master. Also related to users, you should know where to go to modify the default user environment.

System log files are critical troubleshooting tools that are maintained by the system. You should be able to configure what data is logged to what files and know how to use these log files.

Time management is important in Linux. Setting the Linux clocks (both hardware and software) and configuring NTP to keep the software clock accurate are important tasks. Tools that rely on the time include `cron`, `anacron`, and `at`, which enable the system to run programs in the future. These tools are used for many common system tasks, including rotating log files.

# Exam Essentials

**Summarize methods of creating and modifying user accounts.** Accounts can be created or modified with the help of tools designed for the purpose, such as `useradd` and `usermod`. Alternatively, you can directly edit the `/etc/passwd` and `/etc/shadow` files, which hold the account information.

**Describe the function of groups in Linux.** Linux groups enable security features to be applied to arbitrary groups of users. Each group holds an arbitrary collection of users, and group permissions can be set on files giving all group members the same access rights to the files.

**Explain the purpose of the skeleton files.** Skeleton files provide a core set of configuration files that should be present in users' home directories when those directories are created. They provide a starting point for users to modify their important shell and other configuration files.

**Summarize how to configure system logging.** System logging is controlled via the `/etc/syslog.conf` file. Lines in this file describe what types of log data, generated by programs, are sent to log files and to which log files the log messages should go.

**Describe how log rotation is managed.** Log rotation is controlled via the `/etc/logrotate.conf` file (which typically refers to files in `/etc/logrotate.d`). Entries in these files tell the system whether to rotate logs at fixed intervals or when they reach particular sizes. When a log rotates, it's renamed (and possibly compressed), a new log file is created, and the oldest archived log file may be deleted.

**Explain the two types of clocks in x86 hardware.** The hardware clock keeps time when the system is powered down, but it isn't used by most programs while the system is running.

Such programs refer to the software clock, which is set from the hardware clock when the computer boots.

**Summarize the function of NTP.** The Network Time Protocol (NTP) enables a computer to set its clock based on the time maintained by an NTP server system. NTP can function as a tiered protocol, enabling one system to function as a client to an NTP server and as a server to additional NTP clients. This structure enables a single highly accurate time source to be used by anywhere from a few to (theoretically) billions of computers via a tiered system of links.

**Explain the difference between system and user cron jobs.** System cron jobs are controlled from `/etc/crontab`, are created by `root`, and may be run as any user (but most commonly as `root`). System cron jobs are typically run at certain fixed times on an hourly, daily, weekly, or monthly basis. User cron jobs may be created by any user (various security measures permitting), are run under the authority of the account with which they're associated, and may be run at just about any repeating interval desired.

# Review Questions

- Which of the following are legal Linux usernames? (Select all that apply.)
  - larrythemoose
  - 4sale
  - PamJones
  - Samuel\_Bernard\_DeLaney\_the\_Fourth
- Why are groups important to the Linux user administration and security models?
  - They can be used to provide a set of users with access to files without giving *all* users access to the files.
  - They allow you to set a single login password for all users within a defined group.
  - Users may assign file ownership to a group, thereby hiding their own creation of the file.
  - By deleting a group, you can quickly remove the accounts for all users in the group.
- An administrator types **chage -M 7 time**. What is the effect of this command?
  - The `time` account's password must be changed at least once every seven days.
  - All users must change their passwords at least once every seven days.
  - All users are permitted to change their passwords at most seven times.
  - The `time` account's age is set to seven months.
- What is wrong with the following `/etc/passwd` file entry? (Select all that apply.)  
`4sally:x:529:Sally Jones:/home/myhome:/bin/passwd`
  - The default shell is set to `/bin/passwd`, which is an invalid shell.
  - The username is invalid; Linux usernames can't begin with a number.
  - The home directory doesn't match the username.
  - Either the UID or the GID field is missing.
- You want `sally`, `tom`, and `dale` to be members of the group `managers` (GID 501). How would you edit the `managers` entry in `/etc/group` to accomplish this goal?
  - `managers:501:sally tom dale`
  - `managers:501:sally:tom:dale`
  - `managers:x:501:sally:tom:dale`
  - `managers:x:501:dale,sally,tom`
- What types of files might be reasonable files to include in `/etc/skel`? (Select all that apply.)
  - A copy of the `/etc/shadow` file
  - An empty set of directories to encourage good file management practices
  - A README or similar welcome file for new users
  - A starting `.bashrc` file

7. What would a Linux system administrator type to remove the `nemo` account and its home directory?
  - A. `userdel nemo`
  - B. `userdel -f nemo`
  - C. `userdel -r nemo`
  - D. `rm -r /home/nemo`
8. Which of the following system logging codes represents the *highest* priority?
  - A. `emerg`
  - B. `warning`
  - C. `crit`
  - D. `debug`
9. Which of the following configuration files does the `logrotate` program consult for its settings?
  - A. `/etc/logrotate.conf`
  - B. `/usr/sbin/logrotate/logrotate.conf`
  - C. `/usr/src/logrotate/logrotate.conf`
  - D. `/etc/logrotate/.conf`
10. You want to create a log file entry noting that you're manually shutting down the system to add a new network card. How might you create this log entry, just prior to using `shutdown`?
  - A. `dmesg -l "shutting down to add network card"`
  - B. `syslog shutting down to add network card`
  - C. `rsyslogd "shutting down to add network card"`
  - D. `logger shutting down to add network card`
11. Your manager has asked that you configure `logrotate` to run on a regular, unattended basis. What utility/feature should you configure to make this possible?
  - A. `at`
  - B. `logrotate.d`
  - C. `cron`
  - D. `inittab`
12. You've set your system (software) clock on a Linux-only computer to the correct time, and now you want to set the hardware clock to match. What command might you type to accomplish this goal?
  - A. `date --sethwclock`
  - B. `ntpdate`
  - C. `hwclock --utc --systohc`
  - D. `time --set --hw`

13. As root, you type **date 12110710**. What will be the effect?
- A. The software clock will be set to 7:10 a.m. on December 11 of the current year.
  - B. The software clock will be set to 12:11 p.m. on October 7 of the current year.
  - C. The software clock will be set to 7:10 a.m. on November 12 of the current year.
  - D. The software clock will be set to 12:11 p.m. on July 10 of the current year.
14. What will be the effect of a computer having the following two lines in `/etc/ntp.conf`?
- ```
server pool.ntp.org
server tardis.example.org
```
- A. The local computer's NTP server will poll a server in the public NTP server pool; the first server option overrides subsequent server options.
 - B. The local computer's NTP server will poll the `tardis.example.org` time server; the last server option overrides earlier server options.
 - C. The local computer's NTP server will poll both a server in the public NTP server pool and `tardis.example.org` and use whichever site provides the cleanest time data.
 - D. The local computer's NTP server will refuse to run because of a malformed server specification in `/etc/ntp.conf`.
15. You've configured one computer on your five-computer network, `gateway.pangaea.edu`, as an NTP server that obtains its time signal from `ntp.example.com`. What computer(s) should your network's other computers use as their time source(s)?
- A. You should consult a public NTP server list to locate the best server for you.
 - B. Both `gateway.pangaea.edu` and `ntp.example.com`.
 - C. Only `ntp.example.com`.
 - D. Only `gateway.pangaea.edu`.
16. Which of the following tasks are likely to be handled by a cron job? (Select all that apply.)
- A. Starting an important server when the computer boots
 - B. Finding and deleting old temporary files
 - C. Scripting supervised account creation
 - D. Monitoring the status of servers and e-mailing a report to the superuser
17. Which of the following lines, if used in a user cron job, will run `/usr/local/bin/cleanup` twice a day?
- A. `15 7,19 * * * tbaker /usr/local/bin/cleanup`
 - B. `15 7,19 * * * /usr/local/bin/cleanup`
 - C. `15 */2 * * * tbaker /usr/local/bin/cleanup`
 - D. `15 */2 * * * /usr/local/bin/cleanup`

18. You're installing Linux on a laptop computer. Which of the following programs might you want to add to ensure that log rotation is handled correctly?
- A. tempus
 - B. anacron
 - C. crontab
 - D. ntpd
19. What do the following commands accomplish? (The administrator presses Ctrl+D after typing the second command.)
- ```
at teatime
at> /usr/local/bin/system-maintenance
```
- A. Nothing; these commands aren't valid.
  - B. Nothing; `teatime` isn't a valid option to `at`.
  - C. Nothing; you may only type valid `bash` built-in commands at the `at>` prompt.
  - D. The `/usr/local/bin/system-maintenance` program or script is run at 4:00 p.m..
20. How might you schedule a script to run once a day on a Linux computer? (Select all that apply.)
- A. Place the script, or a link to it, in `/etc/cron.daily`.
  - B. Use the `at` command to schedule the specified script to run on a daily basis at a time of your choosing.
  - C. Create a user `cron` job that calls the specified script once a day at a time of your choosing, and install that `cron` job using `crontab`.
  - D. Use `run-parts` to schedule the specified script to run on a daily basis.

# Answers to Review Questions

1. A, C. A Linux username must contain fewer than 32 characters and start with a letter, and it may consist of letters, numbers, and certain symbols. Options A and C both meet these criteria. (Option C uses mixed upper- and lowercase characters, which is legal but discouraged.) Option B begins with a number, which is invalid. Option D is longer than 32 characters.
2. A. Groups provide a good method of file-access control. Although they may have passwords, these are *not* account login passwords; those passwords are set on a per-account basis. Files do have associated groups, but these are *in addition* to individual file ownership and so they can't be used to mask the file's owner. Deleting a group *does not* delete all the accounts associated with the group.
3. A. The `chage` command changes various account expiration options. The `-M` parameter sets the maximum number of days for which a password is valid, and in the context of the given command, `time` is a username. Thus, option A is correct. Options B, C, and D are all made up.
4. B, D. As stated in option B, Linux usernames may not begin with numbers, so the username is invalid. The `/etc/passwd` entries have third and fourth fields of the UID and the GID, but this line has only one of those fields (which one is intended is impossible to determine); this example line's fourth field is clearly the fifth field of a valid entry. Option A is incorrect because, although `/bin/passwd` is an unorthodox login shell, it's perfectly valid. This configuration might be used on, say, a Samba file server or a POP mail server to enable users to change their passwords via SSH without granting login shell access. Option C is a correct observation but an incorrect answer; the username and the user's home directory name need not match.
5. D. Option D shows a valid `/etc/group` entry that has the desired effect. (Note that the order of users in the comma-separated user list is unimportant.) Option A has two problems: It's missing a password field (`x` in the correct entry), and the usernames are separated by spaces rather than commas. Option B also has two problems: It's missing a password field, and its usernames are separated by colons rather than commas. Option C has just one problem: Its usernames are separated by colons rather than commas.
6. B, C, D. Files in `/etc/skel` are copied from this directory to new users' home directories by certain account-creation tools. Thus, files you want in all new users' home directories should reside in `/etc/skel`. Options B, C, and D all describe reasonable possibilities, although none is absolutely required. Including a copy of `/etc/shadow` in `/etc/skel` would be a very bad idea, though, because this would give all users access to all other users' encrypted passwords, at least as of the moment of account creation.

7. C. The `userdel` command deletes an account, and the `-r` option to `userdel` causes it to delete the user's home directory and mail spool, thus satisfying the terms of the question. Option A deletes the account but leaves the user's home directory intact. Option B does the same; the `-f` option forces account deletion and file removal under some circumstances, but it's only meaningful when `-r` is also used. Option D's `rm` command deletes the user's home directory (assuming it's located in the conventional place, given the username) but doesn't delete the user's account.
8. A. The `emerg` priority code is the highest code available and so is higher than all the other options. (The `panic` code is equivalent to `emerg` but isn't one of the options.) From highest to lowest priorities, the codes given as options are `emerg`, `crit`, `warning`, and `debug`.
9. A. The `logrotate` program consults a configuration file called `/etc/logrotate.conf`, which includes several default settings and typically refers to files in `/etc/logrotate.d` to handle specific log files.
10. D. The `logger` utility can be used to create a one-time log file entry that you specify. In its simplest form, it takes no special arguments, just a message to be inserted in the log file, as in option D. The `dmesg` utility in option A is used to review the kernel ring buffer; it doesn't create log file entries. Option B's `syslog` command isn't a Linux user-mode command, although it is the name of the logging system generically, as well as a programming language command name. Option C's `rsyslogd` is the name of one of several system logging daemons; it maintains the system log but isn't used to manually insert log entries.
11. C. The `logrotate` program can be started automatically—and unattended—on a regular basis by adding an entry for it in `cron`. The `at` utility would be used if you wanted the program to run only once, whereas `logrotate.d` defines how the program is to handle specific log files. The `inittab` file is used for services and startup and not for individual programs.
12. C. The `hwclock` utility is used to view or set the hardware clock. The `--utc` option tells it to use UTC, which is appropriate for a Linux-only system, and `--system` sets the hardware clock based on the current value of the software clock. Thus, option C is correct. Option A's `date` utility can be used to set the software clock but not the hardware clock; it has no `--sethwclock` option. Option B's `ntpdate` is used to set the software clock to the time maintained by an NTP server; it doesn't directly set the hardware clock. Option D's `time` command is used to time how long a command takes to complete; it has no `--set` or `--hw` option and does not set the hardware clock.
13. A. The format of the `date` command's date code is `[MMDDhhmm[[CC]YY][.ss]]`. Given that the question specified an eight-digit code, this means that the ordering of the items, in two-digit blocks, is month-day-hour-minute. Option A correctly parses this order, whereas options B, C, and D do not.
14. C. Multiple `server` entries in `/etc/ntp.conf` tell the system to poll all the named servers and to use whichever one provides the best time data. Thus, option C is correct. (The `pool.ntp.org` subdomain and numbered computers within that subdomain give round-robin access to a variety of public time servers.) Options A and B both incorrectly state that one `server` statement overrides another, when in fact this isn't the case. The `server` statements shown in the question are properly formed.

15. D. Once you've configured one computer on your network to use an outside time source and run NTP, the rest of your computers should use the first computer as their time reference. This practice reduces the load on the external time servers, as well as your own external network traffic. Thus, option D is correct. (Very large networks might configure two or three internal time servers that refer to outside servers for redundancy, but this isn't necessary for the small network described in the question.) Option A describes the procedure to locate a time server for the first computer configured (`gateway.pangaea.edu`) but not for subsequent computers. Although configuring other computers to use `ntp.example.com` instead of or in addition to `gateway.pangaea.edu` is possible, doing so will needlessly increase your network traffic and the load on the `ntp.example.com` server.
16. B, D. The `cron` utility is a good tool for performing tasks that can be done in an unsupervised manner, like deleting old temporary files or checking to see that servers are running correctly. Tasks that require interaction, like creating accounts, aren't good candidates for `cron` jobs, which must execute unsupervised. Although a `cron` job could restart a crashed server, it's not normally used to start a server when the system boots; that's done through SysV startup scripts or a super server.
17. B. User `cron` jobs don't include a username specification (`tbaker` in options A and C). The `*/2` specification for the hour in options C and D causes the job to execute every other hour; the `7,19` specification in options A and B causes it to execute twice a day, on the 7th and 19th hours (in conjunction with the 15 minute specification, that means at 7:15 a.m. and 7:15 p.m.).
18. B. The `anacron` program is a supplement to `cron` that helps ensure that log rotation, `/tmp` directory cleanup, and other traditional `cron` tasks are handled even when the computer is shut down (and, hence, when `cron` isn't running) for extended periods of time. Thus, this is the program to add to the system to achieve the stated goal. There is no common Linux utility called `tempus`. Option C's `crontab` is the name of a file or program for controlling `cron`, which is likely to be an unreliable means of log rotation on a laptop computer. The `ntpd` program is the NTP daemon, which helps keep the system clock in sync with an external source. Although running `ntpd` on a laptop computer is possible, it won't directly help with the task of scheduling log rotation.
19. D. The `at` command runs a specified program at the stated time in the future. This time may be specified in several ways, one of which is `teatime`, which stands for 4:00 p.m. Thus, option D is correct. The objections stated in options A, B, and C are all invalid.
20. A, C. The contents of `/etc/cron.daily` are automatically run on a daily basis in most Linux distributions, and the `crontab` utility can create user `cron` jobs that run programs at arbitrary time intervals, so both A and C are correct. The `at` command noted in option B can be used to run a program a single time, but not on a regular basis (such as daily). The `run-parts` utility is used by some distributions as a tool to help run programs in the `/etc/cron.*` subdirectories, but it's not used to schedule jobs.

# Chapter 8

# Configuring Basic Networking

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**THE FOLLOWING LINUX PROFESSIONAL INSTITUTE OBJECTIVES ARE COVERED IN THIS CHAPTER:**

- ✓ 1.109.1 Fundamentals of internet protocols (weight: 4)
- ✓ 1.109.2 Basic network configuration (weight: 4)
- ✓ 1.109.3 Basic network troubleshooting (weight: 4)
- ✓ 1.109.4 Configure client-side DNS (weight: 2)





Most Linux systems are connected to a network, either as clients or as servers (and often as both). Even home computers usually connect to the Internet in one way or another. For this reason, understanding how to set up Linux's basic networking tools is necessary for fully configuring Linux. To begin this task, you must first understand the basics of modern networking, such as the nature of network addresses and the types of tools that are commonly used on networks. From there, you can move on to Linux network configuration, including tasks such as setting a computer's address, routing, and name resolution. Unfortunately, network configuration sometimes goes wrong; understanding the tools and techniques used to diagnose and fix network problems is a necessary part of network configuration, so this chapter covers the basics of network troubleshooting.

## Understanding TCP/IP Networking

Networking involves quite a few components that are built atop one another. These include network hardware, data packets, and protocols for data exchange. Together, these components make up a *network stack*. The most common network stack today is the *Transmission Control Protocol/Internet Protocol* (TCP/IP) stack, but this isn't the only stack available. Nonetheless, understanding the basics of TCP/IP theory will help you to configure and manage networks.

### Knowing the Basic Functions of Network Hardware

Network hardware is designed to enable two or more computers to communicate with one another. Modern computers have network interfaces built into their motherboards, but internal (PCI or ISA) network cards and external (USB, PC Card, and similar) network interfaces are also available. Many networks rely on wires or cables to transmit data between machines as electrical impulses, but network protocols that use radio waves or even light to do the job are growing rapidly in popularity.

Sometimes the line between network hardware and peripheral interface ports can be blurry. For instance, a parallel port normally isn't considered a network port; but when it's used with the Parallel Line Interface Protocol (PLIP; <http://t1dp.org/HOWTO/PLIP.html>), the parallel port becomes a network device. More commonly, a USB or RS-232 serial port can become a network interface when used with the *Point-to-Point Protocol* (PPP), typically in conjunction with a telephone modem.



PPP configuration used to be an important topic but has rapidly dropped in relevance as dial-up telephone connections to the Internet have declined with the rise in broadband Internet access. Linux still supports PPP connections, but they aren't covered in this book or by the latest versions of the LPI exam. If you need to know how to configure a PPP connection, consult your distribution's documentation or the PPP HOWTO (<http://tldp.org/HOWTO/PPP-HOWTO/index.html>).

At its core, network hardware is hardware that facilitates the transfer of data between computers. Hardware that's most often used for networking includes features that help this transfer in various ways. For instance, such hardware may include ways to address data intended for specific remote computers, as described later in the section "Addressing Hardware." When basically non-network hardware is pressed into service as a network medium, the lack of such features may limit the utility of the hardware or require extra software to make up for the lack. If extra software is required, you're unlikely to notice the deficiencies as a user or system administrator because the protocol drivers handle the work, but this makes the hardware more difficult to configure and more prone to sluggishness or other problems than other types of network hardware.

## Investigating Types of Network Hardware

Linux supports several types of common network hardware. The most common of these is Ethernet, which comes in several varieties. Most modern Ethernet hardware uses *twisted-pair* cabling, which consists of pairs of wires twisted around each other to minimize interference. Such varieties of Ethernet are identified by a *-T* suffix to the Ethernet variety name, as in 10Base-T or 100Base-T. The numbers denote the speed of the protocol in megabits per second (Mbps). In the late 1990s, 100Base-T took over from 10Base-T as the standard in office and even home networks. More recently, 1000Base-T and Ethernet variants that use optical cabling and that are capable of 1000Mbps speeds (that is, *gigabit Ethernet*) have become the standard, with 10-gigabit Ethernet the new emerging standard.

Other types of network hardware exist, but most are less common than Ethernet. These include Token Ring, LocalTalk, Fiber Distributed Data Interface (FDDI), High-Performance Parallel Interface (HIPPI), and Fibre Channel. Token Ring was common on some IBM-dominated networks in the 1990s but has been steadily losing ground to Ethernet for years. Likewise, LocalTalk was the favored medium for early Macintoshes, but new Macs ship with Ethernet instead of LocalTalk. FDDI, HIPPI, and Fibre Channel are all high-speed interfaces that are used in high-performance applications. Some of these protocols support significantly greater maximum cable lengths than does Ethernet, which makes them suitable for linking buildings that are many yards, or even miles, apart.

Wireless networking (a.k.a. Wi-Fi) is an exception to Ethernet's dominance. Common wireless protocols include 802.11a, 802.11b, and 802.11g. These protocols support maximum speeds of 11Mbps (for 802.11b) or 54Mbps (for 802.11a and 802.11g). The upcoming



802.11n will support 300Mbps speeds. (Many manufacturers are already shipping products based on pre-release 802.11n documents. The standard is expected to be finalized in late 2009.) With the exception of the rarely used 802.11a, Wi-Fi protocols are compatible with one another, albeit at the speed of the slowest protocol in use. Wireless networking is particularly useful for laptop computers, but it's even handy for homes and small offices that don't have adequate wired network infrastructures in place.



If you use a wireless protocol, your data are transmitted via radio waves, which are easily intercepted. Wireless protocols include optional encryption, but this feature is often disabled by default, and some varieties are notoriously poor. If you use wireless network products, be sure to enable Wi-Fi Protected Access (WPA) or, better, WPA2 encryption. The weaker Wired Equivalent Privacy (WEP) encryption is easily broken. For added protection, use a strong encryption protocol, such as the Secure Shell (SSH) login tool or Secure Sockets Layer (SSL) encryption, when transferring any data that's even remotely sensitive; and be extra cautious about security on networks that support wireless access. In a typical configuration, an intruder who can break into your wireless access point looks to the rest of your network like any other local user, so protecting that access point is extremely important.

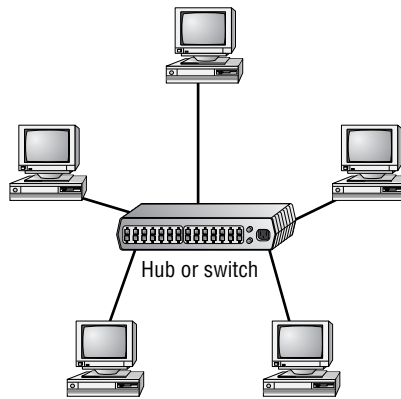
In addition to the network hardware in your computers, you need network hardware outside the computers. With the exception of wireless networks, you need some form of network cabling that's unique to your hardware type. (For 100Base-T Ethernet, get cabling that meets at least Category 5, or Cat-5, specifications. Gigabit Ethernet works best with Cat-5e or optical cables.) Many network types, including twisted-pair Ethernet, require the use of a central device known as a *hub* or *switch*. You plug every computer on a local network into this central device, as shown in Figure 8.1. The hub or switch then passes data between the computers.

As a general rule, switches are superior to hubs. Hubs mirror all traffic to all computers, whereas switches are smart enough to send packets only to the intended destination. Switches also allow *full-duplex* transmission, in which both parties can send data at the same time (like two people talking on a telephone). Hubs permit only *half-duplex* transmission, in which the two computers must take turns (like two people using walkie-talkies). The result is that switches let two pairs of computers engage in full-speed data transfers with each other; with a hub, these two transfers would interfere with each other.

Computers with Wi-Fi adapters can be configured to communicate directly with one another, but it's more common to employ a wireless router, which links together both wireless and Ethernet devices. Such routers also provide connections to an outside network—typically the Internet, sometimes via a broadband connection.



**FIGURE 8.1** Many networks link computers together via a central device known as a hub or switch.



## Understanding Network Packets

Modern networks operate on discrete chunks of data known as *packets*. Suppose you want to send a 100KB file from one computer to another. Rather than send the file in one burst of data, your computer breaks it down into smaller chunks. The system might send 100 packets of 1KB each, for instance. This way, if there's an error sending one packet, the computer can resend just that one packet rather than the entire file. (Many network protocols include error-detection procedures.)

When the recipient system receives packets, it must hold on to them and reassemble them in the correct order to recreate the complete data stream. It's not uncommon for packets to be delayed or even lost in transmission, so error-recovery procedures are critical for protocols that handle large transfers. Some types of error recovery are handled transparently by the networking hardware.

There are several types of packets, and they can be stored within each other. For instance, Ethernet includes its own packet type (known as a *frame*), and the packets generated by networking protocols that run atop Ethernet, such as those described in the next section, are stored within Ethernet frames. All told, a data transfer can involve several layers of wrapping and unwrapping data. With each layer, packets from the layer above may be merged or split up.

## Understanding Network Protocol Stacks

It's possible to think of network data at various levels of abstractness. For instance, at one level, a network carries data packets for a specific network type (such as Ethernet); the data packets are addressed to specific computers on a local network. Such a description, while

useful for understanding a local network, isn't very useful for understanding higher-level network protocols, such as those that handle e-mail transfers. These high-level protocols are typically described in terms of commands sent back and forth between computers, frequently without reference to packets. The addresses used at different levels also vary, as explained in the upcoming section "Using Network Addresses."

A *protocol stack* is a set of software that converts and encapsulates data between layers of abstraction. For instance, the stack can take the commands of e-mail transfer protocols, and the e-mail messages that are transferred, and package them into packets. Another layer of the stack can take these packets and repackage them into Ethernet frames. There are several layers to any protocol stack, and they interact in highly specified ways. It's often possible to swap out one component for another at any given layer. For instance, at the top of each stack is a program that uses the stack, such as an e-mail client. You can switch from one e-mail client to another without too much difficulty; both rest atop the same stack. Likewise, if you change a network card, you have to change the driver for that card, which constitutes a layer very low in the stack. Applications above that driver can remain the same.

Each computer in a transaction requires a compatible protocol stack. When they communicate, the computers pass data down their respective stacks and then send data to the partner system, which passes the data up its stack. Each layer on the receiving system sees the data as packaged by its counterpart on the sending computer.

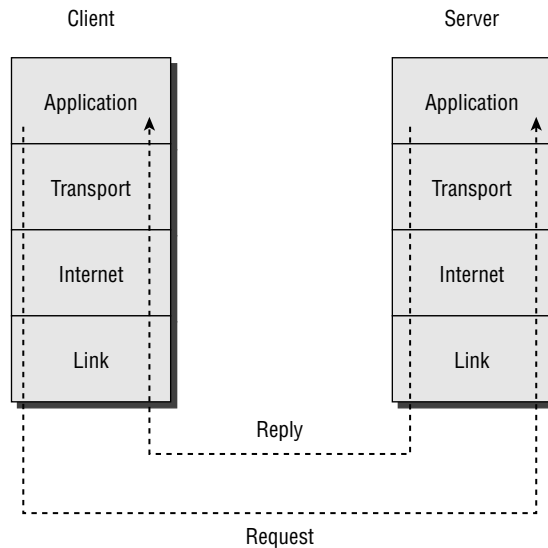
Protocol stacks are frequently represented graphically in diagrams like Figure 8.2, which shows the configuration of the TCP/IP protocol stack that dominates the Internet today. As shown in Figure 8.2, client programs at the application layer initiate data transfers. These requests pass through the transport, internet, and link layers on the client computer, whereupon they leave the client system and pass to the server system. (This transfer can involve a lot of complexity not depicted in Figure 8.2.) On the server, the process reverses itself, with the server program running at the application layer replying to the client program. This reply reverses the journey, traveling down the server computer's stack, across the network, and up the stack on the client. A full-fledged network connection can involve many back-and-forth data transfers.



When spelled with an uppercase *I*, the word *Internet* refers to the globe-spanning network of networks with which you're no doubt familiar. When spelled with a lowercase *i*, however, the word *internet* refers to any collection of networks. An internet in this sense could be a couple of small networks in somebody's basement with no outside connections. Internet networking protocols such as TCP/IP can work on any internet, up to and including *the Internet*.

Each component layer of the sending system is equivalent to a layer on the receiving system, but these layers need not be absolutely identical. For instance, you can have different models of network card at the link layer, or you can even use entirely different network hardware types, such as Ethernet and Token Ring, if some intervening system translates between them. The computers may run different OSs and hence use different—but logically equivalent—protocol stacks. What's important is that the stacks operate in compatible ways.

**FIGURE 8.2** Information travels “down” and “up” protocol stacks, being checked and packed at each step of the way.



Linux was designed with TCP/IP in mind, and the Internet is built atop TCP/IP. Other protocol stacks are available, though, and you may occasionally run into them. In particular, NetBEUI was the original Microsoft and IBM protocol stack for Windows, AppleTalk was Apple’s initial protocol stack, and the Internet Packet Exchange/Sequenced Packet Exchange (IPX/SPX) was Novell’s favored protocol stack. All three are now fading in importance, but you may still need to use them in some environments. Linux supports AppleTalk and IPX/SPX but not NetBEUI.

## Knowing TCP/IP Protocol Types

Within TCP/IP, several different protocols exist. Each of these protocols can be classified as falling on one of the four layers of the TCP/IP stack, as shown in Figure 8.2. The most important of the internet- and transport-layer protocols are the building blocks for the application-layer protocols with which you interact more directly. These important internet- and transport-layer protocols include the following:

**IP** The *Internet Protocol* (IP) is the core protocol in TCP/IP networking. Referring to Figure 8.2, IP is an internet-layer (a.k.a. a network-layer or layer 2) protocol. IP provides a “best effort” method for transferring packets between computers—that is, the packets aren’t guaranteed to reach their destination. Packets may also arrive out of order or corrupted. Other components of the TCP/IP stack must deal with these issues and have their own ways of doing so. IP is also the portion of TCP/IP with which IP addresses are associated. (The Real-World Scenario sidebar “The Coming of IPv6” describes a change in the IP portion of TCP/IP that’s underway.)

**ICMP** The *Internet Control Message Protocol* (ICMP) is a simple protocol for communicating data. ICMP is most often used to send error messages between computers—for instance, to signal that a requested service isn’t available. This is often done by modifying an IP packet and returning it to its sender, which means that ICMP is technically an internet-layer protocol, although it relies upon IP. In most cases, you won’t use programs that generate ICMP packets on demand; they’re created behind the scenes as you use other protocols. One exception is the ping program, which is described in more detail in “Testing Basic Connectivity.”

**UDP** The *User Datagram Protocol* (UDP) is the simplest of the common transport-layer (a.k.a. layer 3) TCP/IP protocols. It doesn’t provide sophisticated procedures to correct for out-of-order packets, guarantee delivery, or otherwise improve the limitations of IP. This fact can be a problem, but it also means that UDP can be faster than more sophisticated tools that provide such improvements to IP. Common application-layer protocols that are built atop UDP include the Domain Name System (DNS), the Network File System (NFS), and many streaming media protocols.

**TCP** The *Transmission Control Protocol* (TCP) may be the most widely used transport-layer protocol in the TCP/IP stack. Unlike UDP, TCP creates full connections with error checking and correction as well as other features. These features simplify the creation of network protocols that must exchange large amounts of data, but the features come at a cost: TCP imposes a small performance penalty. Most of the application-layer protocols with which you may already be familiar, including the Simple Mail Transfer Protocol (SMTP), the Hypertext Transfer Protocol (HTTP), and the File Transfer Protocol (FTP), are built atop TCP.

You may notice that the name of the TCP/IP stack is built up of two of the TCP and IP protocol names. This is because these two protocols are so important for TCP/IP networking generally. TCP/IP, though, is much more than just these two protocols; it includes additional protocols, most of which (below the application layer) are rather obscure. On the other hand, a TCP/IP exchange need not use both TCP and IP—it could be a UDP or ICMP exchange, for instance.

## Understanding Network Addressing

In order for one computer to communicate with another over a network, the computers need to have some way to refer to each other. The basic mechanism for doing this is provided by a network address, which can take several different forms, depending on the type of network hardware, protocol stack, and so on. Large and routed networks pose additional challenges to network addressing, and TCP/IP provides answers to these challenges. Finally, to address a specific program on a remote computer, TCP/IP uses a *port number*, which identifies a specific running program, something like the way a telephone extension number identifies an individual in a large company. The following sections describe all these methods of addressing.

### The Coming of IPv6

Another alternative protocol stack is actually an extension of TCP/IP. The IP portion of TCP/IP has been at version 4 for many years. A major upgrade to this is underway, however, and it goes by the name *IPv6*, for IP version 6. IPv6 adds several features and improvements to TCP/IP, including standard support for more secure connections and support for many more addresses. Check <http://playground.sun.com/pub/ipv6/html/ipv6-main.html> or <http://www.ipv6forum.com> for detailed information about IPv6.

TCP/IP supports a theoretical maximum of about 4 billion addresses. Although this may sound like plenty, those addresses have not been allocated as efficiently as possible. Therefore, as the Internet has expanded, the number of truly available addresses has been shrinking at a rapid rate. IPv6 raises the number of addresses to  $2^{128}$ , or  $3.4 \times 10^{38}$ . This is enough to give every square millimeter of land surface on Earth  $2.2 \times 10^{18}$  addresses.

IPv6 is starting to emerge as a real networking force in many parts of the world. The United States, though, is lagging behind on IPv6 deployment. The Linux kernel includes IPv6 support, and most distributions now attempt to automatically configure IPv6 networking in addition to IPv4. Chances are that by the time the average office will need IPv6, it will be standard. Configuring a system for IPv6 is somewhat different from configuring it for IPv4, which is what this chapter emphasizes.

## Using Network Addresses

Consider an Ethernet network. When an Ethernet frame leaves one computer, it's normally addressed to another Ethernet card. This addressing is done using low-level Ethernet features, independent of the protocol stack in question. Recall, however, that the Internet is composed of many different networks that use many different low-level hardware components. A user may have a dial-up telephone connection (through a serial port) but connect to one server that uses Ethernet and another that uses Token Ring. Each of these devices uses a different type of low-level network address. TCP/IP requires something more to integrate across different types of network hardware. In total, three types of addresses are important when you're trying to understand network addressing: network hardware addresses, numeric IP addresses, and text-based hostnames.

### Addressing Hardware

One of the characteristics of dedicated network hardware such as Ethernet or Token Ring cards is that they have unique *hardware addresses*, also known as *Media Access Control (MAC) addresses*, programmed into them. In the case of Ethernet, these addresses are 6 bytes in length, and they're generally expressed as hexadecimal (base 16) numbers separated by

colons. You can discover the hardware address for an Ethernet card by using the `ifconfig` command. Type `ifconfig ethn`, where *n* is the number of the interface (0 for the first card, 1 for the second, and so on). You'll see several lines of output, including one like the following:

```
eth0 Link encap:Ethernet HWaddr 00:A0:CC:24:BA:02
```

This line tells you that the device is an Ethernet card and that its hardware address is 00:A0:CC:24:BA:02. What use is this, though? Certain low-level network utilities and hardware use the hardware address. For instance, network switches use it to direct data packets. The switch detects that a particular address is connected to a particular wire, and so it sends data directed at that address *only* over the associated wire. The *Dynamic Host Configuration Protocol* (DHCP), which is described in the upcoming section “Configuring with DHCP,” is a means of automating the configuration of specific computers. It has an option that uses the hardware address to consistently assign the same IP address to a given computer. In addition, advanced network diagnostic tools are available that let you examine packets that come from or are directed to specific hardware addresses.

For the most part, though, you don't need to be aware of a computer's hardware address. You don't enter it in most utilities or programs. It's important for what it does in general.



Linux identifies network hardware devices with type-specific codes. Ethernet hardware is `ethn`, where *n* is a number from 0 up. The first Ethernet device is `eth0`, the second is `eth1`, and so on. Wireless devices have names of the form `wlann`. Unlike most Linux hardware devices, network devices don't have entries in `/dev`; instead, low-level network utilities take the device names and work with them directly.

## Managing IP Addresses

Earlier, I said that TCP/IP, at least in its IPv4 incarnation, supports about 4 billion addresses. This figure is based on the size of the *IP address* used in TCP/IP: 4 bytes (32 bits). Specifically,  $2^{32} = 4,294,967,296$ . For IPv6, 16-byte (128-bit) addresses are used. Not all of these addresses are usable; some are overhead associated with network definitions, and some are reserved.

The 4-byte IPv4 (or 16-byte IPv6) address and 6-byte Ethernet address are mathematically unrelated. Instead, the TCP/IP stack converts between the two using the *Address Resolution Protocol* (ARP) for IPv4 or the *Neighbor Discovery Protocol* (NDP) for IPv6. These protocols enable a computer to send a *broadcast* query—a message that goes out to all the computers on the local network. This query asks the computer with a given IP address to identify itself. When a reply comes in, it includes the hardware address, so the TCP/IP stack can direct traffic for a given IP address to the target computer's hardware address.



The procedure for computers that aren't on the local network is more complex. For such computers, a router must be involved. Local computers send packets destined to distant addresses to routers, which send the packets on to other routers or to their destination systems.

IPv4 addresses are usually expressed as four base-10 numbers (0–255) separated by periods, as in 192.168.29.39. If your Linux system’s protocol stack is already up and running, you can discover its IP address by using `ifconfig`, as described earlier. The output includes a line like the following, which identifies the IP address (`inet addr`):

```
inet addr:192.168.29.39 Bcast:192.168.29.255 Mask:255.255.255.0
```

Although it isn’t obvious from the IP address alone, this address is broken into two components: a network address and a computer address. The network address identifies a block of IP addresses that are used by one physical network, and the computer address identifies one computer within that network. The reason for this breakdown is to make the job of routers easier—rather than record how to direct packets destined for each of the 4 billion IP addresses, routers can be programmed to direct traffic based on packets’ network addresses, which is a much simpler job. Ordinarily, a computer can directly communicate only with computers on its local network segment; to communicate outside of this set of computers, a router must be involved.

IPv6 addresses work in a similar way, except that they’re larger. Specifically, IPv6 addresses consist of eight groups of four-digit hexadecimal numbers separated by colons, as in `fed1:0db8:85a3:08d3:1319:8a2e:0370:7334`. If one or more groups of four digits is 0000, that group or those groups may be omitted, leaving two colons. Only one such group of zeroes can be compressed in this way, because if you removed two groups, there would be no way of telling how many sets of zeroes would have to be replaced in each group.

The *network mask* (also known as the *subnet mask* or *netmask*) is a number that identifies the portion of the IP address that’s a network address and the part that’s a computer address. It’s helpful to think of this in binary (base 2) because the netmask uses binary 1 values to represent the network portion of an address and binary 0 values to represent the computer address. The network portion ordinarily leads the computer portion. Expressed in base 10, these addresses usually consist of 255 or 0 values, 255 being a network byte and 0 being a computer byte. If a byte is part network and part computer address, it will have some other value. Another way of expressing a netmask is as a single number representing the number of network bits in the address. This number usually follows the IP address and a slash. For instance, 192.168.29.39/24 is equivalent to 192.168.29.39 with a netmask of 255.255.255.0—the last number shows the network portion to be three solid 8-bit bytes, hence 24 bits. The longer notation showing all 4 bytes of the netmask is referred to as *dotted quad* notation. IPv6 netmasks work just like IPv4 netmasks, except that larger numbers are involved, and IPv6 favors hexadecimal to decimal notation.

On modern IPv4 networks, netmasks are often described in *Classless Inter-Domain Routing* (CIDR) form. Such network masks can be broken at any bit boundary for any address. For instance, 192.168.1.7 could have a netmask of 255.255.0.0, 255.255.255.0, 255.255.255.128, or various other values. (Keeping each byte at 0 or 255 reduces the odds of human error causing problems but sometimes isn’t practical, depending on the required or desired sizes of subnets.) Traditionally, though, IPv4 networks have been broken into one of several classes, as summarized in Table 8.1. Classes A, B, and C are for general networking use. Class D addresses are reserved for *multicasting*—sending data to multiple computers simultaneously. Class E addresses are reserved for future use. There are a few special cases

within most of these ranges. For instance, the *127.x.y.z* addresses are reserved for use as *loop-back* (a.k.a. *localhost*) devices—these addresses refer to the computer on which the address is entered. Addresses in which all the machine bits are set to 1 refer to the network block itself—they’re used for broadcasts. The ultimate broadcast address is *255.255.255.255*, which sends data to all computers on a network segment. (Routers normally block packets directed to this address. If they didn’t, the Internet could easily be brought to its knees by a few people flooding the network with broadcast packets.)

**TABLE 8.1** IPv4 Network Classes and Private Network Ranges

Class	Address Range	Reserved Private Addresses
A	1.0.0.0–127.255.255.255	10.0.0.0–10.255.255.255
B	128.0.0.0–191.255.255.255	172.16.0.0–172.31.255.255
C	192.0.0.0–223.255.255.255	192.168.0.0–192.168.255.255
D	224.0.0.0–239.255.255.255	none
E	240.0.0.0–255.255.255.255	none

Within each of the three general-use network classes is a range of addresses reserved for private use. Most IP addresses must be assigned to individual computers by a suitable authority, lest two systems on the Internet both try to use a single address. Anybody can use the reserved private address spaces, though. (These address blocks are sometimes referred to as RFC1918 addresses, after the standards document—RFC1918—in which they’re defined.) The caveat is that routers normally drop packets sent to these addresses, effectively isolating them from the Internet as a whole. The idea is that these addresses may be safely used by small private networks. Today, they’re often used behind *Network Address Translation* (NAT) routers, which enable arbitrary numbers of computers to “hide” behind a single system. The NAT router substitutes its own IP address on outgoing packets and then directs the reply to the correct system. This is very handy if you want to connect more computers to the Internet than you have IP addresses.



I generally use reserved private addresses for examples in this book. Unless otherwise specified, these examples work equally well on conventional assigned (non-private) IP addresses.

IPv6 has its equivalent to private addresses. IPv6 site-local addresses may be routed within a site but not off-site. They begin with the hexadecimal number *fec*, *fed*, *fee*, or *fef*.



Link-local addresses are restricted to a single network segment; they shouldn't be routed at all. These addresses begin with the hexadecimal number fe8, fe9, fea, or feb.

IPv4 address classes were designed to simplify routing; but as the Internet evolved, they became restrictive. Thus, today they serve mainly as a way to set default netmasks, such as 255.0.0.0 for Class A addresses or 255.255.255.0 for Class C addresses. Most configuration tools set these netmasks automatically, but you can override the settings if necessary.

IP addresses and netmasks are extremely important for network configuration. If your network doesn't use DHCP or a similar protocol to assign IP addresses automatically, you must configure your system's IP address manually. A mistake in this configuration can cause a complete failure of networking or more subtle errors, such as an inability to communicate with just some computers.



Non-TCP/IP stacks have their own addressing methods. NetBEUI uses machine names; it has no separate numeric addressing method. AppleTalk uses two 16-bit numbers. These addressing schemes are independent from IP addresses.

## Broadcasting Data

Earlier, I mentioned broadcasts. A broadcast is a type of network transmission that's sent to all the computers on a local network, or occasionally all of the computers on a remote network. Under TCP/IP, a broadcast is done by specifying binary 1 values in all the machine bits of the IP address. The network portion of the IP address may be set to the network's regular value, and this is required for directed broadcasts—that is, those that are sent to a remote network. (Many routers drop directed broadcasts, though.) In many cases, broadcasts are specified by the use of 255.255.255.255 as an IP address. Packets directed at this address are sent to all the machines on a local network.

Because the broadcast address for a network is determined by the IP address and netmask, you can convert between the broadcast address and netmask, given one of these and a computer's IP address. If the netmask happens to consist of whole-byte values (expressed as 0 or 255 in dotted quad notation), the conversion is easy: Replace the IP address components that have 0 values in the dotted quad netmask with 255 values to get the broadcast address. For instance, consider a computer with an IP address of 172.24.21.201 and a netmask of 255.255.0.0. The final two elements of the netmask have 0 values, so you swap in 255 values for these final two elements in the IP address to obtain a broadcast address of 172.24.255.255.

In the case of a CIDR address that has non-255 and non-0 values in the netmask, the situation is more complex because you must resort to binary (base 2) numbers. For instance, consider a computer with an IP address of 172.24.21.201 and a netmask of 255.255.128.0 (that is, 172.24.21.201/17). Expressed in binary, these numbers are

```
10101100 00011000 00010101 11001001
11111111 11111111 10000000 00000000
```

To create the broadcast address, you must set the top (network address) values to 1 when the bottom (netmask) value is 0. In this case, the result is

```
10101100 00011000 01111111 11111111
```

Converted back into base 10 notation, the resulting broadcast address is 172.24.127.255. Fortunately, you seldom need to perform such computations. When configuring a computer, you can enter the IP address and netmask and let the computer do the binary computations.

## Understanding Hostnames

Computers work with numbers, so it's not surprising that TCP/IP uses numbers as computer addresses. People, though, work better with names. For this reason, TCP/IP includes a way to link names for computers (known as *hostnames*) to IP addresses. In fact, there are *several* ways to do this, some of which are described in the next section, "Resolving Hostnames."

As with IP addresses, hostnames are composed of two parts: *machine names* and *domain names*. The former refers to a specific computer and the latter to a collection of computers. Domain names are not equivalent to the network portion of an IP address, though; they're completely independent concepts. Domain names are registered for use by an individual or organization, which may assign machine names within the domain and link those machine names to any arbitrary IP address desired. Nonetheless, there is frequently some correspondence between domains and network addresses because an individual or organization that controls a domain is also likely to want a block of IP addresses for the computers in that domain.

Internet domains are structured hierarchically. At the top of the hierarchy are the top-level domains (TLDs), such as .com, .edu, and .uk. These TLD names appear at the *end* of an Internet address. Some correspond to nations (such as .uk and .us, for the United Kingdom and the United States, respectively), but others correspond to particular types of entities (such as .com and .edu, which stand for commercial and educational organizations, respectively). Within each TLD are various domains that identify specific organizations, such as sybex.com for Sybex or loc.gov for the Library of Congress. These organizations may optionally break their domains into *subdomains*, such as cis.upenn.edu for the Computer and Information Science department at the University of Pennsylvania. Even subdomains may be further subdivided into their own subdomains; this structure can continue for many levels but usually doesn't. Domains and subdomains include specific computers, such as www.sybex.com, Sybex's Web server.

When you configure your Linux computer, you may need to know its hostname. This will be assigned by your network administrator and will be a machine name within your organization's domain. If your computer isn't part of an organizational network (say, if it's a system that doesn't connect to the Internet at all, or if it connects only via a dial-up account), you'll have to make up a hostname. Alternatively, you can register a domain name, even if you don't use it for running your own servers. Check <http://www.icann.org/registrars/accredited-list.html> for pointers to accredited domain registrars. Most registrars charge between \$10 and \$15 per year for domain registration. If your network uses DHCP, it may or may not assign your system a hostname automatically.



If you make up a hostname, choose an invalid TLD, such as `.invalid`. This will guarantee that you don't accidentally give your computer a name that legitimately belongs to somebody else. Such a name conflict might prevent you from contacting that system, and it could cause other problems as well, such as misdirected e-mail.

## Resolving Hostnames

The *Domain Name System* (DNS) is a distributed database of computers that converts between IP addresses and hostnames. Every domain must maintain at least two DNS servers that can either provide the names for every computer within the domain or redirect a DNS query to another DNS server that can better handle the request. Therefore, looking up a hostname involves querying a series of DNS servers, each of which redirects the search until the server that's responsible for the hostname is found. In practice, this process is hidden from you because most organizations maintain DNS servers that do all the dirty work of chatting with other DNS servers. You need only point your computer to your organization's DNS servers. This detail may be handled through DHCP, or it may be information you need to configure manually, as described later in the section "Configuring Linux for a Local Network."

Sometimes, you need to look up DNS information manually. You might do this if you know the IP address of a server through non-DNS means and suspect your DNS configuration is delivering the wrong address or to check whether a DNS server is working. Several programs can be helpful in performing such checks:

**nslookup** This program performs DNS lookups (on individual computers by default) and returns the results. It also sports an interactive mode in which you can perform a series of queries. This program is officially deprecated, meaning that it's no longer being maintained and will eventually be dropped from its parent package (`bind-utils` or `bind-tools` on most distributions). Thus, you should get in the habit of using `host` or `dig` instead of `nslookup`.

**host** This program serves as a replacement for the simpler uses of `nslookup`, but it lacks an interactive mode, and of course many details of its operation differ. In the simplest case, you can type `host target.name`, where `target.name` is the hostname or IP address you want to look up. You can add various options that tweak the program's basic operation; consult `host`'s man page for details.

**dig** This program performs more complex DNS lookups than `host`. Although you can use it to find the IP address for a single hostname (or a hostname for a single IP address), it's more flexible than `host`.

**whois** You can look up information on a domain as a whole with this command. For instance, typing `whois sybex.com` reveals who owns the `sybex.com` domain, who to contact in case of problems, and so on. You may want to use this command with `-H`, which omits the lengthy legal disclaimers that many domain registries insist on delivering along with `whois` information. Check the man page for `whois` for information on additional options.

Sometimes DNS is overkill. For instance, you might just need to resolve a handful of hostnames. This may be because you're configuring a small private network that's not connected to the Internet at large or because you want to set up a few names for local (or even remote) computers that aren't in the global DNS database. For such situations, `/etc/hosts` may be just what you need. This file holds mappings of IP addresses to hostnames, on a one-line-per-mapping basis. Each mapping includes at least one name, and sometimes more:

```
127.0.0.1 localhost
192.168.7.23 apollo.luna.edu apollo
```

In this example, the name `localhost` is associated with the `127.0.0.1` address and the names `apollo.luna.edu` and `apollo` are tied to `192.168.7.23`. The first of these linkages is standard; it should exist in any `/etc/hosts` file. The second linkage is an example that you can modify as you see fit. The first name is a full hostname, including the domain portion; subsequent names on the line are aliases—typically the hostname without its full domain specification.

Once you've set up an `/etc/hosts` file, you can refer to computers listed in the file by name, whether or not those names are recognized by the DNS servers the computer uses. One major drawback to `/etc/hosts` is that it's a purely local file; setting a mapping in one computer's `/etc/hosts` file only affects name lookups performed by that computer. Thus, to do good on an entire network, you must modify the `/etc/hosts` files on all of the computers on the network.

Linux normally performs lookups in `/etc/hosts` before it uses DNS. You can modify this behavior by editing the `/etc/nsswitch.conf` file, and specifically the `hosts` line. This line lists the order of the files and dns options, which stand for `/etc/hosts` and DNS, respectively:

```
hosts: files dns
```

Reverse the order of the `files` and `dns` options to have the system consult DNS before it consults `/etc/hosts`.



The `/etc/nsswitch.conf` file supports many more options. For instance, you can perform name resolution using Windows NetBIOS calls or a Lightweight Directory Access Protocol (LDAP) server by adding appropriate options to the `hosts` line, along with the necessary support software. The `passwd`, `shadow`, and `group` lines control how Linux authenticates users and manages groups. You should not attempt to change these configurations unless you understand the systems involved, but you should be aware of the importance of `/etc/nsswitch.conf` generally.

In addition to `/etc/hosts`, Linux supports a file called `/etc/networks`. It works much like `/etc/hosts`, but it applies to network addresses, and it reverses the order of the names and the IP address on each line:

```
loopback 127.0.0.0
mynet 192.168.7.0
```

This example sets up two linkages: the loopback name to the 127.0.0.0/8 network and mynet for the 192.168.7.0/24 network. It's seldom necessary to edit this file.

## Network Ports

Contacting a specific computer is important, but one additional type of addressing is left: The sender must have an address for a specific program on the remote system. For instance, suppose you're using a Web browser. The Web server computer may be running more servers than just a Web server—it may also be running an e-mail server or an FTP server, to name just two of many possibilities. Another number beyond the IP address enables you to direct traffic to a specific program. This number is a network port number, and programs that access a TCP/IP network typically do so through one or more ports.



Port numbers are features of the UDP and TCP protocols. Some protocols, such as ICMP, don't use port numbers.

When they start up, servers tie themselves to specific ports, which by convention are associated with specific server programs. For instance, port 25 is associated with e-mail servers, and port 80 is used by Web servers. Table 8.2 summarizes the purposes of several important ports. A client can direct its request to a specific port and expect to contact an appropriate server. The client's own port number isn't fixed; it's assigned by the OS. Because the client initiates a transfer, it can include its own port number in the connection request, so clients don't need fixed port numbers. Assigning client port numbers dynamically also enables one computer to easily run several instances of a single client because they won't compete for access to a single port.

**TABLE 8.2** Port Numbers, Their Purposes, and Typical Linux Servers

Port Number	TCP or UDP	Purpose	Example Linux Servers
20	TCP	File Transfer Protocol (FTP) data	ProFTPD, vsftpd
21	TCP	FTP	ProFTPD, vsftpd
22	TCP	Secure Shell (SSH)	OpenSSH, Dropbear
23	TCP	Telnet	in.telnetd
25	TCP	Simple Mail Transfer Protocol (SMTP)	Sendmail, Postfix, Exim, qmail
53	TCP and UDP	Domain Name System (DNS)	Berkeley Internet Name Domain (BIND; a.k.a. named), djbdns

**TABLE 8.2** Port Numbers, Their Purposes, and Typical Linux Servers *(continued)*

Port Number	TCP or UDP	Purpose	Example Linux Servers
67	UDP	Dynamic Host Configuration Protocol (DHCP)	Internet Software Consortium (ISC) DHCP (dhcpd)
80	TCP	Hypertext Transfer Protocol (HTTP)	Apache, Roxen, thttpd
110	TCP	Post Office Protocol version 3 (POP-3)	Dovecot, Qpopper, popa3d
111	TCP and UDP	Portmapper	NFS, NIS, other RPC-based services
113	TCP	auth/ident	identd
119	TCP	Network News Transfer Protocol (NTTP)	InterNetNews (INN), Diablo, Leafnode
139	TCP	NetBIOS Session (Windows file sharing)	Samba
143	TCP	Internet Mail Access Protocol (IMAP)	Dovecot, Cyrus IMAP, UW-IMAP
161	UDP	Simple Network Management Protocol (SNMP)	Net-SNMP
177	UDP	XDMCP	XDM, KDM, GDM
389	TCP	LDAP	OpenLDAP
443	TCP	HTTP over SSL (HTTPS)	Apache, Roxen
445	TCP	Microsoft Directory Services (DS)	Samba
465	TCP	SMTP over SSL; or URL Rendezvous Directory (URD) <sup>1</sup>	Sendmail, Postfix, Exim, qmail; or network routers
631	TCP	Internet Printing Protocol	Common Unix Printing System (CUPS)
993	TCP	IMAP over SSL	Dovecot, Cyrus IMAP, UW-IMAP

**TABLE 8.2** Port Numbers, Their Purposes, and Typical Linux Servers (*continued*)

Port Number	TCP or UDP	Purpose	Example Linux Servers
995	TCP	POP-3 over SSL	Dovecot, Qpopper, popa3d
5900+	TCP	Remote Framebuffer (RFB)	Virtual Network Computing (VNC): OpenVNC, TightVNC
6000–6007	TCP	The X Window System (X)	X.org-X11, XFree86

<sup>1</sup>Port 465 is officially registered for URD; however, it's also commonly used as a secure e-mail delivery port, although this isn't the officially designated purpose of this port.

One key distinction in TCP/IP ports is that between *privileged ports* and *unprivileged ports*. The former have numbers less than 1024. Unix and Linux systems restrict access to privileged ports to `root`. The idea is that a client can connect to a privileged port and be confident that the server running on that port was configured by the system administrator and can therefore be trusted. Unfortunately, on today's Internet, this trust would be unjustified based solely on the port number, so this distinction isn't very useful. Port numbers greater than 1024 may be accessed by ordinary users.

### Clients and Servers

An important distinction is the one between clients and servers. A *client* is a program that initiates a network connection to exchange data. A *server* listens for such connections and responds to them. For instance, a Web browser, such as Firefox or Opera, is a client program. You launch the program and direct it to a Web page, which means that the Web browser sends a request to the Web (HTTP) server at the specified address. The Web server sends back data in reply to the request. Clients can also send data, as when you enter information in a Web form and click a Submit or Send button.

The terms *client* and *server* can also be applied to entire computers that operate mostly in one or the other role. Thus, a phrase such as *Web server* is somewhat ambiguous—it can refer either to the Web server program or to the computer that runs that program. When this distinction is important and unclear from context, I clarify it (for instance, by referring to “the Web server program”).

Fortunately, for basic functioning, you need to do nothing to configure ports on a Linux system. You may have to deal with this issue if you run unusual servers, though, because you may need to configure the system to link the servers to the correct ports. This can sometimes

involve editing the `/etc/services` file, which maps port numbers to names, enabling you to use names in server configurations and elsewhere. This file consists of lines that begin with a name and end with a port number, including the type of protocol it uses (TCP or UDP):

```
ssh 22/tcp # SSH Remote Login Protocol
ssh 22/udp # SSH Remote Login Protocol
telnet 23/tcp
smtp 25/tcp
```

## Configuring Linux for a Local Network

Now that you know something about how networking functions, the question arises: How do you implement networking in Linux? Most Linux distributions provide you with the means to configure a network connection during system installation. Therefore, chances are good that networking already functions on your system. In case it doesn't, though, the following sections summarize what you must do to get the job done. Actual configuration can be done using either the automatic DHCP tool or static IP addresses. Linux's underlying network configuration mechanisms rely on startup scripts and their configuration files, but you may be able to use GUI tools to do the job instead.

### Network Hardware Configuration

The most fundamental part of network configuration is getting the network hardware up and running. In most cases, this task is fairly automatic—most distributions ship with system startup scripts that auto-detect the network card and load the correct driver module. If you recompile your kernel, building the correct driver into the main kernel file will also ensure that it's loaded at system startup.

If your network hardware isn't correctly detected, though, subsequent configuration (as described in the upcoming sections “Configuring with DHCP” and “Configuring with a Static IP Address”) won't work. To correct this problem, you must load your network hardware driver. You can do this with the `modprobe` command:

```
modprobe tulip
```

You must know the name of your network hardware's kernel module (`tulip` in this example). Chapter 3, “Configuring Hardware,” describes the task of hardware configuration and activation in more detail.

### Configuring with DHCP

One of the easiest ways to configure a computer to use a TCP/IP network is to use DHCP, which enables one computer on a network to manage the settings for many other computers. It works like this: When a computer running a DHCP client boots up, it sends a broadcast in



search of a DHCP server. The server replies (using nothing but the client’s hardware address) with the configuration information the client needs to enable it to communicate with other computers on the network—most important, the client’s IP address and netmask and the network’s gateway and DNS server addresses. The DHCP server may also give the client a hostname. The client then configures itself with these parameters. The IP address isn’t assigned permanently; it’s referred to as a *DHCP lease*, and if it’s not renewed, the DHCP server may give the lease to another computer. Therefore, from time to time the client checks back with the DHCP server to renew its lease.

Three DHCP clients are in common use on Linux: `pump`, `dhclient`, and `dhcpcd` (not to be confused with the DHCP server, `dhcpcd`). Some Linux distributions ship with just one of these, but others ship with two or even all three. All distributions have a default DHCP client—the one that’s installed when you tell the system you want to use DHCP at system installation time. Those that ship with multiple DHCP clients typically enable you to swap out one for another simply by removing the old package and installing the new one.

Ideally, the DHCP client runs at system bootup. This is usually handled either by its own SysV startup file, as described in Chapter 5, “Booting Linux and Editing Files,” or as part of the main network configuration startup file (typically a SysV startup file called `network` or `networking`). The system often uses a line in a configuration file to determine whether to run a DHCP client. For instance, Red Hat and Fedora set this option in a file called `/etc/sysconfig/network-scripts/ifcfg-eth0` (this filename may differ if you use something other than a single Ethernet interface). The line in question looks like this:

```
BOOTPROTO=dhcp
```

If the `BOOTPROTO` variable is set to something else, changing it as shown here will configure the system to use DHCP. It’s usually easier to use a GUI configuration tool to set this option, though.

Ubuntu uses the `/etc/network/interfaces` file for a similar purpose, but the details differ. On a system that uses DHCP, a line like the following appears:

```
iface eth0 inet dhcp
```

Details may vary, of course; for instance, the interface name (`eth0`) may be something else. You may prefer to use the GUI system configuration tools to adjust these options.

Once a DHCP client is configured to run when the system boots, the configuration task is done—at least, if everything works as it should. On very rare occasions, you may need to tweak DHCP settings to work around client/server incompatibilities or to have the DHCP client do something unusual. Consult the `man` page for your DHCP client if you need to make changes. You’ll then have to modify its SysV startup script or a file to which it refers in order to change its operation.

If you need to manually run a DHCP client, you can usually do so by typing its name (as root), optionally followed by a network identifier, as in `dhclient eth0` to have the DHCP client attempt to configure `eth0` with the help of any DHCP server it finds on that network.

## Configuring with a Static IP Address

If a network lacks a DHCP server, you must provide basic network configuration options manually. You can set these options using interactive commands, as described shortly; but to set them in the long term, you adjust a configuration file such as `/etc/sysconfig/network-scripts/ifcfg-eth0` or `/etc/network/interfaces`. Listing 8.1 shows a typical `ifcfg-eth0` file, configured to use a static IP address. (Note that this file's exact location and name may vary from one distribution to another.)

### Listing 8.1: A Sample Network Configuration File

```
DEVICE=eth0
BOOTPROTO=static
IPADDR=192.168.29.39
NETMASK=255.255.255.0
NETWORK=192.168.29.0
BROADCAST=192.168.29.255
GATEWAY=192.168.29.1
ONBOOT=yes
```

Several specific items are required, or at least helpful, for static IP address configuration:

**IP address** You can set the IP address manually via the `ifconfig` command (described in more detail shortly) or via the `IPADDR` item in the configuration file.

**Network mask** The netmask can be set manually via the `ifconfig` command or via the `NETMASK` item in a configuration file.

**Gateway address** You can manually set the gateway via the `route` command. To set it permanently, you need to adjust a configuration file, which may be the same configuration file that holds other options or another file, such as `/etc/sysconfig/network/routes`. In either case, the option is likely to be called `GATEWAY`. The gateway isn't necessary on a system that isn't connected to a wider network—that is, if the system works *only* on a local network that contains no routers.

**DNS settings** In order for Linux to use DNS to translate between IP addresses and hostnames, you must specify at least one DNS server in the `/etc/resolv.conf` file. Precede the IP address of the DNS server by the keyword `nameserver`, as in `nameserver 192.168.29.1`. You can include up to three `nameserver` lines in this file. Adjusting this file is all you need to do to set the name server addresses; you don't have to do anything else to make the setting permanent. You can also set your computer's local domain name in this file using the `domain` option, as in `domain luna.edu` to set the domain to `luna.edu`.

The network configuration script may hold additional options, but most of these are related to others. For instance, Listing 8.1 has an option specifying the interface name (`DEVICE=eth0`), another that tells the computer to assign a static IP address (`BOOTPROTO=static`), and a third to bring up the interface when the computer boots (`ONBOOT=yes`). The `NETWORK` and `BROADCAST`

items in Listing 8.1 are derived from the IPADDR and NETMASK items, but you can change them if you understand the consequences.

Unfortunately, these configuration details vary from one distribution to another. For instance, if you use Ubuntu, you would edit `/etc/network/interfaces` rather than `/etc/sysconfig/network-scripts/ifcfg-eth0`. The precise layout and formatting of information in the two files differs, but the same basic information is present in both of them. You may need to consult distribution-specific documentation to learn about these details. Alternatively, GUI tools are usually fairly easy to figure out, so you can look for these.

If you aren't sure what to enter for the basic networking values (the IP address, network mask, gateway address, and DNS server addresses), you should consult your network administrator. *Do not* enter random values or values you make up that are similar to those used by other systems on your network. Doing so is unlikely to work at all, and it can conceivably cause a great deal of trouble—say, if you mistakenly use an IP address that's reserved for another computer.

As just mentioned, the `ifconfig` program is critically important for setting both the IP address and netmask. This program can also display current settings. Basic use of `ifconfig` to bring up a network interface resembles the following:

```
ifconfig interface up addr netmask mask
```

For instance, the following command brings up `eth0` (the first Ethernet card) using the address `192.168.29.39` and the netmask `255.255.255.0`:

```
ifconfig eth0 up 192.168.29.39 netmask 255.255.255.0
```

This command links the specified IP address to the card so that the computer responds to the address and claims to be that address when sending data. It doesn't, though, set up a route for traffic beyond your current network. For that, you need to use the `route` command:

```
route add default gw 192.168.29.1
```

Substitute your own gateway address for `192.168.29.1`. (Routing and the `route` command are described in more detail shortly, in “Configuring Routing.”) Both `ifconfig` and `route` can display information on the current network configuration. For `ifconfig`, omit `up` and everything that follows; for `route`, omit `add` and everything that follows. For instance, to view interface configuration, you might issue the following command:

```
ifconfig eth0
eth0 Link encap:Ethernet HWaddr 00:A0:CC:24:BA:02
 inet addr:192.168.29.39 Bcast:192.168.29.255 Mask:255.255.255.0
 UP BROADCAST RUNNING MULTICAST MTU:1500 Metric:1
 RX packets:10469 errors:0 dropped:0 overruns:0 frame:0
 TX packets:8557 errors:0 dropped:0 overruns:0 carrier:0
 collisions:0 txqueuelen:100
 RX bytes:1017326 (993.4 Kb) TX bytes:1084384 (1.0 Mb)
 Interrupt:10 Base address:0xc800
```

When configured properly, `ifconfig` should show a hardware address (HWaddr), an IP address (`inet addr`), and additional statistics. There should be few or no errors, dropped packets, or overruns for both received (RX) and transmitted (TX) packets. Ideally, few (if any) collisions should occur, but some are unavoidable if your network uses a hub rather than a switch. If collisions total more than a few percent of the total transmitted and received packets, you may want to consider replacing a hub with a switch. To use `route` for diagnostic purposes, you might try the following:

```
route
Kernel IP routing table
Destination Gateway Genmask Flags Metric Ref Use Iface
192.168.29.0 * 255.255.255.0 U 0 0 0 eth0
127.0.0.0 * 255.0.0.0 U 0 0 0 lo
default 192.168.29.1 0.0.0.0 UG 0 0 0 eth0
```

This shows that data destined for 192.168.29.0 (that is, any computer with an IP address between 192.168.29.1 and 192.168.29.254) goes directly over `eth0`. The 127.0.0.0 network is a special interface that “loops back” to the originating computer. Linux uses this for some internal networking purposes. The last line shows the *default route*, which describes what to do with everything that doesn’t match any other entry in the routing table. This line specifies the default route’s gateway system as 192.168.29.1. If it’s missing or misconfigured, some or all traffic destined for external networks, such as the Internet, won’t make it beyond your local network segment.

As with DHCP configuration, it’s almost always easier to use a GUI configuration tool to set up static IP addresses, at least for new administrators. The exact locations of the configuration files differ from one distribution to another, so the examples listed earlier may not apply to your system.

## Configuring Routing

As explained earlier, routers pass traffic from one network to another. You configure your Linux system to directly contact systems on the local network. You also give the computer a router’s address, which your system uses as a gateway to the Internet at large. Any traffic that’s not destined for the local network is directed at this router, which passes it on to its destination. In practice, there are likely to be a dozen or more routers between you and most Internet sites. Each router has at least two network interfaces and keeps a table of rules concerning where to send data based on the destination IP address. Your own Linux computer has such a table, but it’s probably very simple compared to those on major Internet routers.

Linux can function as a router, which means it can link two or more networks together, directing traffic between them on the basis of its routing table. This task is handled, in part, by the `route` command. This command can be used to do much more than specify a

single gateway system, though, as described earlier. A simplified version of the `route` syntax is as follows:

```
route {add | del} [-net | -host] target [netmask nm] [gw gw]➤
[reject] [[dev] interface]
```

You specify `add` or `del` along with a *target* (a computer or network address) and optionally other parameters. The `-net` and `-host` options force `route` to interpret the *target* as a network or computer address, respectively. The `netmask` option lets you set a netmask as you desire, and `gw` lets you specify a router through which packets to the specified *target* should go. (Some versions of `route` use `gateway` rather than `gw`.) The `reject` keyword installs a blocking route, which refuses all traffic destined for the specified network. (This is *not* a firewall, though.) Finally, although `route` can usually figure out the interface device (for instance, `eth0`) on its own, you can force the issue with the `dev` option.

As an example, consider a network in which packets destined for the 172.20.0.0/16 subnet should be passed through the 172.21.1.1 router, which isn't the default gateway system. You can set up this route with the following command:

```
route add -net 172.20.0.0 netmask 255.255.0.0 gw 172.21.1.1
```



Incorrect routing tables can cause serious problems because some or all computers won't respond. You can examine your routing table by typing **route** alone and compare the results to what your routing table should be. (Consult a network administrator if you're not sure what your routing table should contain.) You can then delete incorrect routes and add new ones to replace them, if necessary. Ultimately, of course, changing your configuration files is the best solution, but typing a couple of `route` commands will do the trick in the short term.

One more thing you may need to do if you're setting up a router is enabling routing. Ordinarily, a Linux system won't forward packets it receives from one system that are directed at another system. If Linux is to act as a router, though, it must accept these packets and send them on to the destination network (or at least to an appropriate gateway). To enable this feature, you must modify a key file in the `/proc` filesystem:

```
echo "1" > /proc/sys/net/ipv4/ip_forward
```

This command enables IP forwarding. Permanently setting this option requires modifying a configuration file. Some distributions set it in `/etc/sysctl.conf`:

```
net.ipv4.ip_forward = 1
```

Other distributions use other configuration files and options, such as `/etc/sysconfig/sysctl` and its `IP_FORWARD` line. If you can't find it, try using `grep` to search for `ip_forward` or `IP_FORWARD`, or modify a local startup script to add the command to perform the change.

## Using GUI Configuration Tools

Most distributions include their own GUI configuration tools for network interfaces. For instance, Fedora and Red Hat ship with a custom GUI tool called Network Configuration (system-config-network), and SUSE has a text-mode and GUI tool called YaST. The details of operating these programs differ, but the GUI configuration tool provides a means to enter the information described earlier.

Although the LPI exam doesn't cover GUI network configuration tools, they're generally easier to locate and use than the configuration files in which settings are stored. Thus, you may want to look for your distribution's tool and learn to use it. Once you understand the principles of network configuration (IP addresses, DHCP, and so on), you shouldn't have trouble entering the necessary information in the GUI fields.

The precise details of how to configure a Linux system using GUI tools differ from one distribution to another. For instance, SUSE's YaST doesn't lay out its options in precisely the same way as Fedora's Network Configuration tool. The basic principles are the same, though; you must choose whether to use static IP address assignment or an automatic system such as DHCP and enter a number of key options, depending on what configuration method you choose.

## Using the *ifup* and *ifdown* Commands

Most Linux distributions today ship with two commands, *ifup* and *ifdown*, that combine the functions of several other network commands, most notably *ifconfig* and *route*. In their simplest forms, they bring interfaces up or shut them down based on information in whatever files your distribution uses to store network configuration data:

```
ifup eth0
```

```
Determining IP information for eth0... done.
```

After you issue this command, *eth0* will be fully configured, including all routing information, assuming you've properly configured it by using your distribution's network configuration tools or by manually editing configuration files such as */etc/network/interfaces* and */etc/sysconfig/network-scripts/ifcfg-eth0*. You can bring the interface down with equal ease by typing ***ifdown eth0***.

The *ifup* and *ifdown* commands are useful for verifying that the network settings are configured properly for the next time the computer boots. They're also useful if you want to quickly take down the network or bring it back up again, because you can type fewer commands and you don't need to remember all the details of IP addresses, routes, and so on. If you need to experiment or debug a problem, though, using *ifconfig* and *route* individually is preferable, because they give you finer control over the process.



---

The *ifup* and *ifdown* commands are implemented as scripts that consult the configuration files and run the relevant low-level commands behind the scenes.

## Configuring Hostnames

The hostnames described earlier (in “Resolving Hostnames”) are configured in a couple of ways:

**On DNS** Your network administrator should be able to add an entry for your system to your network’s DNS server. This entry should make your computer addressable by name from other computers on your local network, and perhaps from the Internet at large. Alternatively, remote systems’ `/etc/hosts` files can be modified to include your system.

**On your local computer** Various local programs should know your computer’s name. For instance, you may want to have your hostname displayed as part of a command prompt or entered automatically in e-mail programs. For this task, you must set your hostname locally. Note that this is entirely independent of your DNS hostname. In theory, you can set the two to very different values, but this practice is likely to lead to confusion and perhaps even failure of some programs to operate properly.

The most basic tool for setting your hostname locally is called, appropriately enough, `hostname`. Type the command alone to see what your hostname is, or type it with a new name to set the system’s hostname to that name:

```
hostname nessus.example.com
```

Similar commands, `domainname` and `dnsdomainname`, display or set the computer’s domain name (such as `example.com`). The `domainname` command sets the domain name as used by Network Information System (NIS), whereas `dnsdomainname` sets the domain name as used by DNS. These commands don’t affect remote servers—just the name given to programs that use calls designed for these servers.

Many Linux distributions look in the `/etc/hostname` or `/etc/HOSTNAME` file for a hostname to set at boot time. Thus, if you want to set your hostname permanently, you should look for these files, and if one is present, you should edit it. Fedora uses `/etc/sysconfig/network` for this purpose, among others. If you can’t find one of these files, consult your distribution’s documentation; it’s conceivable that your distribution stores its hostname in some unusual location.

In Exercise 8.1, you’ll familiarize yourself with some of the tools used to configure basic network settings. You’ll use these tools both to study and to change your network configuration.

### EXERCISE 8.1

#### Configuring a Network Connection

In this exercise, the assumption is that the computer is correctly configured to use an IPv4 Ethernet network, including both local network access and access to a larger network (probably the Internet) via a router.

Some of the procedures in this exercise can easily break your network connectivity if something goes wrong. If this happens, typing `ifdown` followed by `ifup` is one way to recover. If this fails, rebooting the computer is almost certain to work, although it’s a radical solution.

**EXERCISE 8.1 (continued)**

To study and modify your system's network configuration, follow these steps:

1. Log into the Linux system as a normal user.
2. Launch an xterm from the desktop environment's menu system, if you used a GUI login method.
3. Acquire root privileges. You can do this by typing **su** in an xterm, by selecting Session > New Root Console from a Konsole, or by using **sudo** (if it's configured) to run the commands in the following steps.
4. Type **ifconfig**. This command displays information about your local network settings for all your network interfaces. Most systems have both a loopback interface (lo) and an Ethernet interface (eth0). Look for a line in the Ethernet section that includes the string **inet addr:**. The following 4-byte number is your IP address. Write it down, as well as the value of your netmask (**Mask:**). Study the other information in this output, too, such as the number of received (RX) and transmitted (TX) packets, the number of errors, the number of collisions, and the Ethernet adapter's hardware address.
5. Type **route -n**. The output is your computer's routing table information. This normally includes information about the loopback network address (127.0.0.0/24), the local network address, and a default route (identified as the route for 0.0.0.0). Some systems may display fewer or additional lines, depending on local configuration. The default route includes an IP address under the Gateway column. Write down that address.
6. Use **ping** to test connectivity to both local and remote computers. (This command is described in more detail shortly, in "Testing Basic Connectivity.") You need the name or IP address of at least one local computer and at least one distant computer (beyond your local router). Type **ping address**, where *address* is the name or IP address of each test machine. Perform this test for localhost or 127.0.0.1, your own machine (use the IP address you noted in step 4), your local router (use the IP address you noted in step 5), and a distant computer (if you're connected to the Internet, you can use an Internet-accessible site, such as [www.linux.org](http://www.linux.org)). All of these ping tests should be successful. Note, however, that some systems are configured to ignore packets sent by ping. Thus, some of these tests may fail if you run into such systems. You can learn the configuration of local systems from their administrators, but for Internet sites, you may want to simply try another site if the first one you test fails.
7. Bring down the local Ethernet connection by typing **ifconfig eth0 down**.
8. Repeat steps 4–6. Note that the eth0 interface is no longer shown when you type **ifconfig**, all routes associated with it have been removed from the routing table, and pinging systems accessible from the interface no longer works. (Linux retains some information about its former Ethernet link, so you may still be able to ping the computer itself via its former eth0 address.)



**EXERCISE 8.1 (continued)**

9. Bring the local Ethernet connection back up by typing `ifconfig eth0 up address netmask mask`, where *address* is the original IP address and *mask* is the original netmask, both as identified in step 4.
  10. Repeat steps 4–6. Note that the `ifconfig` command automatically added back your local network to the routing table but that the default route is still missing. As a result, you can't contact any systems that are located off the local network. If your DNS server is such a system, this means your ability to contact even local machines by name may be impaired as well.
  11. Restore the default route by typing `route add default gw gateway`, where *gateway* is the router address you identified in step 5.
  12. Repeat steps 4–6. If your network configuration is typical, all connectivity should be restored. (Some more exotic systems may still be lacking certain routes.)
- 

**Real World Scenario****Using PPP with DSL**

Broadband users, and particularly those with Digital Subscriber Line (DSL) connections, sometimes have to use a variant of PPP to make their connections. PPP is a login-based way to access the Internet—you use a PPP utility to initiate a connection to a remote computer, which includes an exchange of a username and a password. A decade ago, PPP was used in dial-up Internet access (and it's still used in this capacity), but some DSL providers have adapted PPP for their own purposes. In the case of DSL, this configuration method is called PPP over Ethernet (PPPoE).

In many cases, the simplest way to use a PPPoE configuration is to purchase a broadband router. This device attaches to the DSL modem and makes the PPPoE connection. The broadband router then works just like an ordinary Ethernet or Wi-Fi router, as far as your local computers are concerned, so you can configure Linux as you would on any other local network.

If you must connect a Linux system directly to a DSL network that uses PPPoE, you must use a Linux PPPoE client. Most Linux distributions ship with such clients; but configuration details vary from one distribution to another. Your best bet is to look for your distribution's GUI network configuration tool; chances are, you'll be able to find a set of options that are clearly labeled as applying to DSL or PPPoE.

# Diagnosing Network Connections

Network configuration is a complex topic, and unfortunately, things don't always work as planned. Fortunately, there are a few commands you can use to help diagnose a problem. Five of these are `ping`, `traceroute`, `tracpath`, `netstat`, and `tcpdump`. Each of these commands exercises the network in a particular way and provides information that can help you track down the source of a problem. You can also use some common network programs that aren't primarily debugging tools in your debugging efforts.

## Testing Basic Connectivity

The most basic network test is the `ping` command, which sends a simple ICMP packet to the system you name (via IP address or hostname) and waits for a reply. In Linux, `ping` continues sending packets once every second or so until you interrupt it with a Ctrl+C key-stroke. (You can instead specify a limited number of tests via the `-c num` option.) Here's an example of its output:

```
$ ping -c 4 speaker
PING speaker (192.168.1.1) 56(84) bytes of data.
64 bytes from speaker.example.com (192.168.1.1): icmp_seq=1 ttl=64 time=0.194ms
64 bytes from speaker.example.com (192.168.1.1): icmp_seq=2 ttl=64 time=0.203ms
64 bytes from speaker.example.com (192.168.1.1): icmp_seq=3 ttl=64 time=0.229ms
64 bytes from speaker.example.com (192.168.1.1): icmp_seq=4 ttl=64 time=0.217ms
--- speaker ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3002ms
rtt min/avg/max/mdev = 0.194/0.210/0.229/0.022 ms
```

This command sent four packets and waited for their return, which occurred quite quickly (in an average of 0.210ms) because the target system was on the local network. By pinging systems on both local and remote networks, you can isolate where a network problem occurs. For instance, if you can ping local systems but not remote systems, the problem is most probably in your router configuration. If you can ping by IP address but not by name, the problem is with your DNS configuration.

## Tracing a Route

A step up from `ping` is the `traceroute` command, which sends a series of three test packets to each computer between your system and a specified target system. The result looks something like this:

```
$ traceroute -n 10.1.0.43
traceroute to 10.1.0.43 (10.1.0.43), 30 hops max, 52 byte packets
```

```
1 192.168.1.254 1.021 ms 36.519 ms 0.971 ms
2 10.10.88.1 17.250 ms 9.959 ms 9.637 ms
3 10.9.8.173 8.799 ms 19.501 ms 10.884 ms
4 10.9.8.133 21.059 ms 9.231 ms 103.068 ms
5 10.9.14.9 8.554 ms 12.982 ms 10.029 ms
6 10.1.0.44 10.273 ms 9.987 ms 11.215 ms
7 10.1.0.43 16.360 ms * 8.102 ms
```

The `-n` option to this command tells it to display target computers' IP addresses rather than their hostnames. This can speed up the process a bit, particularly if you're having DNS problems, and it can sometimes make the output easier to read—but you may want to know the hostnames of problem systems because that can help you pinpoint who's responsible for a problem.

This sample output shows a great deal of variability in response times. The first hop, to 192.168.1.254, is purely local; this router responded in 1.021, 36.519, and 0.971 milliseconds (ms) to its three probes. (Presumably the second probe caught the system while it was busy with something else.) Probes of most subsequent systems are in the 8–20ms range, although one is at 103.068ms. The final system has only two times; the middle probe never returned, as the asterisk (\*) on this line indicates.

Using `traceroute`, you can localize problems in network connectivity. Highly variable times and missing times can indicate a router that's overloaded or that has an unreliable link to the previous system on the list. If you see a dramatic jump in times, it typically means that the physical distance between two routers is great. This is common in intercontinental links. Such jumps don't necessarily signify a problem unless the two systems are close enough that a huge jump isn't expected.

What can you do with the `traceroute` output? Most immediately, `traceroute` is helpful in determining whether a problem in network connectivity exists in a network for which you're responsible. For instance, the variability in the first hop of the preceding example could indicate a problem on the local network, but the lost packet associated with the final destination most likely is not a local problem. If the trouble link is within your jurisdiction, you can check the status of the problem system, nearby systems, and the network segment in general.



Some routers are configured in such a way that `traceroute` isn't a useful tool; these routers block all `traceroute` data, either to themselves only or for all packets that pass through them. If your `traceroute` output contains one or two lines of all asterisks but everything else seems OK, chances are you've run into such a system. If you see nothing but asterisks after a certain router but diagnostic tools such as `ping` still work, a router is probably blocking all `traceroute` operations.

The `tracpath` program is an alternative to `traceroute`. In basic operation, it's similar, although it produces one line of output for each test packet and so yields longer outputs than `traceroute`. There are also fewer `tracpath` options than there are `traceroute` options.

## Checking Network Status

Another useful diagnostic tool is `netstat`. This is something of a Swiss Army knife of network tools because it can be used in place of several others, depending on the parameters it's passed. It can also return information that's not easily obtained in other ways. Some examples include the following:

**Interface information** Pass `netstat` the `--interface` or `-i` parameter to obtain information about your network interfaces similar to what `ifconfig` returns. (Some versions of `netstat` return information in the same format, but others display the information differently.)

**Routing information** You can use the `--route` or `-r` parameter to obtain a routing table listing similar to what the `route` command displays.

**Masquerade information** Pass `netstat` the `--masquerade` or `-M` parameter to obtain information about connections mediated by Linux's NAT features, which often go by the name *IP masquerading*. NAT enables a Linux router to “hide” a network behind a single IP address. This can be a good way to stretch limited IPv4 addresses.

**Program use** Some versions of `netstat` support the `--program` (or `-p`) parameter, which attempts to provide information about the programs that are using network connections. This attempt isn't always successful, but it often is, so you can see what programs are making outside connections.

**Open ports** When used with various other parameters, or without any parameters at all, `netstat` returns information about open ports and the systems to which they connect.

**All connections** The `--all` or `-a` option is used in conjunction with others. It causes `netstat` to display information about the ports that server programs open to listen for network connections, in addition to already-open connections. This use of `netstat` is described in more detail in Chapter 10, “Securing Your System.”

Keep in mind that `netstat` is a very powerful tool, and its options and output aren't entirely consistent from one distribution to another. You may want to peruse its `man` page and experiment with it to learn what it can do.

## Examining Raw Network Traffic

One advanced network troubleshooting tool is `tcpdump`. This utility is a *packet sniffer*, which is a program that can intercept network packets and log them or display them on the screen. Packet sniffers can be useful diagnostic tools because they enable you to verify that a computer is actually receiving data from other computers. They also enable you to examine the data in its raw form, which can be useful if you understand enough of the protocol's implementation details to spot problems.



Although packet sniffers are useful diagnostic tools, they can also be abused. For instance, unscrupulous individuals can run packet sniffers to capture passwords that others send over the network. Depending on your network configuration, this trick can work even if the packet sniffer isn't running on either the sending or the receiving computer. For this reason, many organizations have policies forbidding the use of packet sniffers except under limited circumstances. Thus, before running a packet sniffer, you should obtain written permission to use such a program from an individual who is authorized to grant such permission. Failure to do so can lead you into serious trouble, possibly up to losing your job or even being sued.

In its most basic form, you can use `tcpdump` by typing its name:

```
tcpdump
```

```
tcpdump: verbose output suppressed, use -v or -vv for full protocol decode
listening on eth0, link-type EN10MB (Ethernet), capture size 96 bytes
19:31:55.503759 IP speaker.example.com.631 > 192.168.1.255.631: UDP,↵
 length: 139
19:31:55.505400 IP nessus.example.com.33513 > speaker.example.com.domain:↵
 46276+ PTR? 255.1.168.192.in-addr.arpa. (44)
19:31:55.506086 IP speaker.example.com.domain > nessus.example.com.33513:↵
 46276 NXDomain* 0/1/0 (110)
```

The first thing to note about this command is that you must run it as `root`; ordinary users aren't allowed to monitor network traffic in this way. Once it's run, `tcpdump` summarizes what it's doing and then begins printing lines, one for each packet it monitors. (Some of these lines can be quite long and so may take more than one line on your display.) These lines include a time stamp, a stack identifier (IP in all of these examples), the origin system name or IP address and port, the destination system name or IP address and port, and packet-specific information. Ordinarily, `tcpdump` keeps displaying packets indefinitely, so you must terminate it by pressing `Ctrl+C`. Alternatively, you can pass it the `-c num` option to have it display `num` packets and then quit.

Even this basic output can be very helpful. For instance, consider the preceding example of three packets, which was captured on `nessus.example.com`. This computer successfully received one broadcast packet (addressed to `192.168.1.255`) from `speaker.example.com`'s UDP port 631, sent a packet to `speaker.example.com`, and received a packet from that system directed at `nessus.example.com` rather than sent as a broadcast. This sequence verifies that at least minimal communication exists between these two computers. If you were having problems establishing a connection, you could rule out a whole range of possibilities based on this evidence, such as faulty cables or a firewall that was blocking traffic.

If you need more information, `tcpdump` provides several options that enhance or modify its output. These include `-A` to display packet contents in ASCII, `-D` to display a list of

interfaces to which `tcpdump` can listen, `-n` to display all addresses numerically, `-v` (and additional `-v` options, up to `-vvv`) to display additional packet information, and `-w file` to write the captured packets to the specified *file*. Consult `tcpdump`'s man page for more details on these options and for additional options.

## Using Additional Tools

In addition to specialized network diagnostic programs, you can use some common user programs as debugging tools. One of the most useful of these may be Telnet. This program and protocol is mainly a remote login tool; type the program name followed by the name of a remote system to receive a login prompt on that system:

```
$ telnet speaker
Trying 192.168.1.1...
Connected to speaker.
Escape character is '^]'.

speaker login: harry
Password:
Last login: Mon Apr 25 21:48:44 from nessus.example.com
Have a lot of fun...
harry@speaker:~>
```



Telnet is a poor choice as a remote login protocol because it's entirely unencrypted. As a general rule, you should remove the Telnet server from your system and never use the `telnet` client program. It can be a useful lowest-common-denominator protocol on sufficiently protected private networks, though, and it can also be a handy tool for debugging, as described next. Chapter 10 describes SSH, which is a much safer alternative to Telnet.

You can also use Telnet to debug network protocols; if you give it a port number after the remote hostname, the `telnet` program connects to that port, enabling you to interact with the server:

```
$ telnet speaker 25
Trying 192.168.1.1...
Connected to speaker.
Escape character is '^]'.
220 speaker.example.com ESMTP Postfix
HELO nessus.example.com
250 speaker.example.com
```

This example connects to port 25, which is used by e-mail servers. After connecting, I entered a HELO command, which is used by SMTP to identify a client; the remote system responded with a 250 code, which indicates an accepted command.

Of course, to use Telnet in this way, you must know a great deal about the protocol. Even without this knowledge, though, you can use Telnet to test whether a server is running: If you try to connect but get a `Connection refused` error message, you know that a remote server isn't running or is inaccessible for some reason (say, because it's being blocked by a firewall). If you get in (to the `Escape character` message shown in the earlier example or beyond), the server is running, although it may not be working correctly. This test only works for protocols that use TCP. Some simple tools use UDP instead, and Telnet won't connect with them.

Sometimes the File Transfer Protocol (FTP) can be a useful diagnostic tool, as well. This program, as its name suggests, enables you to transfer files between systems. To use it, type the program name followed by the FTP server's name. You'll then see a login prompt and be able to issue FTP commands:

```
$ ftp speaker
```

```
Connected to speaker.
```

```
220 (vsFTPd 1.2.1)
```

```
Name (speaker:harry): harry
```

```
530 Please login with USER and PASS.
```

```
SSL not available
```

```
331 Please specify the password.
```

```
Password:
```

```
230 Login successful.
```

```
Remote system type is UNIX.
```

```
Using binary mode to transfer files.
```

```
ftp> get zathras.wav
```

```
local: zathras.wav remote: zathras.wav
```

```
200 PORT command successful. Consider using PASV.
```

```
150 Opening BINARY mode data connection for zathras.wav (109986 bytes).
```

```
226 File send OK.
```

```
109986 bytes received in 0.104 secs (1e+03 Kbytes/sec)
```

```
ftp> quit
```

```
221 Goodbye.
```

This example retrieves a single file, `zathras.wav`, from the remote computer. The basic ftp client displays a file size, transfer time, and transfer rate (`1e+03 Kbytes/sec`—in other words,  $1 \times 10^3$  KB/s, or 1000 KB/s). This can be a useful way to test your network transfer speed, although you'll get more reliable results with files that are several hundred kilobytes or larger in size. In addition to `get`, which retrieves files, you can issue commands such as `put`, to upload a file; `ls` or `dir`, to display the remote system's directory contents; `cd`, to change directories on the remote system; `delete`, to remove a file; and `quit` or `exit`, to

exit from the program. You can use the `help` or `?` command to see a list of available `ftp` commands.

Like Telnet, FTP is a poor choice of protocol for security reasons. The same SSH protocol that can substitute for Telnet can also handle most FTP duties. One important exception exists to the rule not to use FTP, though: Anonymous FTP sites are a common method of distributing public files on the Internet. You can download Linux itself from anonymous FTP sites. These sites typically take a username of `anonymous` and any password (your e-mail address is the conventional reply) and give you read access to their contents. In most cases, you can't upload files to anonymous FTP sites, and you can access only a limited number of files.



You can access public FTP sites using a Web browser. Enter a URL that begins with `ftp://`, such as `ftp://downloads.example.org`, and the Web browser connects to the site using FTP rather than HTTP.

## Summary

Linux is a network-enabled OS, and it relies on its networking features more than most OSs do. This networking is built around TCP/IP, so you should understand the basics of this protocol stack, including IP addresses, hostnames, and routing. Most Linux distributions provide tools to configure networking during system installation; but if you want to temporarily or permanently change your settings, you can do so. Tools such as `ifconfig` and `route` can temporarily change your network configuration, and editing critical files or running distribution-specific utilities enables you to make your changes permanent.

## Exam Essentials

**Describe the information needed to configure a computer on a static IP network.** Four pieces of information are important: the IP address, the netmask (a.k.a. the network mask or subnet mask), the network's gateway address, and the address of at least one DNS server. The first two are required, but if you omit either or both of the latter two, basic networking will function, but you won't be able to connect to the Internet or use most DNS hostnames.

**Determine when using `/etc/hosts` over DNS makes the most sense.** The `/etc/hosts` file provides a static mapping of hostnames to IP addresses on a single computer. As such, maintaining this file on a handful of computers for a small local network is fairly straightforward; but when the number of computers rises beyond a few or when IP addresses change frequently, running a DNS server to handle local name resolution makes more sense.



**Summarize tools you can use to translate between hostnames and IP addresses.** The `nslookup` program can perform these translations in both directions using either command-line or interactive modes, but this program has been deprecated. You're better off using `host` for simple lookups or `dig` for more complex tasks.

**Describe the function of network ports.** Network ports enable packets to be directed to specific programs; each network-enabled program attaches itself to one or more ports, sending data from that port and receiving data directed to the port. Certain ports are assigned to be used by specific servers, enabling client programs to contact servers by directing requests at specific port numbers on the server computers.

**Explain when you should use static IP addresses or DHCP.** Static IP address configuration involves manually entering the IP address and other information and is used when a network lacks a Dynamic Host Configuration Protocol (DHCP) server or when a computer shouldn't be configured by that server (say, because the computer *is* the DHCP server). DHCP configuration is easier to set up on the client but works only if the network has a DHCP server system.

**Explain what the `route` command accomplishes.** The `route` command displays or modifies the routing table, which tells Linux how to direct packets based on their destination IP addresses.

**Describe some basic network diagnostic tools.** The `ping` program tests basic network connectivity, and `traceroute` and `tracert` perform similar but more complex tests that can help you localize where on a route between two systems a problem exists. The `netstat` utility is a general-purpose network status tool that can report a wide variety of information about your network configuration. Packet sniffers such as `tcpdump` provide detailed information about the network packets "seen" by a computer, which can be a useful way to verify that certain packet types are actually being sent or received.

# Review Questions

1. Which types of network hardware does Linux support? (Select all that apply.)
  - A. Token Ring
  - B. Ethernet
  - C. DHCP
  - D. Fibre Channel
2. Which of the following is a valid IPv4 address for a computer on a TCP/IP network?
  - A. 202.9.257.33
  - B. 63.63.63.63
  - C. 107.29.5.3.2
  - D. 98.7.104.0/24
3. You want to set up a computer on a local network via a static TCP/IP configuration, but you lack a gateway address. Which of the following is true?
  - A. Because the gateway address is necessary, no TCP/IP networking functions will work.
  - B. TCP/IP networking will function, but you'll be unable to convert hostnames to IP addresses or vice versa.
  - C. You'll be able to communicate with machines on your local network segment but not with other systems.
  - D. The computer won't be able to tell which other computers are local and which are remote.
4. Using a packet sniffer, you notice a lot of traffic directed at TCP port 22 on a local computer. What protocol does this traffic use, assuming it's using the correct port?
  - A. HTTP
  - B. SMTP
  - C. Telnet
  - D. SSH
5. What network port would an IMAP server normally use for IMAP exchanges?
  - A. 21
  - B. 25
  - C. 110
  - D. 143
6. Which of the following is *not* a Linux DHCP client?
  - A. pump
  - B. dhcpcd
  - C. dhcpd
  - D. dhclient

7. Which of the following types of information are returned by typing **ifconfig eth0**? (Select all that apply.)
- A. The names of programs that are using **eth0**
  - B. The IP address assigned to **eth0**
  - C. The hardware address of **eth0**
  - D. The hostname associated with **eth0**
8. Which of the following programs can be used to perform a DNS lookup?
- A. **host**
  - B. **dnslookup**
  - C. **pump**
  - D. **ifconfig**
9. Which of the following commands should you use to add to host 192.168.0.10 a default gateway to 192.168.0.1?
- A. **route add default gw 192.168.0.10 192.168.0.1**
  - B. **route add default gw 192.168.0.1**
  - C. **route add 192.168.0.10 default 192.168.0.1**
  - D. **route 192.168.0.10 gw 192.168.0.1**
10. How might you manually bring up an interface on **eth1**? (Select all that apply.)
- A. Type **dhclient eth1**.
  - B. Type **ifup eth1**.
  - C. Type **ifconfig eth1**.
  - D. Type **network eth1**.
11. What is the purpose of **/etc/hostname**, if it's present on the system?
- A. It holds the computer's default hostname.
  - B. It holds a list of servers that resolve hostnames.
  - C. It holds a list of IP addresses and associated hostnames.
  - D. It holds the hostname of the local gateway computer.
12. Network accesses to parts of the Internet work fine, but several common addresses have stopped responding. Which of the following tools will be most helpful in diagnosing the source of this problem?
- A. **netstat**
  - B. **ping**
  - C. **traceroute**
  - D. **ifconfig**

13. The `ping` utility responds normally when you use it with an IP address but not when you use it with a hostname that you're positive corresponds to this IP address. What might cause this problem? (Select all that apply.)
- A. The target computer may be configured to ignore packets from `ping`.
  - B. Your computer's DNS configuration may be broken.
  - C. The DNS configuration on the target system may be broken.
  - D. The route between your computer and its DNS server may be incorrect.
14. How can you learn what programs are currently accessing the network on a Linux system?
- A. Type `ifconfig -p eth0`.
  - B. Examine `/proc/network/programs`.
  - C. Type `netstat -p`.
  - D. Examine `/etc/xinetd.conf`.
15. To diagnose a problem with an IMAP server (`imap.example.com`), you type `telnet imap.example.com 143` from a remote client. How can this procedure help you? (Select all that apply.)
- A. You can verify basic connectivity between the client computer and the server program.
  - B. By examining the output, you can locate intermediate routers that are misbehaving.
  - C. By using an encrypted protocol, you ensure that problems aren't caused by a packet-sniffing intruder.
  - D. Once connected, you can type IMAP commands to test the server's response to them.
16. You're configuring a new system, and your network administrator scribbles its IP address (172.25.78.89), netmask (255.255.255.0), gateway address (172.25.79.1), and DNS server address (10.24.89.201) on a piece of paper. You enter this information into your configuration files and type `ifup eth0`, but you find that you can't access the Internet with this computer. Which of the following is definitely true?
- A. Because the DNS server is on a completely different network, it won't function properly for your system. You should ask for the local network's DNS server's IP address.
  - B. The netmask identifies the gateway as being on a different network segment than the computer you're configuring, so the two can't communicate directly. You most likely misread one address.
  - C. Because the IP addresses involved are private IP addresses, there's no way for them to access the Internet. You must ask for public IP addresses for this system or use only your local private network.
  - D. The computer's IP address is a Class B address, but the netmask is for a Class C address. This combination can't work together, so you must obtain a new IP address or netmask.

17. What is the purpose of the `-n` option to `route`?
- A. It causes no operation to be performed; `route` reports what it would do if `-n` were omitted.
  - B. It precedes specification of a netmask when setting the route.
  - C. It causes machines to be identified by IP address rather than hostname in output.
  - D. It forces interpretation of a provided address as a network address rather than a host address.
18. What is the purpose of `/etc/resolv.conf`?
- A. It sets the computer's domain and identifies (by IP address) the name servers that the computer may use.
  - B. It controls whether the computer's network options are configured statically or via a DHCP server.
  - C. It specifies the IP address of a DHCP server from which the computer attempts to obtain an IP address.
  - D. It holds the routing table for the computer, determining the route that network packets take to other computers.
19. Which of the following entries are found in the `/etc/hosts` file?
- A. A list of hosts allowed to remotely access this one
  - B. Mappings of IP addresses to hostnames
  - C. A list of users allowed to remotely access this host
  - D. Passwords for remote Web administration
20. How can you reconfigure Linux to use DNS queries prior to consulting `/etc/hosts`?
- A. Edit the `/etc/resolv.conf` file, and be sure the `nameserver dns` line comes before the `nameserver files` line.
  - B. As root, type `nslookup dns`.
  - C. Edit the `/etc/named.conf` file, and change the `preferred-resolution` option from `files` to `dns`.
  - D. Edit `/etc/nsswitch.conf`, and change the order of the `files` and `dns` options on the `hosts:` line.

# Answers to Review Questions

1. A, B, D. Ethernet is currently the most common type of network hardware for local networks. Linux supports it very well, and Linux also includes support for Token Ring and Fibre Channel network hardware. DHCP is a protocol used to obtain a TCP/IP configuration over a TCP/IP network. It's not a type of network hardware, but it can be used over hardware that supports TCP/IP.
2. B. IP addresses consist of four 1-byte numbers (0–255). They're normally expressed in base 10 and separated by periods. 63.63.63.63 meets these criteria. 202.9.257.33 includes one value (257) that's not a 1-byte number. 107.29.5.3.2 includes five 1-byte numbers. 98.7.104.0/24 is a network address—the trailing /24 indicates that the final byte is a machine identifier, and the first 3 bytes specify the network.
3. C. The gateway computer is a router that transfers data between two or more network segments. As such, if a computer isn't configured to use a gateway, it won't be able to communicate beyond its local network segment. (If your DNS server is on a different network segment, name resolution via DNS won't work, although other types of name resolution, such as `/etc/hosts` file entries, will still work.)
4. D. The Secure Shell (SSH) protocol uses port 22, so if the traffic to port 22 is using the correct protocol, it's SSH traffic. The Hypertext Transfer Protocol (HTTP) is conventionally bound to port 80; the Simple Mail Transfer Protocol (SMTP) uses port 25; and Telnet uses port 22. None of these would normally be directed to port 22.
5. D. The Internet Mail Access Protocol (IMAP) is assigned to TCP port 143. Ports 21, 25, and 110 are assigned to the File Transfer Protocol (FTP), the Simple Mail Transfer Protocol (SMTP), and the Post Office Protocol version 3 (POP-3), respectively. Although some IMAP server programs also support POP-3 and might therefore listen to both ports 110 and 143, the question specifies IMAP exchanges, so option D is the only correct answer.
6. C. Option C, `dhcpcd`, is the Linux DHCP *server*. The others are all DHCP clients. Any given computer will use just one DHCP client (or none at all), but from one to three of A, B, and D will be available choices.
7. B, C. When used to display information on an interface, `ifconfig` shows the hardware and IP addresses of the interface, the protocols (such as TCP/IP) bound to the interface, and statistics on transmitted and received packets. This command does *not* return information about programs using the interface or the hostname associated with the interface.
8. A. The `host` program is a commonly used program to perform a DNS lookup. There is no standard `dnslookup` program, although the `nslookup` program is a deprecated program for performing DNS lookups. `pump` is a DHCP client, whereas `ifconfig` is used for configuration of networking parameters and cards.
9. B. To add a default gateway of 192.168.0.1, the command would be **`route add default gw 192.168.0.1`**. Specifying the IP address of the host system is not necessary and in fact will confuse the `route` command.

10. A, B. The `dhclient` utility, if installed, attempts to configure and bring up the network(s) passed to it as options (or all networks if it's given no options) using a DHCP server for guidance. Thus, option A may work, although it won't work if no DHCP server is available. Option B applies whatever network options are configured using distribution-specific tools and brings up the network. Thus, options A and B both may work, although neither is guaranteed to work. Option C displays the network status of `eth1`, but it won't activate `eth1` if it's not already active. There is no standard network utility in Linux. Thus, options C and D won't work.
11. A. Although not all systems use `/etc/hostname`, option A correctly describes it for those systems that use it. Option B describes the purpose of `/etc/resolv.conf`. Option C describes the purpose of `/etc/hosts`. Option D doesn't describe any standard Linux configuration file, although the gateway computer's IP address is likely to appear in a distribution-specific configuration file.
12. C. The `traceroute` command identifies the computers that lie between your own computer and a destination computer, along with some very basic information about network packet travel time and reliability. Thus, `traceroute` can help you track down the source of the described problem—perhaps a router that's critical to reaching all of the non-responsive systems has failed. The `netstat` and `ifconfig` utilities of options A and D both provide information about local network configuration options, but they most likely won't be of much help in diagnosing a problem that affects only some sites. The `ping` utility may help you quickly identify sites that have failed but won't be of much use beyond that.
13. B, D. DNS problems can manifest as an ability to connect to computers using IP addresses but not using hostnames. Thus, options B and D (and various other DNS-related problems) could create the symptoms described. If the target system were configured to ignore `ping` packets, as described in option A, then it wouldn't respond when you identified it by IP address. The target system's DNS configuration (option C) doesn't enter into the equation, because it responds to the `ping` request via IP address alone.
14. C. The `netstat` program produces various network statistics, including the process IDs (PIDs) and names of programs currently accessing the network when passed the `-p` parameter. Thus, option C is correct. The `ifconfig` program can't produce this information, and the `-p` option to this program is fictitious, so option A is incorrect. Option B's `/proc/network/programs` file is also fictitious. Option C's `/etc/xinetd.conf` file is real and may provide some information about some servers that are using the network (as described in Chapter 10); but this file won't provide information about all servers, much less about clients that are accessing the network.
15. A, D. If you get any response at all, you know that the basic network connection is working, including that the server is responding to the client. With basic knowledge of IMAP commands, `telnet` enables you to test the server's responses in more detail than most IMAP clients (mail readers) permit. Thus, options A and D are both correct. Option C describes the functionality of `traceroute` or `tracepath`; `telnet` provides no information about intermediate routers' functionality, so option B is incorrect. Because neither `telnet` nor IMAP on port 143 uses encryption, option C is incorrect. Furthermore, a packet sniffer is likely to have no effect on the transfer of data; it just copies the data so that the packet sniffer's user can see it.

16. B. The computer's IP address (172.25.78.89) and netmask (255.255.255.0) mean that the computer can directly address computers with IP addresses in the range of 172.25.78.1 to 172.25.78.254; but the gateway address (172.25.79.1) is outside of this range. Thus, either the IP address or the gateway address is wrong, and option B is correct. Nothing about the way DNS operates necessitates that the DNS server be on the same network segment as the DNS client, so option A is incorrect. Although private IP addresses are often isolated from the Internet, as option C specifies, Network Address Translation (NAT) can get around this limitation. Thus, although there could be some truth to option C, it's not certain to be true. The class A/B/C distinctions are just guidelines that can be overridden by specific configurations. Thus, option C is incorrect.
17. C. The `-n` option is used when you want to use `route` to display the current routing table, and it does as option C specifies. There is no `route` parameter that behaves as option A specifies. Option B describes the purpose of the `netmask` parameter to `route`. Option D describes the purpose of the `-net` parameter to `route`.
18. A. Option A correctly identifies the function of `/etc/resolv.conf`. Various distribution-specific configuration files perform the function described in option B, but `/etc/resolv.conf` is not one of these files. A DHCP client sends a broadcast to locate a DHCP server; there is no client configuration file that holds the DHCP server's address, as option C describes. The routing table is maintained internally, although basic routing information may be stored in distribution-specific configuration files, so option D is also incorrect.
19. B. The `/etc/hosts` file holds mappings of IP addresses to hostnames, on a one-line-per-mapping basis. It does not list the users or other hosts allowed to remotely access this one or affect remote administration through a Web browser.
20. D. The `/etc/nsswitch.conf` file controls the order of name resolution, among other things. Option D correctly describes the procedure for changing the order in which Linux performs name resolution. The `/etc/resolv.conf` file mentioned in option A controls the DNS servers that Linux consults, but it doesn't control access to `/etc/hosts`. Option B's `nslookup` command resolves a hostname, so option B will return the IP address of the computer called `dns`, if Linux can find such a system. The `/etc/named.conf` file of option C is the configuration file for the standard name server. This server isn't likely to be installed on most Linux systems, and even if it is, the procedure described in option C is invalid.



# Chapter 9

## Writing Scripts, Configuring E-mail, and Using Databases

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**THE FOLLOWING LINUX PROFESSIONAL  
INSTITUTE OBJECTIVES ARE COVERED IN  
THIS CHAPTER:**

- ✓ 1.105.1 Customize and use the shell environment (weight: 4)
- ✓ 1.105.2 Customize or write simple scripts (weight: 4)
- ✓ 1.105.3 SQL data management (weight: 2)
- ✓ 1.108.3 Mail Transfer Agent (MTA) basics (weight: 3)





This chapter covers a number of miscellaneous topics. The first of these relate to shell management and scripting. Linux shells (introduced in Chapter 1, “Exploring Linux Command-Line Tools”) can be customized in various ways. Knowing how to do this will help you be productive when using Linux. You may even need to set various options to use particular programs, and you may need to make similar changes on a global level so that all your users can work effectively. Managing your shell environment is done, essentially, by modifying standard shell startup scripts, so this chapter covers scripting next. You can write scripts to help automate tedious repetitive tasks or to perform new and complex tasks. Many of Linux’s startup functions (described in Chapter 5, “Booting Linux and Editing Files”) are performed by scripts, so mastering scripting will help you manage the startup process.

The next major topic of this chapter is Structured Query Language (SQL) data management. Many Linux installations rely on a SQL database to store information, and so you may need at least a minimal grounding in how to interact with SQL databases.

Finally, this chapter describes the basics of e-mail management under Linux. Several Linux e-mail packages exist, and you’re not expected to understand the details of their configuration for the LPI Level 1 exam; however, you should know how to configure mail forwarding, examine mail queues, and otherwise interact with a Linux mail server that’s already basically working.

## Managing the Shell Environment

Chapter 1 introduced Linux shell use, including topics such as command completion, history, redirection, and the basics of environment variables. Now it’s time to go further, with more details about environment variables, aliases, and configuration files. Using this information, you’ll be able to customize your shell environment to suit your personal tastes or change the default environment for all the users on your system.

### Reviewing Environment Variables

As described in Chapter 1, environment variables provide the means to pass named data (variables) to programs launched from a shell. Shells themselves also rely on environment variables. For instance, `$HOSTNAME` conventionally holds the computer’s name, such as

carson.example.com. A program that needs to know the computer’s name can refer to `$HOSTNAME` to obtain this information.

You set an environment variable manually via an equal-sign assignment operator. To make the variable available to programs you launch from your shell, you then use the `export` command:

```
$ HOSTNAME=carson.example.com
$ export HOSTNAME
```

You can combine these two commands into one for brevity:

```
$ export HOSTNAME=carson.example.com
```

On a bash command line, you can refer to an environment variable by using the `echo` command to examine a single variable (as in `echo $HOSTNAME`) or by typing `env` to display all the environment variables.



Environment variable names are usually preceded by a dollar sign (\$) in scripts and on shell command lines, except when they’re assigned. Getting this detail wrong can produce results you weren’t expecting; for instance, typing `echo HOSTNAME` produces the output `HOSTNAME`, rather than the computer’s hostname.

Although you can set environment variables manually at a bash prompt, a more common approach is to set them in a global or local bash startup script. These scripts are described in more detail shortly, in “Modifying Shell Configuration Files.”

## Understanding Common Environment Variables

You may encounter many common environment variables on your system. You can find out how environment variables are configured by typing `env`. This command is used to run a program with a changed set of environment variables; but when it’s typed alone, it returns all the environment variables that are currently set, in a format similar to that of bash environment variable assignments:

```
$ env | grep HOSTNAME
HOSTNAME=carson.example.com
```

Of course, the variables you see and their values will be unique to your system and even your account—that’s the whole point of environment variables. Table 9.1 summarizes common variables you may see in this output.

**TABLE 9.1** Common Environment Variables and Their Meanings

Variable Name	Explanation
USER or USERNAME	This is your current username. It's a variable that's maintained by the system.
SHELL	This variable holds the path to the current command shell.
PWD	This is the present working directory. This environment variable is maintained by the system. Programs may use it to search for files when you don't provide a complete pathname.
HOSTNAME	This is the current TCP/IP hostname of the computer.
PATH	This is an unusually important environment variable. It sets the <i>path</i> for a session, which is a colon-delimited list of directories in which Linux searches for executable programs when you type a program name. For instance, if <i>PATH</i> is <code>/bin:/usr/bin</code> and you type <code>ls</code> , Linux looks for an executable program called <code>ls</code> in <code>/bin</code> and then in <code>/usr/bin</code> . If the command you type isn't on the path, Linux responds with a command not found error. The <i>PATH</i> variable is typically built up in several configuration files, such as <code>/etc/profile</code> and the <code>.bashrc</code> file in the user's home directory.
HOME	This variable points to your home directory. Some programs use it to help them look for configuration files or as a default location in which to store files.
MAIL	This variable holds the location of the user's mail spool. It's usually <code>/var/spool/mail/username</code> .
LANG	The system holds your current language, specified as a locale, using this variable. Locales are described further in Chapter 6, "Configuring the X Window System, Localization, and Printing."
LD_LIBRARY_PATH	A few programs use this environment variable to indicate directories in which library files may be found. It works much like <i>PATH</i> .
PS1	This is the default prompt in bash. It generally includes variables of its own, such as <code>\u</code> (for the username), <code>\h</code> (for the hostname), and <code>\W</code> (for the current working directory). This value is frequently set in <code>/etc/profile</code> , but it's often overridden by users.
NNTPSERVER	Some Usenet news reader programs use this environment variable to specify the name of the news server system. This value may be set in <code>/etc/profile</code> or in the user's configuration files.

**TABLE 9.1** Common Environment Variables and Their Meanings (*continued*)

Variable Name	Explanation
TERM	This variable is the name of the current terminal type. To move a text-mode cursor and display text effects for programs like text-mode editors, Linux has to know what commands the terminal supports. The TERM environment variable specifies the terminal in use. This information is combined with data from additional files to provide terminal-specific code information. TERM is normally set automatically at login, but in some cases you may need to change it.
DISPLAY	This variable identifies the display used by X. It's usually :0.0, which means the first (numbered from 0) display on the current computer. When you use X in a networked environment, though, this value may be preceded by the name of the computer at which you're sitting, as in machine4.luna.edu:0.0. This value is set automatically when you log in, but you may change it if necessary. You can run multiple X sessions on one computer, in which case each one gets a different DISPLAY number—for instance, :0.0 for the first session and :1.0 for the second.
EDITOR	Some programs launch the program pointed to by this environment variable when they need to call a text editor for you to use. Thus, changing this variable to your favorite editor can help you work in Linux. It's best to set this variable to a text-mode editor, though; GUI editors may cause problems if they're called from a program that was launched from a text-mode login.



The PATH variable sometimes includes the current directory indicator (.) so that programs in the current directory can be run. This practice poses a security risk, though, because a miscreant can create a program with the same name as some other program (such as ls) and trick another user into running it by simply leaving it in a directory the victim frequents. Even the root user may be victimized this way. For this reason, it's best to omit the current directory from the PATH variable, especially for the superuser. If it's really needed for ordinary users, put it at the *end* of the path.

Any given system is likely to have several other environment variables set, but these are fairly esoteric or relate to specific programs. If a program's documentation says that it needs certain environment variables set, you can set them system-wide in /etc/profile or some other suitable file, or you can set them in user configuration files, as you deem appropriate.

Although you can see the entire environment by typing **env**, this output can be long enough to be intimidating. If you just want to know the value of one variable, you can use the echo

command, which echoes what you type to the screen. If you pass it a variable name preceded by a dollar sign (\$), echo returns the value of the variable. Here's an example:

```
$ echo $PS1
[\u@\h \W]\$
```

This command reveals that the PS1 environment variable is set to `[\u@\h \W]\$`, which in turn produces a bash prompt like `[david@penguin homes]$`. Exercise 9.1 illustrates how you can change your bash prompt.

## EXERCISE 9.1

### Changing Your bash Prompt

This exercise describes how to change your bash prompt to show the current time and number of jobs managed by the shell rather than whatever your distribution's default is. To accomplish this task, follow these steps:

1. Log into the Linux system as a normal user.
  2. Launch an xterm from the desktop environment's menu system, if you used a GUI login method.
  3. Type `export PS1="\T; \j jobs> "`. The backslash (\) is an escape character that denotes special data to be inserted into the prompt when used in the PS1 environment variable. \T is expanded into the current time in 12-hour format, and \j is expanded into the number of jobs the shell manages. The man page for bash has a complete list of expansions the PS1 variable accepts. The result of typing this command should be an immediate change in your prompt to resemble something like `04:42; 0 jobs>`.
  4. Wait for a minute, and then run a program in the background by typing its name and appending an ampersand (&). For instance, you can type `xeyes &` to run the xeyes program from an xterm. You should see the number of jobs increase, and the time should change.
  5. To make this change permanent, edit the `.bashrc` file in your home directory. Load this file into your favorite editor, and add a line to its end that reads `export PS1="\T; \j jobs> "`. Save the file, and exit the editor. (Shell configuration files are described in more detail shortly, in "Modifying Shell Configuration Files.")
  6. To test your change to `.bashrc`, log out and then log back in again. Instead of your distribution's default prompt, you should see the new one.
  7. If you don't like the new prompt, edit `.bashrc` again and delete the line you added in step 5.
-

## Using Aliases

Most Linux shells, including `bash`, support command *aliases*, which are new names you can give to regular commands. Typically, you'll use aliases to assign easier-to-remember names to obscure commands, to implement desirable command options as the default for commands, or to create a shortened version of a command to minimize the amount of typing you must do. You can define aliases in a one-off fashion at any `bash` prompt, but they're typically included in your `bash` startup scripts, as described shortly in “Modifying Shell Configuration Files.”

To implement an alias, you use the following syntax:

```
alias alias_name='commands'
```

The *alias\_name* is what you want to type at the command prompt, and the shell substitutes *commands* for whatever you type. As an example, consider the `ls` command, which lists the contents of a directory. A popular option for this command is `--color`, which color-codes the output, giving directories, links, and other special files particular colors to make them stand out. If you want to use this option as the default, you can use `alias`:

```
$ alias ls='ls --color'
```

In this example, `ls` becomes an alias for an extended version of itself. This doesn't result in recursion—that is, the `ls` to the right of the equal sign is *not* expanded. After you type this `alias` command, typing `ls` will work as if you'd typed `ls --color`. In fact, this particular alias is popular enough that it's included as a standard part of many distributions' `bash` startup scripts.

You can use an alias name that's unrelated to the original command name. For instance, suppose you want to type `bye` instead of `logout` to terminate a text-mode login session. You can do so with `alias`:

```
$ alias bye='logout'
```

In practice, this particular alias isn't likely to be useful if you type it manually at a command prompt, because you'll only log out of a session once. You might want to include it in a `bash` startup script, though. If you do that, then you won't need to type the alias manually at each session; it will be created automatically whenever you log in.

## Modifying Shell Configuration Files

Configuring shells requires editing shell configuration files. These files can be classified in a couple of ways. First, files may be global files that affect all users of a shell or local files that affect just one user. Second, files may be login files that are launched only by a login process (such as a text-mode console login) or non-login files that are launched by other processes (such as when starting an `xterm` window). The result is a  $2 \times 2$  matrix of configuration files, as shown in Table 9.2. (This table shows only `bash` configuration files; consult your shell's documentation if you're using another shell.)

**TABLE 9.2** Common bash Configuration Files

Type of File	Login File Location	Non-Login File Location
Global	/etc/profile and files in /etc/profile.d	/etc/bashrc or /etc/bash.bashrc
User	~/.bash_login, ~/.profile, or ~/.bash_profile	~/.bashrc

Precisely which of these files are used differs from one distribution to another. No matter the name, though, these files are shell scripts. Shell scripting is described in more detail later, in “Writing Scripts,” but most bash startup scripts contain a series of bash commands. These commands may include both built-in commands and external commands.

Global configuration files affect all users of a system; however, their settings may be overridden by individual users, either in user configuration files or in commands the users type themselves. Thus, you shouldn’t rely on global configuration files to set options that shouldn’t be changed by users. For that, you should look to global security features, such as permissions on executable files.

The /etc/skel directory holds files that are copied to individual users’ home directories when their accounts are created. These files are sometimes called *skeleton files*. Typically, this set of files includes local bash startup files. You can examine these files and, if necessary, alter them to suit your local needs. Changes to these files affect only new accounts, not existing accounts. If you want to make a change that affects both existing and new users, you should edit a global configuration file instead.

Just as shells have startup scripts, they may also have logout scripts—scripts that run when the user logs out. For bash, this script is ~/.bash\_logout. Most distributions don’t create this script as part of users’ default home directories, but individual users can do so. The logout script might execute programs to clean up temporary directories, remove security keys from memory, or perform other tasks that are appropriate when a user logs out.



One problem with logout scripts is that they may not work well when users log in multiple times. If you regularly have multiple sessions open, such as logins in multiple Linux virtual terminals, be careful about what you do in a logout script lest you wipe out important temporary files when you log out of just one session.

Another bash configuration file is ~/.inputrc, which helps customize your keyboard configuration. It consists of lines that look like this:

```
M-Control-u: universal-argument
```

This line maps the Meta-Ctrl-U keystroke to the universal-argument action. The Meta key is usually the Esc key on x86 systems, and the universal-argument action is one of



many possible actions defined by the readline library, which is one of the basic text-mode input libraries used by Linux.

In most cases, there's no need to adjust the `~/ .inputrc` file, because the default readline mappings work well for x86 systems with standard keyboards. If you find that certain key-strokes don't work the way they should in text mode, though, you may want to research this configuration file further.



X uses its own keyboard input routines, so `~/ .inputrc` doesn't affect programs run in X, even text-mode programs run inside xterm windows.

## Writing Scripts

You'll do much of your work on a Linux system by typing commands at a shell prompt. As you use Linux, though, you're likely to find some of these tasks to be repetitive. If you need to add 100 new users to the system, for instance, typing `useradd 100` times can be tedious. Fortunately, Linux includes a way to cut through the tedium: *shell scripts*. These are simple programs written in an interpreted computer language that's embedded in the Linux shell you use to type commands.

Most Linux systems use the `bash` shell by default, so shell scripts are often written in the `bash` shell scripting language; but `tcsh` and other shell scripting languages are similar. In fact, it's not uncommon to see shell scripts that run in any common Linux shell. You're not restricted to running shell scripts written in your default shell, however; the first line of a shell script identifies the shell that should be used to run it.



Many Linux startup scripts, including SysV startup scripts, are in fact shell scripts. Therefore, understanding shell scripting is necessary if you want to modify a Linux startup script.



Like any programming task, shell scripting can be quite complex. Consequently, this chapter barely scratches the surface of what can be accomplished through shell scripting. Consult a book on the topic, such as Cameron Newham's *Learning the Bash Shell, 3rd Edition* (O'Reilly, 2005) or Richard Blum's *Linux Command Line and Shell Scripting Bible* (Wiley, 2008), for more information.

To use a shell script, you must first know how to start one. Once you start one, you'll find that one of the easiest tasks to do is to call external commands. More advanced tasks include using variables and using conditional expressions.

## Beginning a Shell Script

Shell scripts are plain-text files, so you create them in text editors. A shell script begins with a line that identifies the shell that's used to run it, such as the following:

```
#!/bin/sh
```

The first two characters are a special code that tells the Linux kernel that this is a script and to use the rest of the line as a pathname to the program that's to interpret the script. (This line is sometimes called the *shebang*, *hashbang*, *hashpling*, or *pound bang* line.) Shell scripting languages use a hash mark (#) as a comment character, so the script utility ignores this line, although the kernel doesn't. On most systems, `/bin/sh` is a symbolic link that points to `/bin/bash`, but it can point to some other shell. Specifying the script as using `/bin/sh` guarantees that any Linux system will have a shell program to run the script; but if the script uses any features specific to a particular shell, you should specify that shell instead—for instance, use `/bin/bash` or `/bin/tcsh` instead of `/bin/sh`.

When you're done writing the shell script, you should modify it so that it's executable. You do this with the `chmod` command, as described in Chapter 4, "Managing Files." Specifically, you use the `+x` option to add execute permissions, probably in conjunction with `a` to add these permissions for all users. For instance, to make a file called `my-script` executable, you should issue the following command:

```
$ chmod a+x my-script
```

You'll then be able to execute the script by typing its name, possibly preceded by `./` to tell Linux to run the script in the current directory rather than searching the current path. If you fail to make the script executable, you can still run the script by running the shell program followed by the script name (as in `bash my-script`), but it's generally better to make the script executable. If the script is one you run regularly, you may want to move it to a location on your path, such as `/usr/local/bin`. When you do that, you won't have to type the complete path or move to the script's directory to execute it; you can just type `my-script`.



It's possible to set a script's SUID or SGID bits. (See Chapter 4 for information about the SUID and SGID bits.) Doing so is potentially dangerous, particularly if the script is owned by root, for reasons described in Chapter 4. You should therefore be very cautious about applying the SUID bit to scripts.

## Using Commands

One of the most basic features of shell scripts is the ability to run commands. You can use both shell internal commands and external commands. Most of the commands you type in a shell prompt are external commands—they're programs located in `/bin`, `/usr/bin`, and other directories on your path. You can run such programs, as well as internal commands,

by including their names in the script. You can also specify parameters to such programs in a script. For instance, suppose you want a script that launches two `xterm` windows and the KMail mail reader program. Listing 9.1 presents a shell script that accomplishes this goal.

**Listing 9.1:** A Simple Script That Launches Three Programs

```
#!/bin/bash
/usr/bin/xterm &
/usr/bin/xterm &
/usr/bin/kmail &
```

Aside from the first line that identifies it as a script, the script looks just like the commands you might type to accomplish the task manually, except for one fact: The script lists the complete paths to each program. This is usually not strictly necessary, but listing the complete path ensures that the script will find the programs even if the `PATH` environment variable changes. On the other hand, if the program files move (say, because you upgrade the package from which they're installed and the packager decides to move them), scripts that use complete paths will break.

Each program-launch line in Listing 9.1 ends in an ampersand (&). This character tells the shell to go on to the next line without waiting for the first to finish. If you omit the ampersands in Listing 9.1, the effect will be that the first `xterm` will open but the second won't open until the first is closed. Likewise, KMail won't start until the second `xterm` terminates.

Although launching several programs from one script can save time in startup scripts and some other situations, scripts are also frequently used to run a series of programs that manipulate data in some way. Such scripts typically do *not* include the ampersands at the ends of the commands because one command must run after another or may even rely on output from the first. A comprehensive list of such commands is impossible because you can run any program you can install in Linux as a command in a script—even another script. A few commands that are commonly used in scripts include the following:

**Normal file manipulation commands** The file manipulation commands, such as `ls`, `mv`, `cp`, and `rm`, are often used in scripts. You can use these commands to help automate repetitive file maintenance tasks.

**grep** This command is described in Chapter 1. It locates files that contain specific strings.

**find** Where `grep` searches for patterns within the contents of files, `find` does so based on filenames, ownership, and similar characteristics. This command is described in Chapter 4.

**cut** This command extracts text from fields in a file. It's frequently used to extract variable information from a file whose contents are highly patterned. To use it, you pass it one or more options that specify what information you want, followed by one or more filenames. For instance, users' home directories appear in the sixth colon-delimited field of the `/etc/passwd` file. You can therefore type `cut -f 6 -d ":" /etc/passwd` to extract this information. The same command in a script will extract this information, which you'll probably save to a variable or pass to a subsequent command.

**sed** This program is described in Chapter 1. It provides many of the capabilities of a conventional text editor but via commands that can be typed at a command prompt or entered in a script.

**echo** Sometimes a script must provide a message to the user; `echo` is the tool to accomplish this goal. You can pass various options to `echo` or just a string to be shown to the user. For instance, `echo "Press the Enter key"` causes a script to display the specified string.

**mail** The `mail` command can be used to send e-mail from within a script. Pass it the `-s` *subject* parameter to specify a subject line, and give it an e-mail address as the last argument. If used at the command line, you then type a message and terminate it with a Ctrl+D keystroke. If used from a script, you might omit the subject entirely, pass it an external file as the message using input redirection, or use a here document to pass text to the `mail` command as input. (Chapter 1 describes input redirection and here documents.) You might want to use this command to send mail to the superuser about the actions of a startup script or a script that runs on an automated basis. This command is described in more detail later in this chapter.



---

Many of these commands are extremely complex, and completely describing them is beyond the scope of this chapter. You can consult these commands' man pages for more information. A few of them are described elsewhere in this book.

Even if you have a full grasp of how to use some key external commands, simply executing commands you might when typing them at a command prompt is of limited utility. Many administrative tasks require you to modify what you type at a command, or even what commands you enter, depending on information from other commands. For this reason, scripting languages include additional features to help you make your scripts useful.

## Using Variables

*Variables* can help you expand the utility of scripts. A variable is a placeholder in a script for a value that will be determined when the script runs. Variables' values can be passed as parameters to scripts, generated internally to the scripts, or extracted from the script's environment.

Variables that are passed to the script are frequently called *parameters*. They're represented by a dollar sign (\$) followed by a number from 0 to 9—\$0 stands for the name of the script, \$1 is the first parameter to the script, \$2 is the second parameter, and so on. To understand how this might be useful, consider the task of adding a user. As described in Chapter 7, "Administering the System," creating an account for a new user typically involves running at least two commands—`useradd` and `passwd`. You may also need to run additional site-specific commands, such as commands that create unusual user-owned directories aside from the user's home directory.



The shift command shifts the parameter variables, so that what would ordinarily be \$2 becomes \$1, what would be \$3 becomes \$2, and so on. Adding a number, as in `shift 3`, shifts the assignments by that number of units. The `shift` command does not alter the \$0 variable, though.

As an example of how a script with a parameter variable can help in such situations, consider Listing 9.2. This script creates an account and changes the account's password (you'll be prompted to enter the password when you run the script). It creates a directory in the `/shared` directory tree corresponding to the account, and it sets a symbolic link to that directory from the new user's home directory. It also adjusts ownership and permissions in a way that may be useful, depending on your system's ownership and permissions policies.

**Listing 9.2:** A Script That Reduces Account-Creation Tedium

```
#!/bin/sh
useradd -m $1
passwd $1
mkdir -p /shared/$1
chown $1.users /shared/$1
chmod 775 /shared/$1
ln -s /shared/$1 /home/$1/shared
chown $1.users /home/$1/shared
```

If you use Listing 9.2, you need type only three things: the script name with the desired username and the password (twice). For instance, if the script is called `mkuser`, you can use it like this:

```
mkuser ajones
Changing password for user ajones
New password:
Retype new password:
passwd: all authentication tokens updated successfully
```

Most of the scripts' programs operate silently unless they encounter problems, so the interaction (including typing the passwords, which don't echo to the screen) is a result of just the `passwd` command. In effect, Listing 9.2's script replaces seven lines of commands with one. Every one of those lines uses the username, so by running this script, you also reduce the chance of a typo causing problems.

Another type of variable is assigned within scripts—for instance, such variables can be set from the output of a command. These variables are also identified by leading dollar signs, but they're typically given names that at least begin with a letter, such as `$Addr` or `$Name`. (When values are assigned to variables, the dollar sign is omitted, as illustrated shortly.) You can then use these variables in conjunction with normal commands as if they were command parameters, but the value of the variable is passed to the command.

For instance, consider Listing 9.3, which checks to see if the computer's router is up with the help of the `ping` utility. This script uses two variables. The first is `$ip`, which is extracted from the output of `route` using the `grep`, `tr`, and `cut` commands. (These commands are described in Chapter 1.) When you're assigning a value to a variable from the output of a command, that command should be enclosed in back-quote characters (```), which appear on the same key as the tilde (`~`) on most keyboards. These are *not* ordinary single quotes, which appear on the same key as the regular quote character (`"`) on most keyboards. The second variable, `$ping`, simply points to the `ping` program. It can as easily be omitted, with subsequent uses of `$ping` replaced by the full path to the program or simply by `ping` (relying on the `$PATH` environment variable to find the program). Variables like this are sometimes used to make it easier to modify the script in the future. For instance, if you move the `ping` program, you need only modify one line of the script. They can also be used in conjunction with conditionals to ensure that the script works on more systems—for instance, if `ping` were called something else on some systems.

**Listing 9.3:** Script Demonstrating Assignment and Use of Variables

```
#!/bin/sh
ip=`route -n | grep UG | tr -s " " | cut -f 2 -d " "`
ping="/bin/ping"
echo "Checking to see if $ip is up..."
$ping -c 5 $ip
```

In practice, you use Listing 9.3 by typing the script's name. The result should be the message `Checking to see if 192.168.1.1 is up` (with `192.168.1.1` replaced by the computer's default gateway system) and the output from the `ping` command, which should attempt to send five packets to the router. If the router is up and is configured to respond to pings, you'll see five return packets and summary information. If the router is down, you'll see error messages to the effect that the host was unreachable.



Listing 9.3 is of limited practical use and contains bugs. For instance, the script identifies the computer's gateway merely by the presence of the string `UG` in the router's output line from `route`. If a computer has two routers defined, this won't work correctly, and the result is likely to be a script that misbehaves. Listing 9.3 does demonstrate how variables can be assigned, though.

Scripts like Listing 9.3, which obtain information from running one or more commands, are useful in configuring features that rely on system-specific information or information that varies with time. You can use a similar approach to obtain the current hostname (using the `hostname` command), the current time (using `date`), the total time the computer's been running (using `uptime`), free disk space (using `df`), and so on. When combined with conditional expressions (described shortly), variables become even more powerful because then your script can perform one action when one condition is met and another in some other

case. For instance, a script that installs software can check free disk space and abort the installation if insufficient disk space is available.

In addition to assigning variables with the assignment operator (=), you can read variables from standard input using `read`, as in `read response` to read input for subsequent access as `$response`. This method of variable assignment is useful for scripts that must interact with users. For instance, instead of reading the username from the command line, Listing 9.2 may be modified to prompt the user for the username. Listing 9.4 shows the result. To use this script, you type its name *without* typing a username on the command line. The script will then prompt for a username, and after you enter one, the script will attempt to create an account with that name.

**Listing 9.4:** Modified Version of Listing 9.2 That Employs User Interaction

```
#!/bin/sh
echo -n "Enter a username: "
read name
useradd -m $name
passwd $name
mkdir -p /shared/$name
chown $name.users /shared/$name
chmod 775 /shared/$name
ln -s /shared/$name /home/$name/shared
chown $name.users /home/$name/shared
```

One special type of variable was mentioned earlier in this chapter: environment variables, described in “Managing the Shell Environment.” Environment variables are assigned and accessed just like shell script variables. The difference is that the script or command that sets an environment variable uses the `export` command (in `bash`) to make the value of the variable accessible to programs launched from the shell or shell script that made the assignment. In other words, you can set an environment variable in one script and use it in another script that the first script launches. Environment variables are most often set in shell startup scripts, but the scripts you use can access them. For instance, if your script calls `X` programs, it might check for the presence of a valid `$DISPLAY` environment variable and abort if it finds that this variable isn’t set. By convention, environment variable names are all uppercase, whereas non-environment shell script variables are all lowercase or mixed case.

## Using Conditional Expressions

Scripting languages support several types of *conditional expressions*. These enable a script to perform one of several actions contingent on some condition—typically the value of a variable. One common command that uses conditional expressions is `if`, which allows the system to take one of two actions depending on whether some condition is true. The `if` keyword’s conditional expression appears in brackets after the `if` keyword and can take many forms. For instance, `-f file` is true if `file` exists and is a regular file; `-s file` is true if `file`

exists and has a size greater than 0; and *string1* == *string2* is true if the two strings have the same values.

Conditionals may be combined together with the logical and (&&) or logical or (||) operators. When conditionals are combined with &&, both sides of the operator must be true for the condition as a whole to be true. When || is used, if either side of the operator is true, the condition as a whole is true.

To better understand the use of conditionals, consider the following code fragment:

```
if [-s /tmp/tempstuff]
then
 echo "/tmp/tempstuff found; aborting!"
 exit
fi
```

This fragment causes the script to exit if the file /tmp/tempstuff is present and is larger than 0 bytes. The then keyword marks the beginning of a series of lines that execute only if the conditional is true, and fi (if backward) marks the end of the if block. Such code may be useful if the script creates and then later deletes this file, because its presence indicates that a previous run of the script didn't succeed or is still underway.

An alternative form for a conditional expression uses the test keyword rather than square brackets around the conditional:

```
if test -s /tmp/tempstuff
```

You can also test a command's return value by using the command as the condition:

```
if [command]
then
 additional-commands
fi
```

In this example, the *additional-commands* will be run only if *command* completes successfully. If *command* returns an error code, the *additional-commands* won't be run.

Conditional expressions may be expanded by use of the else clause:

```
if [conditional-expression]
then
 commands
else
 other-commands
fi
```

Code of this form causes either *commands* or *other-commands* to execute, depending on the evaluation of *conditional-expression*. This is useful if *something* should happen in a part of the program, but precisely what should happen depends on some condition. For instance, you may want to launch one of two different file archiving programs depending on a user's input.



What do you do if more than two outcomes are possible—for instance, if a user may provide any one of four possible inputs? You can nest several `if/then/else` clauses, but this gets awkward very quickly. A cleaner approach is to use `case`:

```
case word in
 pattern1) command(s) ;;
 pattern2) command(s) ;;
 ...
esac
```

For a `case` statement, a *word* is likely to be a variable, and each *pattern* is a possible value of that variable. The patterns can be expanded much like filenames, using the same wildcards and expansion rules (`*` to stand for any string, for instance). You can match an arbitrary number of patterns in this way. Each set of commands must end with a double semicolon (`;;`), and the case statement as a whole ends in the string `esac` (case backward).

Upon execution, `bash` executes the commands associated with the first pattern to match the *word*. Execution then jumps to the line following the `esac` statement; any intervening commands don't execute. If no patterns match the word, no code within the `case` statement executes. If you want to have a default condition, use `*` as the final *pattern*; this pattern matches any *word*, so its commands will execute if no other *pattern* matches.

## Using Loops

Conditional expressions are sometimes used in *loops*. Loops are structures that tell the script to perform the same task repeatedly until some condition is met (or until some condition is no longer met). For instance, Listing 9.5 shows a loop that plays all the `.wav` audio files in a directory.

**Listing 9.5:** A Script That Executes a Command on Every Matching File in a Directory

```
#!/bin/bash
for d in `ls *.wav` ; do
 aplay $d
done
```



The `aplay` command is a basic audio file player that works with the Advanced Linux Sound Architecture (ALSA) audio drivers. On some systems, you may need to use `play` or some other command instead of `aplay`.

The `for` loop as used here executes once for every item in the list generated by `ls *.wav`. Each of those items (filenames) is assigned in turn to the `$d` variable and so is passed to the `aplay` command.

The `seq` command can be useful in creating `for` loops (and in other ways, too): This command generates a list of numbers starting from its first argument and continuing to its last one. For instance, typing `seq 1 10` generates 10 lines, each with a number between

1 and 10. You can use a `for` loop beginning `for x in `seq 1 10`` to have the loop execute 10 times, with the value of `x` incrementing with each iteration. If you pass just one parameter to `seq`, it interprets that number as an ending point, with the starting point being 1. If you pass three values to `seq`, it interprets them as a starting value, an increment amount, and an ending value.

Another type of loop is the `while` loop, which executes for as long as its condition is true. The basic form of this loop type is like this:

```
while [condition]
do
 commands
done
```

The `until` loop is similar in form, but it continues execution for as long as its condition is *false*—that is, until the condition becomes true.

## Using Functions

A *function* is a part of a script that performs a specific sub-task and that can be called by name from other parts of the script. Functions are defined by placing parentheses after the function name and enclosing the lines that make up the function within curly braces:

```
myfn() {
 commands
}
```

The keyword `function` may optionally precede the function name. In either event, the function is called by name as if it were an ordinary internal or external command.

Functions are very useful in helping to create modular scripts. For instance, if your script needs to perform half a dozen distinct computations, you may place each computation in a function and then call them all in sequence. Listing 9.6 demonstrates the use of functions in a simple program that copies a file but aborts with an error message if the target file already exists. This script accepts a target and a destination filename and must pass those filenames to the functions.

### Listing 9.6: A Script Demonstrating the Use of Functions

```
#!/bin/bash

doit() {
 cp $1 $2
}

function check() {
```

```

if [-s $2]
then
 echo "Target file exists! Exiting!"
 exit
fi
}

check $1 $2
doit $1 $2

```

If you enter Listing 9.6 and call it `safercp`, you can use it like this, assuming the file `original.txt` exists and `dest.txt` doesn't:

```

$./safercp original.txt dest.txt
$./safercp original.txt dest.txt
Target file exists! Exiting!

```

The first run of the command succeeded because `dest.txt` didn't exist. When the command was run a second time, though, the destination file did exist, so the program terminated with the error message.

Note that the functions aren't run directly and in the order in which they appear in the script. They're run only when called in the main body of the script (which in Listing 9.6 consists of just two lines, each corresponding to one function call).

Shell scripts are useful tools, and creating them effectively requires practice. Exercise 9.2 begins your exploration of shell scripts, but in the long run, you'll need to learn to design your own shell scripts by doing more than copying examples from a book.

## EXERCISE 9.2

### Creating a Simple Script

This exercise presents a shell script that gives you the option of reading every text file (with a name ending in `.txt`) in the current directory with `less`. To begin with this script, follow these steps:

1. Log into the Linux system as a normal user.
2. Launch an `xterm` from the desktop environment's menu system, if you used a GUI login method.
3. Start an editor, and tell it to edit a file called `testscript`.
4. Type the following lines into the editor:

```

#!/bin/bash
for file in `ls *.txt` ; do
 echo -n "Display $file? "

```

**EXERCISE 9.2 (continued)**

```
read answer
if [$answer == 'y']
then
 less $file
fi
done
```

Be sure you've typed every character correctly; any mistake may cause the script to misbehave. One common error is mistyping the back-tick characters ( ` ) as ordinary single quote characters ( ' ).

5. Save the file, and exit the editor.
6. Type **chmod a+x testscript** to add the executable bit to the file's permissions.
7. Type **./testscript** to run the script. If there are no text (\*.txt) files in your current directory, the script displays a no such file or directory error message; but if any text files are present, the script gives you the option of viewing each one in turn via **less**.

This example script is extremely limited, but it illustrates several important script features, such as variable assignment and use, for loops, and if/then conditional expressions.

---

## Managing E-mail

E-mail is one of the most important network services. What's more, Linux relies on e-mail even in a completely non-networked environment—certain Linux subsystems, such as *cron* (described in Chapter 7), may use e-mail to notify you of activities. For this reason, most Linux distributions ship with e-mail server software installed and configured for basic activities, and you should have a basic understanding of how to use these servers to accomplish various tasks. You should understand the basics of e-mail and be able to identify the specific e-mail server package your system is running. You should also be able to set up e-mail aliases (alternate names for users) and forwarding (to send mail for a user to another destination). Finally, you should understand the security implications of e-mail so that you can prevent problems or identify them when they occur.

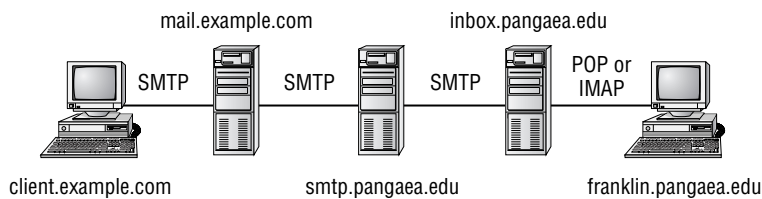
### Understanding E-mail

Several protocols exist to manage e-mail. The most common of these is the *Simple Mail Transfer Protocol* (SMTP), which is designed as a push mail protocol, meaning that the sending system initiates the transfer. This design is good for sending data, so SMTP is used

through most of a mail delivery system. The final stage, though, often employs a pull mail protocol, such as the Post Office Protocol (POP) or the Internet Message Access Protocol (IMAP). With these protocols, the receiving system initiates the transfer. This is useful when the receiving system is an end user's workstation, which may not be powered on at all times or able to receive incoming connections.

SMTP was designed to enable a message to be relayed through an arbitrary number of computers. For instance, an end user may compose a message, which is sent to the local SMTP server. (SMTP servers are also known as mail transfer agents, or MTAs.) This server looks up a recipient system using the Domain Name System (DNS) and sends the message to that system. This system may use its own internal routing table to redirect the message to another local system, from which the message may be read, either directly or via a POP or IMAP server. This arrangement is illustrated in Figure 9.1. Bear in mind that the number of links in this chain is variable and depends on how each system is configured. In the simplest case, local e-mail stays on just one system. In theory, an arbitrarily large number of computers can be involved in an e-mail exchange, although in practice it's rare to see e-mail pass through more than half a dozen systems.

**FIGURE 9.1** E-mail typically traverses several links between sender and recipient.



At each step in a relay chain, e-mail is altered. Most important, each server adds a *header* to the e-mail, which is a line that provides information about the message. In particular, mail servers add Received: headers to document the path the mail has taken. In theory, this enables you to trace the e-mail back to its source. Unfortunately, spammers and other e-mail abusers have learned to forge e-mail headers, which greatly complicates such analysis.

Because an SMTP server can function as both a server (receiving mail from other systems) and a client (sending mail to other systems), you must deal with both sides of the configuration equation. For the most part, this chapter and the LPI Level 1 exam don't cover all these details, though, just a few of them. Sometimes a system never functions in one role or the other, which can simplify matters—but you must then be careful not to accidentally configure the system incorrectly. In particular, *open relay* configurations, in which a mail server relays mail from anybody, should be avoided. This and other security implications of running an SMTP server are covered in “Securing Your E-Mail Server.”

On Linux, e-mail is tied intricately to user accounts. The mail server holds incoming messages for each user, typically in a file in `/var/spool/mail`—for instance, `/var/spool/mail/benf` holds mail for the user `benf`. Some e-mail servers store incoming mail in sub-directories of the users' home directories, though. This incoming mail file or directory is referred to as the user's *mail spool*.



You may recall that the `userdel` command, described in Chapter 7, includes options related to the handling of users' mail spools. If you delete a user account but leave the user's mail spool intact, the mail can still be accessed. If the mail server software stores mail in `/var/spool/mail`, leftover mail spools can cause problems if you eventually re-use an old username.

E-mail can be sent as well as received. The traditional Linux approach to sending e-mail is to have local programs contact the local mail server to send e-mail. The local mail server then contacts its outgoing e-mail server, as in Figure 9.1. Most Linux e-mail clients (a.k.a. mail user agents, or MUAs), as well as similar programs on other platforms, provide the option to directly contact a remote SMTP server when sending e-mail. Such a configuration slightly simplifies the e-mail path but can make operation unreliable if the local network link goes down. If your e-mail client talks to an SMTP server that runs locally, the e-mail can be queued for delivery by the SMTP server even if the network is temporarily down.

## Choosing E-mail Software

Linux supports quite a few e-mail servers. Chances are, one of the major servers will be installed on your system by default. If not, and if you want to install one, you'll have to pick one. You may also want to change your e-mail server if you need to configure it in advanced ways; some servers are easier to configure than others or support specific options that others don't. Four e-mail servers are most popular on Linux:

**Sendmail** The `sendmail` program (<http://www.sendmail.org>) was for many years the dominant e-mail server package on the Internet. In recent years it's lost some of its dominance to the other servers described here, as well as to Windows e-mail servers. Nonetheless, `sendmail` remains a popular server. It's very powerful, but it's also difficult to configure because its configuration file formats are rather arcane.

**Postfix** `Postfix` (<http://www.postfix.org>) was designed as a modular replacement for `sendmail`—rather than a single program that does everything (as `sendmail` is designed), `Postfix` uses multiple programs, each of which handles its own specific small task. This design improves security, at least in theory. `Postfix` tends to be easier to configure than `sendmail`, and it's become the default e-mail server on many Linux distributions.

**Exim** Although `Exim` (<http://www.exim.org>) is a monolithic server, like `sendmail`, it has a much simpler configuration file format and so is easier to configure. A few Linux distributions use `Exim` as the default e-mail server.

**qmail** The fourth major Linux e-mail server, `qmail` (<http://www.qmail.org>), is a modular server with security as a major design goal. Like `Postfix` and `Exim`, `qmail` is easier to configure than `sendmail`. It's not the standard e-mail server in any Linux distribution because its license is a bit strange and complicates `qmail` distribution with Linux; however, many system administrators like `qmail` enough that they replace their distributions' standard e-mail servers with `qmail`.

You can learn which e-mail server your Linux distribution runs in several ways. The two most reliable are to use `ps` (described in Chapter 2, “Managing Software”) to look for running processes, or to use your package management tools (also described in Chapter 2) to see which package is installed. In either case, you may need to check for each of the programs in turn. For instance, you might see results like these:

```
$ ps ax |grep send
31129 pts/2 R+ 0:00 grep send
$ ps ax | grep post
 7778 ? Ss 0:45 /usr/lib/postfix/master
31132 pts/2 S+ 0:00 grep post
```

The search for a process containing the string *send* failed, but the search for *post* returned a process called `/usr/lib/postfix/master`—thus, it appears that Postfix is running on this system.

You can also look for executable filenames for each e-mail server in `/usr/bin` or `/usr/sbin`; but be aware that most Linux e-mail servers include a program called `sendmail`. This is done for compatibility reasons; because the original `sendmail` program was once ubiquitous, providing a compatible interface for scripts and administrators helps other SMTP servers work.

In addition to the SMTP server, a fully functional Linux e-mail system is likely to include other software:

**Pull mail servers** Two pull mail protocols, POP and IMAP, are popular. If a Linux system should function as a mail server from which users can read their e-mail remotely, chances are you’ll install a POP or an IMAP server package, such as Cyrus IMAP (<http://cyrusimap1.andrew.cmu.edu/imapd/>) or Dovecot (<http://www.dovecot.org>).

**Fetchmail** This program, based at <http://fetchmail.berlios.de>, fills an odd gap in the e-mail delivery chain. If you run a small site that relies on an external ISP for e-mail delivery, chances are the ISP supports only POP or IMAP. If you want to use a variety of e-mail clients, you may want to run your own SMTP server, and perhaps your own POP or IMAP server, to deliver mail locally. To do this, you need a program that pulls mail using POP or IMAP and then injects it into a local SMTP mail queue. This is the job of Fetchmail. Most sites don’t need it, but for those that do, it’s indispensable.

**Mail readers** The final link in the e-mail chain is the mail reader. Examples in Linux include Evolution (<http://www.gnome.org/projects/evolution/>), KMail (<http://kontakt.kde.org/kmail/>), pine (<http://www.washington.edu/pine/>), and mutt (<http://www.mutt.org>). The `mail` utility, which is installed on most Linux systems by default, is the lowest-common-denominator e-mail utility. It’s described shortly, in “Sending and Receiving E-mail.” Most Linux e-mail clients enable reading either from a local mail queue or from a remote POP or IMAP mail server. A multi-user system is likely to have multiple e-mail clients installed, enabling each user to choose which client to use.

Neither this book nor the LPI Level 1 exam covers pull mail servers, Fetchmail, or mail readers in any detail. As a practical matter, you may need to learn how to configure any or

all of these packages, depending on your site's needs. Fortunately, mail reader configuration, which is the most common task, is usually fairly straightforward, as long as you have information on the hostnames of your outgoing (SMTP) and incoming (POP, IMAP, or local queue) e-mail servers.

## Managing E-mail

Although setting up an e-mail server for a site is beyond the scope of this book and the LPI Level 1 exam, managing a few common e-mail server administrative tasks is not. I therefore describe some common administrative tasks involving sending and receiving mail using the `mail` utility, e-mail queue management, configuring aliases, and forwarding e-mail.

### Sending and Receiving E-mail

Linux supports a wide variety of e-mail clients, some of which were mentioned earlier, in “Choosing E-mail Software.” Chances are, you'll use a full-fledged e-mail client for your personal e-mail; however, you should also know how to use the `mail` program. This tool is a very basic command-line e-mail utility. It has the advantage of being usable from a script, so you can write a script to automatically handle some e-mail tasks, and perhaps even run that script automatically. For instance, you might write a script to check for user passwords that are about to expire and then e-mail the users about this impending event so that they can change their passwords before their accounts are locked.



Some Linux systems ship with a program called `mail` rather than `mail`. The `mail` program supports additional features compared to the original `mail`, such as the ability to add attachments; but the two programs are very similar in basic operation. Typically, a link with the name `mail` points to `mail`, so you can call `mail` as `mail`.

The `mail` program is intended to be used on the command line to send or receive messages. The basic syntax for `mail`, including its most useful options, is as follows:

```
mail [-v] [-s subject] [-c cc-addr] [-b bcc-addr] to-addr
mail [-v] [-f [name] | -u user]
```

The first of these syntax lines is used for sending e-mail; the second is used for reading e-mail. (Unlike most e-mail readers, `mail` only supports reading the local e-mail queue, not e-mail stored on remote servers and read via POP or IMAP.) You can achieve various goals with the options to `mail`:

**Use verbose operation** As with many commands, the `-v` option produces more verbose output. This may be helpful if you need to debug problems.

**Specify a subject line** The `-s subject` option enables you to specify a subject line.



**Set a carbon copy address** You can send a message to multiple people by sending a *carbon copy* using the `-c cc-addr` or `-b bcc-addr` options. These options vary in that the `-b` option produces a “blind” carbon copy, meaning that the recipient’s address doesn’t appear in the address list. This is useful if you want to discreetly send a copy of an e-mail to somebody, but some spam filters may delete such e-mails.

**Set the recipient’s address** The main recipient’s e-mail address terminates the `mail` command’s line for an outgoing e-mail.

**Read e-mail** To read your e-mail, pass the `-f` option to the program, optionally followed by the name of the mail spool file. Alternatively, you can use the `-u user` option to read the mail of the specified user.

This list of options is incomplete, but it includes the most important features. You should consult the man page for `mail` to learn about more exotic options. Remember that some systems use `mail` whereas others use `mail`, and available options differ for these two programs. The preceding options have the same effect for both programs; but some options, such as `-a`, have different meanings for the two programs. (The `-a` option enables you to insert an arbitrary e-mail header in the original `mail`, but in `mail` it’s how you attach a file to an outgoing message.)

As an example of `mail` in action, consider the task of sending a quick e-mail message. Suppose you want to send an e-mail to two recipients informing them of a meeting. You can do so as follows:

```
$ mail -s "Meeting reminder" -c benf@example.com sallyg@example.com
```

**Remember the meeting at 4:00 today!**

Cc: benf@example.com

After you type the `mail` command, the program waits for input via standard input, but there’s no prompt. You signal the end of the message by pressing `Ctrl+D`. This example shows a simple one-line message. After you press `Ctrl+D`, the program displays the `Cc:` line to verify this option. You can still change the address at this point, but if you don’t want to, you can press the `Enter` key and the message will be on its way.

To use `mail` in a script, you can use input redirection to pass it the contents of a file to be mailed:

```
mail -s "Automated alert!" < /tmp/alert.txt benf@example.com
```

This line, if included in a script, sends the contents of `/tmp/alert.txt` to `benf@example.com` with the specified subject.

You can use `mail` to read incoming e-mail, too, but only if it’s stored on a local Linux mail spool. In this case, you’ll normally use `mail` interactively. Type `mail`, and you’ll see the contents of your mail spool. Each message has a summary line that lists the sender, date, and subject, among other things:

```
0046 sally@luna.edu Sun Aug 17 18:27 116/4262 Priorities
```

This is message number 46; it's from `sally@luna.edu`; it arrived on August 17 at 18:27 (6:27 p.m.); it has 116 lines and 4262 bytes (including headers); and its subject is `Priorities`. To read a message, type its number. You can then delete the message by typing `d` or reply to it by typing `r`.

As a practical matter, most people prefer to use more sophisticated mail readers for their day-to-day mail reading. You'll probably find `mail` more useful for the scripted sending of e-mail than for reading e-mail or sending personal e-mail.

## Checking the E-mail Queue

An e-mail server manages a queue of e-mail messages that it must deliver. This queue is similar in some respects to the queue of print jobs that the Linux printing system handles, as described in Chapter 6. Instead of sending jobs to a printer, though, the e-mail server sends e-mail messages to another computer or stores them in local users' mail spools. This task may sound simple, but it can be surprisingly complex. The server may be asked to deliver many messages in a very short period of time, and thus it may need to delay delivery of some messages while it works on others. Furthermore, any number of problems can lead to temporary or permanent inability to deliver messages. When a problem seems to be temporary, such as a network routing failure, the e-mail server must store the message and try to deliver it again later. Thus, a Linux computer's e-mail queue may contain undelivered messages. Knowing how to identify these messages and manage the queue can help you keep your Linux computer's e-mail subsystem working smoothly.

The `mailq` program is the main tool to help in e-mail queue management. This program was originally part of the `sendmail` package, but Postfix, Exim, `qmail`, and other Linux SMTP servers have all implemented compatible commands. Unfortunately, command options differ between implementations. The basic command, without any options, shows the contents of the e-mail queue on all systems:

```
$ mailq
-Queue ID- --Size-- ----Arrival Time---- -Sender/Recipient-----
5B42F963F* 440 Sat Aug 23 13:58:19 sally@example.com
 benf@luna.edu

-- 0 Kbytes in 1 Request.
```

This example, taken from a system running Postfix, shows one message in the queue, along with relevant identifying information. The exact display format varies from one SMTP server to another. In most cases, typing `mailq` is equivalent to typing `sendmail -bp`.

If your network connection goes down temporarily, or if an upstream e-mail server goes down for a while, e-mail messages can pile up in the queue. Your SMTP server will ordinarily attempt redelivery at a later date; but if your network connection has come up again and you want to clear the queue immediately, you can do so. Typing `sendmail -q` will do the job with most SMTP servers, and some have other equivalent commands, such as `postqueue` in Postfix or `runq` in Exim.

All e-mail servers offer a wide variety of advanced options to prioritize e-mail delivery, accept messages on the command line, delete specific messages from the queue, debug e-mail connections, and so on. Unfortunately, commands and procedures to use these features vary from one e-mail server to another. Thus, you should consult your server's documentation to learn how to use these features.

## Redirecting E-mail

E-mail *aliases* enable one address to stand in for another one. For instance, all e-mail servers are supposed to maintain an account called `postmaster`. E-mail to this account should be read by somebody who's responsible for maintaining the system. One way to do this is to set up an alias linking the `postmaster` name to the name of a real account. You can do this by editing the `aliases` file, which usually resides in `/etc` or sometimes in `/etc/mail`.

The `aliases` file format is fairly straightforward. Comment lines begin with hash marks (`#`), and other lines take the following form:

```
name: addr1[,addr2[,...]]
```

The *name* that leads the line is a local name, such as `postmaster`. Each address (*addr1*, *addr2*, and so on) can be a local account name to which the messages are forwarded, the name of a local file in which messages are stored (denoted by a leading slash), a command through which messages are piped (denoted by a leading vertical bar character), the name of a file whose contents are treated as a series of addresses (denoted by a leading `:include:` string), or a full e-mail address (such as `fred@example.com`).

A typical default configuration includes a few useful aliases for accounts such as `postmaster`. Most such configurations map most of these aliases to `root`. Reading mail as `root` is inadvisable, though—doing so increases the odds of a security breach or other problem because of a typo or bug in the mail reader. Thus, you may want to set up an alias line like the following:

```
root: yourusername
```

This redirects all of `root`'s mail, including mail directed to `root` via another alias, to *yourusername*, which can take any of the forms just described (it's most likely to be a local username or a valid remote e-mail address). Some mail servers, including `sendmail`, `Postfix`, and `qmail`, require you to compile `/etc/aliases` into a binary file that can be processed more quickly. To do so, use the `newaliases` command:

```
newaliases
```



Exim has a `newaliases` command for compatibility with `sendmail`, but it doesn't do anything, by default.

Another approach to redirecting mail is to do so on the user level. In particular, you can edit the `~/forward` file in a user's home directory to have mail for that user sent to another address. Specifically, the `~/forward` file should contain the new address—either a username on the current computer or an entire e-mail address on another computer. This approach has the advantage that it can be employed by individual users—say, to consolidate e-mail from multiple systems into one account without bothering system administrators. A drawback is that it can't be used to set up aliases for nonexistent accounts or for accounts that lack home directories. The `~/forward` file can also be changed or deleted by the account owner, which might not be desirable if you want to enforce a forwarding rule that the user shouldn't be able to override.

## Securing Your E-mail Server

Like any server, an e-mail server is a potential security risk. Broadly speaking, this risk takes two forms:

**Bugs** Bugs in the e-mail server can expose your system to danger. In theory, a bug might enable somebody to gain access to your system by sending an e-mail or by connecting to the SMTP port (25) via a Telnet client and typing SMTP commands to trigger the bug. For this reason, many Linux distributions today limit access to the e-mail server to the local computer only.

**Misconfiguration** Poor configuration of an e-mail server can cause problems. E-mail servers aren't designed to provide login access, so they aren't likely to be abusable to gain full login access. Instead, the big risk is a configuration that will make your system a menace to the Internet. The most common misconfiguration of this nature is an open relay, which is a computer that will relay mail from any computer to any other computer. In the past, spammers made heavy use of open relays as a way to help hide their true identities, but spammers today have largely moved on to other techniques. Nonetheless, some spammers still abuse open relays.

To guard against bugs, you should ensure that your e-mail server is upgraded to the latest version. Chapter 2 describes software management, so you should consult it for advice on keeping your system software up to date.

Major Linux distributions configure their e-mail servers so that they aren't open relays; however, a misconfiguration can open your e-mail server. Various Web sites provide tests for such misconfigurations. Check <http://www.abuse.net/relay.html> or <http://www.spamhelp.org/shopenrelay/> to test your system to verify that it's not an open relay. These sites, and others like them, run a series of tests, attempting to relay e-mail through your server. If your server is properly configured, the page will report that it was unable to connect or that it was unable to relay e-mail. If the testing site was able to relay e-mail, though, you'll need to learn more to properly configure your server. Unfortunately, the steps needed to secure an open relay vary from one e-mail server to another, and they require relatively advanced configuration, which is beyond the scope of this book or the LPI Level 1 exam. You can learn about closing open relay configurations in your e-mail server's documentation.

# Managing Data with SQL

The Structured Query Language (SQL), as its expanded name suggests, is a language used for retrieving data from a database. In practice, SQL is implemented in several different database products. Thus, you should know a little about the SQL products that are available for Linux. With a SQL package installed, you can begin learning about the principles of SQL use and move on to actual data storage and retrieval.

## Picking a SQL Package

SQL is a language for accessing data, and specific SQL packages implement that language. This distinction is similar to that between a network protocol (such as SMTP) and the servers that implement it (such as sendmail, Postfix, and Exim). In principle, you can use any SQL package to satisfy your SQL database needs. In practice, specific products that store data using SQL may work better with (or even require) particular packages. Some of the more common choices in Linux include the following:

**MySQL** Sun owns this SQL implementation, which it has released under the GPL. Most major Linux distributions include MySQL in their package databases. For a complete installation, you'll probably need to install multiple packages, such as a client, a server, and perhaps development tools. You can learn more at <http://www.sun.com/software/products/mysql/>.

**PostgreSQL** This SQL implementation evolved from the earlier Ingres software (the name *PostgreSQL* is a compressed form of *post-Ingres SQL*). It's available under the BSD license and is available as multiple packages in most Linux distributions. As with MySQL, you'll most likely have to install a client, a server, and perhaps additional support packages. PostgreSQL is headquartered at <http://www.postgresql.org>.

**SQLite** This package, based at <http://www.sqlite.org>, is a library that implements SQL. As such, it's not a standalone database; instead, it's intended as a way to provide programs with a way to store data using a SQL interface within the program. If you install a program that uses SQLite, your distribution's package manager should install the relevant libraries for you. If you want to write a program that requires database access and you don't want to install a complete client/server SQL package such as MySQL or PostgreSQL, SQLite may be just what you need.

There are literally dozens more SQL database products for Linux. For the purpose of learning SQL, MySQL or PostgreSQL should do fine, or you can use another full implementation if you prefer. If you have a specific purpose in mind for using SQL, though, you should research SQL packages in more detail. You may need a particular product for compatibility with other software, or you may need a SQL package that provides specific features.

As just noted, some SQL packages, including MySQL and PostgreSQL, operate on a client-server model: One program (the server) manages the database, while another (the client) provides users and programs with access to the database. Such implementations can work over a network, enabling users at multiple client systems to access a centralized database server.

## Understanding SQL Basics

SQL is a tool for accessing databases, and more specifically, *relational databases*. Figure 9.2 illustrates data in a relational database. Each row (sometimes known as a *tuple*) represents a single object or other item, and each column (sometimes referred to as an *attribute* or *field*) represents a specific feature. The combination of rows and columns is referred to as a *table*. Each database may contain multiple tables, and SQL supports multiple databases. Thus, to access data, you must first select a database and a table, as described in more detail shortly.

The data in a table are unordered, at least conceptually. (In practice, of course, data will be stored in some order on disk, but this order is arbitrary.) You can impose an order on query results, as described shortly; for instance, you may retrieve data from the database represented by Figure 9.2 and order the results according to cost (the final column).

**FIGURE 9.2** A relational database stores data in a table, with each row representing one object or item and each column representing specific attributes.

		attributes (columns)				
tuples (rows)		lizard	green	5 inches	soft	\$10
		tree	green	10 feet	medium	\$200
		pillow	white	18 inches	soft	\$5
		brick	red	8 inches	hard	\$1
		banana	yellow	8 inches	soft	\$0.10

A database enables retrieval of information that matches specific criteria. You can search for all the green objects in Figure 9.2, for instance. You can also insert, delete, and update information in a table. SQL supports multiple tables, so you can have, for instance, different tables for property in your office and for employees who work in your office.

Columns (attributes) in a database hold specific types of data, and swapping them around makes little sense. For instance, it's clear that the second column in Figure 9.2 is a color, whereas the final column is a price or value, expressed in dollars. It would make little sense to enter **green** as a value or **\$1.00** as a color. The restrictions placed on what may appear in a column are known as a *domain* or a *data type*: The domain for the second column is a set of color names, whereas the domain for the final column is a numeric value expressed in dollars. Table 9.3 summarizes some common SQL data types.

**TABLE 9.3** Common SQL Data Types

<b>Data Type Name</b>	<b>Purpose</b>
INTEGER (a.k.a. INT)	4-byte integer value
SMALLINT	2-byte integer value
DECIMAL	Precision storage of decimal values
NUMERIC	Precision storage of decimal values
FLOAT	Floating-point number
DOUBLE PRECISION	Floating-point number stored with twice the precision of FLOAT
DATETIME	A date and time
DATE	A date
TIME	A time, in <i>HH:MM:SS</i> format; may be a time of day or a period of time
CHAR	One or more characters
VARCHAR	A variable number of characters
ENUM	An enumerated list, such as one of <code>small</code> , <code>medium</code> , or <code>large</code>
SET	Data that may have zero or more values, as in any of the set of <code>nuts</code> , <code>sprinkles</code> , <code>fudge</code> , and <code>cherry</code> for ice cream toppings

Additional data types exist; Table 9.3 is intended to give you a feel for what's available and to list some of the data types you're likely to encounter. Some implementations support unique data types, too. Each of these data types has its own features. For instance, the numeric data types (INTEGER, DECIMAL, and so on) can be manipulated by mathematic operators.

## Using MySQL

To learn about SQL, you should have access to a SQL database. For purposes of demonstration, I'm using MySQL as a reference. Other SQL implementations are similar to what I describe here, but some details differ. One of these details is how to start the database. In the case of MySQL, your distribution should include a SysV or other startup script for the SQL server. This server may also need to be configured with its own root password. Debian and related distributions will prompt for this when you install the package, but you may need to set this manually with other distributions.

## Starting to Use MySQL

To begin a SQL session, you should first ensure that the server is running, as just described. You can then start the SQL client. In the case of MySQL, this program is called `mysql`:

```
$ mysql
```

If you've just installed MySQL for learning purposes, it may have no databases defined. To learn what's defined, you can use the `SHOW DATABASES` command:

```
mysql> SHOW DATABASES;
+-----+
| Database |
+-----+
| information_schema|
+-----+
1 row in set (0.00 sec)
```



This example illustrates an important feature of SQL: Commands are terminated by semicolons (;). There are a few exceptions to this rule, but if you forget the semicolon, you're likely to see a new prompt that reads `->` rather than `mysql>`, at least in MySQL. You can use this fact to split your commands across multiple lines, if you like. If you forget the semicolon that terminates a command, you can enter it by itself on the `->` prompt line. SQL commands are conventionally shown in uppercase, but SQL commands are case-insensitive, so you can type your commands in uppercase, lowercase, or any mixture of case you like.

In this example, one database is already defined: `information_schema`. Some installations define a database called `test`. If you see such a database, you can probably use it for your own tests; however, other users may be able to see and modify this database, so don't store important data in it. If you're not in charge of the SQL installation, you should double-check with whoever is in charge of it to be sure you can use the `test` database—or any other database, for that matter.

## Creating Databases and Tables

If no database for testing purposes exists, you can create one with the `CREATE DATABASE` command, which takes a database name as an option:

```
mysql> CREATE DATABASE test;
Query OK, 1 row affected (0.00 sec)
```





Although SQL commands are case-insensitive, database names are not. Thus, be sure to create the database name using whatever case you intend to use to refer to it in the future.

If you type **SHOW DATABASES;**, you'll see the `test` database in addition to any that already existed. Regardless of whether `test` (or some other testing database) existed when you first started MySQL or had to be created, you can begin using it with the `USE` command:

```
mysql> USE test;
```

Within each database, tables must be created and selected for use. The commands to do so are similar to the commands used to create and select databases. In a newly created database, no tables exist:

```
mysql> SHOW TABLES;
Empty set (0.00 sec)
```

The response `Empty set` denotes an empty database. To fill the database with data, you must first decide on a table structure—what sort of data you want to record. For instance, Figure 9.2 shows various attributes of common objects: their names, colors, sizes, hardnesses, and values in dollars. To create a table that includes columns for these five attributes, you use a `CREATE TABLE` command, passing it various details:

```
mysql> CREATE TABLE objects (name VARCHAR(30), color VARCHAR(20),
 -> size FLOAT, hardness ENUM('soft', 'medium', 'hard'),
 -> value DECIMAL(10,2));
Query OK, 0 rows affected (0.01 sec)
```

This example creates a table with five columns: `name`, `color`, `size`, `hardness`, and `value`. Each column has an associated data type, as described in Table 9.3. A few points worth noting about this table definition are as follows:

- The `name` and `color` columns are both `VARCHAR` examples, but with different sizes: The `name` may be up to 30 characters, whereas the `color` may be up to 20 characters. If these were defined as `CHARs`, each `name` would have to be precisely 30 characters in size, and each `color` precisely 20 characters. A limited set of colors can be specified by using an `ENUM` rather than a `VARCHAR`. Presumably you wouldn't want to limit object names this way.
- The `size` column is a `FLOAT`, which is less precise than an integer data type, but a `FLOAT` can hold real (non-integer) numbers. Figure 9.2 includes sizes in inches (including fractions of an inch) and feet, but in practice you'll need to convert everything to one unit—probably inches, in this case.

- Note the syntax for defining the ENUM: The list of values as a whole is enclosed in parentheses (C), and each enumerated value is enclosed in single quotes (') and separated from other values by a comma (,).
- The DECIMAL value includes a specification of the number of digits (10 in this example) and the number of digits after the decimal point (2 in this example), separated by a comma. Some implementations support a MONEY data type that can be used in this case, but MySQL lacks this data type, so DECIMAL is the best choice for the job. A DECIMAL type is better for currency than FLOAT because a FLOAT type is likely to introduce rounding errors due to the way numbers are encoded in a FLOAT value. Such errors are typically unacceptable in currency, although they may be tolerable in some applications.

If you need to create a table with other types of values, you should consult the documentation for your specific SQL implementation to see what data types it supports.

With the table created, you may want to verify that it's been created correctly. You can do so by typing **DESCRIBE objects;**. The result should be a summary of the fields you've just created for the objects table.

## Storing Data

You can now begin storing data in your database. To do so, use the **INSERT INTO** command:

```
mysql> INSERT INTO objects
-> VALUES('lizard', 'green', 6, 'soft', 10.00);
```

This example creates an entry for the first row of Figure 9.2 (but with one error, which is deliberate). You can verify that the database now holds this information by typing **SELECT \* FROM objects;**. The result is a listing of all the data in the objects table, which in this case should be just the one entry. (The next section, “Retrieving Data,” covers data retrieval in more detail.)

This example entered incorrect data for one field: The lizard is entered in the table as being 6 inches in size, rather than 5. You can correct this error by using **UPDATE**:

```
mysql> UPDATE objects SET size=5 WHERE name='lizard';
Query OK, 1 row affected (0.00 sec)
Rows matched: 1 Changed: 1 Warnings: 0
```

This example begins with the keyword **UPDATE** and the table name (**objects**). The example then tells MySQL what to update: **SET size=5**—in other words, set the **size** field to 5. The **WHERE** keyword begins a specification of which rows to change. In this case, with only one row present, you can use any data or even omit **WHERE** and the rest of the line up to the semicolon. In most cases, though, you must provide enough criteria to uniquely identify the column you want to change. In this example, the name of the object is used—hence **name='lizard'**, which tells MySQL to change the data for all rows for which the **name** field is **lizard**.

Before you continue with data retrieval activities, you should complete a database. Exercise 9.3 will guide you through this process.

**EXERCISE 9.3****Creating a SQL Database**

In this exercise, you'll continue creating a small database. This exercise assumes that you've performed the steps described in "Creating Databases and Tables" and "Storing Data" and that you therefore have a SQL database called `test`, which contains a table called `objects`, which contains one entry based on the first line in the matrix in Figure 9.2. To complete this database, follow these steps:

1. If you're not currently running MySQL, do so by typing `mysql`.
2. If you're not already using the `test` database, type `USE test;` to begin using the test database.
3. Type `INSERT INTO objects VALUES('tree', 'green', 120, 'medium', 200);`. (You may split this command across lines, if you like.) This entry is based on the second row of Figure 9.2, but note that the size value has been expressed in inches.
4. Verify that you entered the data correctly by typing `SELECT * FROM objects;` and verifying that the new entry is present.
5. Repeat step 3 (and step 4, if you like) for the remaining rows in Figure 9.2.

If you like, you can continue and enter more data; however, if you do so, some subsequent examples may not work as described.

**Retrieving Data**

The whole point of having a database is to be able to retrieve data from it. The main command for doing so has already been described: `SELECT`. This command's power lies in its ability to accept specifications of *what* to select. You can use a variety of keywords to select data that matches various criteria, such as exact matches or matches to a range of values. The overall form of `SELECT` may be described in this way:

```
SELECT field(s) FROM table [WHERE conditions] [ORDER BY field]
```

Previous uses of `SELECT` have used an asterisk (\*) as `field(s)`, meaning that the command returns all the columns that match the remaining criteria. You can instead specify columns by name. For instance, suppose you're only interested in the colors and values of `objects`. You can view this restricted set of data using `SELECT`:

```
mysql> SELECT value,color FROM objects;
+-----+-----+
| value | color |
+-----+-----+
| 10.00 | green |
```

```
| 200.00 | green |
| 5.00 | white |
| 1.00 | red |
| 0.10 | yellow |
+-----+-----+
5 rows in set (0.00 sec)
```

The *field(s)* criteria appears as a comma-separated list of columns. In this example, the criteria were listed in the reverse order from their order in the database, and so they appear in the reverse order in the output.

A more interesting way to retrieve data is to use `WHERE conditions`. This tool has already been mentioned, in reference to updating data. You can use *conditions* to retrieve specific data in several ways:

**Exact matches** Using a column name, an equal sign, and a value to match returns only those rows that match the specified value. For instance, typing `SELECT * FROM objects WHERE color='green'`; returns the two entries for green objects (lizard and tree).

**Numeric tests** You can retrieve data that match certain numeric criteria. For instance, to retrieve data on all objects that are greater than 10 inches in size, you can type `SELECT * FROM objects WHERE size>10;`

**Alphabetic tests** The greater-than (>) and less-than (<) operators work on letters as well as numbers. This fact can be used to retrieve data based on the first letter of a string, as in `SELECT * FROM objects WHERE name>'b'`; to retrieve records for which the name begins with b or later letters in the alphabet. (Although this example uses a greater-than operator, it does in fact match the letter *b*.)

**Multiple tests** You can combine multiple criteria using the AND and OR operators. For instance, to retrieve data on soft objects valued at more than \$7.50, you can type `SELECT * FROM objects WHERE hardness='soft' AND value>7.50;`

You can have MySQL return the data as an ordered list by specifying a field name after the `ORDER BY` keyword:

```
mysql> SELECT * FROM objects WHERE hardness='soft' ORDER BY value;
+-----+-----+-----+-----+-----+
| name | color | size | hardness | value |
+-----+-----+-----+-----+-----+
| banana | yellow | 8 | soft | 0.10 |
| pillow | white | 18 | soft | 5.00 |
| lizard | green | 5 | soft | 10.00 |
+-----+-----+-----+-----+-----+
3 rows in set (0.00 sec)
```

## Combining Data from Multiple Tables

As noted earlier, a database may contain multiple tables. This feature of SQL enables you to create tables for different functions. For instance, Figure 9.2 might represent a database of object characteristics that are of interest for some reason. You might also have a database containing the locations and conditions (on a 10-point scale) of different objects, as shown in Table 9.4. Sometimes you might want to combine these two tables to create a master table on which you can perform queries. In order to do so, though, the two tables must have one matching field that can be used to bind the two tables together, and each table must have one field whose value uniquely identifies each row. This uniquely identifying field is known as a *primary key*. In the case of Figure 9.2, the first column (called name) can serve as a primary key. In the case of Table 9.4, the Object ID column will do the job.

**TABLE 9.4** Data on Object Locations and Conditions

Object ID	Object Name	Location	Condition
1	banana	kitchen	9
2	banana	kitchen	8
3	tree	back yard	2
4	brick	garage	10
5	brick	garage	9
6	brick	back yard	9
7	lizard	living room	8

You can create this table much as you created the first one:

```
mysql> CREATE TABLE locations (id INTEGER, name VARCHAR(30),
-> location VARCHAR(30), cond INTEGER);
mysql> INSERT INTO locations VALUES(1, 'banana', 'kitchen', 9);
```

Additional INSERT operations will fill out the table. At this point, you can use the SELECT operator to select data based on fields from both tables. For instance, suppose you want to know where all the green objects are located. The first table (objects) contains color data but not locations, whereas the second table (locations) holds locations but not color data. You can accomplish the goal by using a few tricks:

```
mysql> SELECT objects.name, objects.color, locations.location
-> FROM objects, locations
```

```

-> WHERE objects.name=locations.name AND objects.color='green';
+-----+-----+-----+
| name | color | location |
+-----+-----+-----+
| tree | green | back yard |
| lizard | green | living room |
+-----+-----+-----+
2 rows in set (0.00 sec)

```

MySQL automatically combines the two tables and produces output based on the criteria you specify. The final output in this example includes the name, color, and location of the objects, even though each table has just two of those three values.

A second way to combine data from multiple tables is to use JOIN. This approach is very similar to the preceding one, but you specify one table using FROM and the other using JOIN:

```

mysql> SELECT objects.name, objects.color, locations.location
-> FROM objects
-> JOIN locations
-> WHERE objects.name=locations.name AND objects.color='green';

```

Combining data enables you to simplify the structure of your database in certain situations. The examples used here illustrate this fact, albeit with very small data sets. The data in the `objects` table describes objects generically, whereas the data in the `locations` table describes objects specifically. A retail business might use similar tables to describe its inventory—something analogous to the `objects` table can hold descriptions of products, whereas something like the `locations` table can specify where each box holding a particular product is shelved, perhaps even across multiple warehouses or stores. This design enables each table to be relatively small. If all the data were stored in a single table, that table would require multiple entries for each item, duplicating a lot of data. By splitting the data across tables, each table can be much smaller, thus reducing storage space.

A retrieval command that requires special mention is `GROUP BY`. This command is used in conjunction with mathematical operators, such as `SUM()`, to restrict the operation of the operator to the specified columns. For instance, suppose you want to know the total value of all the objects in the database, grouped by object type. You can do so as follows, combining data from both tables:

```

mysql> SELECT objects.name, objects.value, SUM(value)
-> FROM objects, locations
-> WHERE locations.name=objects.name
-> GROUP BY value;

```

The result is a summary of the values of all the objects by type. Omitting the `GROUP BY` clause produces an error message in MySQL.

## Deleting Data

Sometimes your data need to be deleted. Table 9.4 suggests that the tree in the back yard is ill—its condition rating is just 2 on a 10-point scale. Perhaps you'll decide to cut it down, and therefore remove it from the `locations` database. To do so, you'll use the `DELETE` command, which takes the following form:

```
DELETE FROM table WHERE conditions
```

For instance, to delete that now-removed tree, you can type the following command:

```
mysql> DELETE FROM locations
-> WHERE name='tree' AND location='back yard' ;
Query OK, 1 row affected (0.05 sec)
```

In this specific case, the `WHERE` condition is more detailed than it needs to be, because the back-yard tree is the only one in the table. As usual when deleting any sort of data on a computer, though, it's better to be overly cautious than overly sloppy.



Before deleting data, try using `SELECT` to see what data your `WHERE` conditions match. Doing this will help you prevent accidentally deleting too much data.

You can delete all the data from a table by using a variant of the `DELETE` command: **`DELETE * from locations;`** This command deletes all the table's data without deleting the table itself. This may be useful if the table is hopelessly messed up from experimentation. An even more drastic deletion operation is `DROP`: **`DROP TABLE locations;`** This example completely eliminates the `locations` table. Naturally, this is an extremely dangerous command, but you may want to use it when cleaning up your own SQL practice session.

## Learning More About SQL

SQL is a very complex topic, and this chapter can only scratch the surface. For more information, you should read more from various sources. Your own SQL package's documentation can be a good starting point, particularly if you need to use features that are unique to your implementation. Books on SQL, such as Alan Beaulieu's *Learning SQL* (O'Reilly, 2005) and Baron Schwartz's *High-Performance MySQL: Optimization, Backups, Replication, and More* (O'Reilly, 2008), are also worth reading if you need to do more than trivial SQL work.

## Summary

Serious Linux administrators must have at least a basic understanding of shell scripts. Many configuration and startup files are in fact shell scripts, and being able to read them, and perhaps modify them, will help you administer your system. Being able to create new

shell scripts is also important, because doing so will help you simplify tedious tasks and create site-specific tools by gluing together multiple programs to accomplish your goals.

E-mail server administration is another task with which you must have at least a passing familiarity. Although most Linux systems don't operate as e-mail servers in the sense of computers whose primary duty is to handle e-mail, most Linux installations do include e-mail servers for processing locally-generated e-mail, and sometimes to send e-mail to outside systems or even to receive e-mail for local users. You can configure e-mail forwarding and perform a few other tweaks without delving too heavily into e-mail server configuration.

The final topic of this chapter, SQL use, will help you manage simple databases stored using the SQL language. Many programs rely on SQL for their operation, so being able to perform simple SQL queries will help you work with these programs. You may even decide to set up databases to help manage your own tasks, such as tracking where you keep things in your office or home.

## Exam Essentials

**Explain the function of environment variables.** Environment variables are used to store information on the system for the benefit of running programs. Examples include the `PATH` environment variable, which holds the locations of executable programs, and `HOSTNAME`, which holds the system's hostname.

**Describe how a shell script can be useful.** A shell script combines several commands, possibly including conditional expressions, variables, and other programming features, to make the script respond dynamically to a system. Therefore, a shell script can reduce administrative effort by performing a series of repetitive tasks at one command.

**Describe the purpose of shell aliases.** Aliases enable you to create a command “shortcut”—a simple command that can stand in for a different or longer command. Aliases are typically defined in shell startup scripts as a way to create a shortened version of a command, to have useful options for a command be used as new defaults, or to create an easier-to-remember version of a command.

**Summarize the major SMTP servers for Linux.** Sendmail was the most common SMTP server a decade ago and is still very popular today. Postfix and Exim are often supplied as the default mail servers on modern distributions, whereas qmail is often installed by administrators but isn't the default for any major distribution. Postfix and qmail use modular designs, whereas sendmail and Exim are monolithic.

**Explain the difference between an e-mail alias and e-mail forwarding.** An e-mail alias is configured systemwide, typically in `/etc/aliases`. It can set up forwarding for any local address, even if that address doesn't correspond to a real account; and if the system is properly configured, only root may edit `/etc/aliases` and therefore modify aliases. E-mail forwarding, on the other hand, is handled by the `~/ .forward` file in a user's home directory; it's intended as a means for users to control their own e-mail forwarding without bothering the system administrator.



**Summarize the structure of a SQL database.** Each SQL installation consists of a number of named databases, each of which in turn may contain multiple tables. Each table can be thought of as a two-dimensional array of data. Each row in a table describes some object or concept (inventory items, employees, movies in a personal DVD collection, and so on), and each column in a table holds data about these objects or concepts (model number, salary, or director, for example).

**Describe the commands used to enter data in a SQL database.** The INSERT command inserts a single entry into a database. It requires a table name and a set of values, as in **INSERT INTO movies VALUES('Brazil', 'Terry Gilliam', 1985)**; The UPDATE command can be used in a similar way to update an existing entry, but you must use SET to specify the column to set and WHERE to identify the row or rows to be modified.

**Explain the commands used to extract data from a SQL database.** The SELECT command retrieves data from a SQL database. It can be used with a variety of additional options, such as FROM, JOIN, and WHERE, to identify the table or tables from which data should be retrieved and to locate specific values of interest.

## Review Questions

1. Where is the best location for the current directory indicator (.) to reside in root's PATH environment variable?
  - A. Before all other directories.
  - B. After all other directories.
  - C. Nowhere; it shouldn't be in root's path.
  - D. Wherever is convenient.
2. You want to create a shortcut for the command `cd ~/papers/trade`. Which of the following lines, if entered in a bash startup script, will accomplish this goal?
  - A. `alias cdpt='cd ~/papers/trade'`
  - B. `export cdpt='cd ~/papers/trade'`
  - C. `cd ~/papers/trade`
  - D. `shortcut cdpt "cd ~/papers/trade"`
3. What is the purpose of the EDITOR environment variable?
  - A. Set to Y (the default), the shell environment permits editing of commands; set to N, such editing is disallowed.
  - B. Some, but not all, programs refer to EDITOR to determine what external editor to launch when they do so.
  - C. If you type `edit filename` at a command prompt, the program specified by EDITOR will be launched.
  - D. Set to GUI, programs call a GUI editor; set to TEXT, programs call a text-based editor.
4. In what environment variable is the current working directory stored?
  - A. PATH
  - B. CWD
  - C. PWD
  - D. PRESENT
5. Which of the following commands, if typed in a bash shell, will create an environment variable called MYVAR with the contents mystuff which will be accessible to subsequently-launched programs?
  - A. `export MYVAR='mystuff'`
  - B. `MYVAR='mystuff'`
  - C. `$MYVAR==mystuff`
  - D. `echo $MYVAR mystuff`

6. What file might a user modify to alter his or her own `bash` environment?
  - A. `~/startup`
  - B. `/etc/bashrc`
  - C. `/home/.bashrc`
  - D. `~/bashrc`
7. What commands might you use (along with appropriate options) to learn the value of a specific environment variable? (Select all that apply.)
  - A. `env`
  - B. `DISPLAY`
  - C. `export`
  - D. `echo`
8. After using a text editor to create a shell script, what step should you take before trying to use the script?
  - A. Set one or more executable bits using `chmod`.
  - B. Copy the script to the `/usr/bin/scripts` directory.
  - C. Compile the script by typing `bash scriptname`, where *scriptname* is the script's name.
  - D. Run a virus checker on the script to be sure it contains no viruses.
9. Describe the effect of the following short script, `cp1`, if it's called as `cp1 big.c big.cc`:

```
#!/bin/sh
cp $2 $1
```

  - A. It has the same effect as the `cp` command—copying the contents of `big.c` to `big.cc`.
  - B. It compiles the C program `big.c` and calls the result `big.cc`.
  - C. It copies the contents of `big.cc` to `big.c`, eliminating the old `big.c`.
  - D. It converts the C program `big.c` into a C++ program called `big.cc`.
10. What is the purpose of conditional expressions in shell scripts?
  - A. They prevent scripts from executing if license conditions aren't met.
  - B. They display information about the script's computer environment.
  - C. They enable the script to take different actions in response to variable data.
  - D. They enable scripts to learn in a manner reminiscent of Pavlovian conditioning.
11. Which of the following lines identify valid shell scripts on a normally configured system? (Select all that apply.)
  - A. `#!/bin/script`
  - B. `#!/bin/bash`
  - C. `!#/bin/tcsh`
  - D. `#!/bin/sh`

12. Which of the following is *not* a valid looping statement in bash shell scripting?
- A. `for`
  - B. `while`
  - C. `goto`
  - D. `until`
13. Your SMTP e-mail server, `mail.luna.edu`, receives a message addressed to `postmaster@mail.luna.edu`. There is no `postmaster` account on this computer. Assuming the system is properly configured, how should the e-mail server respond?
- A. Deliver the e-mail to another account, either locally or on another computer.
  - B. Bounce the message so that the recipient knows the account doesn't exist.
  - C. Hold the message in the local mail queue until the `postmaster` account is created.
  - D. Delete the message without bouncing it so as to reduce e-mail clutter.
14. Which of the following is *not* a popular SMTP server for Linux?
- A. Postfix
  - B. Sendmail
  - C. Fetchmail
  - D. Exim
15. You see the following line in a script:
- ```
mail -s "Error" -c abort < /tmp/msg root
```
- What is the effect of this line, if and when it executes?
- A. An e-mail is sent to the user `Error`, the script is aborted using `root` privileges, and error messages are written to `/tmp/msg`.
 - B. An e-mail with the subject of `Error` and the contents from `/tmp/msg` is sent to the local users `root` and `abort`.
 - C. An e-mail with the subject of `Error` and the contents of `/tmp/msg` is sent to the local user `root`, and then the script is aborted.
 - D. An e-mail is sent with `Error` priority to the local user `root`, and the e-mail system is then shut down with error messages being stored in `/tmp/msg`.
16. Your Internet connection has gone down for several hours. What is true of e-mail sent by your users to off-site recipients via a properly configured local SMTP server?
- A. The SMTP server will refuse to accept e-mail from local clients during the outage.
 - B. E-mail will be neither delayed nor lost.
 - C. All e-mail sent during the outage will be lost.
 - D. E-mail will be delayed by a few hours but not lost.

17. You examine your `/etc/aliases` file and find it contains the following line:
`root: jody`
What can you conclude from this?
- A. E-mail addressed to `jody` on this system will be sent to the local user `root`.
 - B. E-mail addressed to `root` on this system will be sent to the local user `jody`.
 - C. The local user `jody` has broken into the system and acquired `root` privileges.
 - D. The local user `jody` has permission to read e-mail directly from `root`'s mail queue.
18. You've just installed MySQL and run it by typing `mysql`. How would you create a database called `fish` to store data on different varieties of fish?
- A. Type **NEW DATABASE fish;** at the `mysql>` prompt.
 - B. Type **create database fish;** at the `mysql>` prompt.
 - C. Type **NEW DATABASE FISH;** at the `mysql>` prompt.
 - D. Type **DATABASE CREATE fish;** at the `mysql>` prompt.
19. Which of the following are true statements about SQL tables? (Select all that apply.)
- A. Multiple tables may exist in a single SQL database.
 - B. Tables may be combined for cross-table searches using the `DROP` command.
 - C. Tables consist of rows, each of which holds attributes, and columns, each of which defines a specific database item.
 - D. Careful table design can reduce the amount of data entry and database storage size.
20. What is the effect of the following SQL command, assuming the various names and data exist?
`mysql> UPDATE stars SET magnitude=2.25 WHERE starname='Mintaka';`
- A. It returns database entries from the `stars` table for all stars with `magnitude` of 2.25 and `starname` of `Mintaka`.
 - B. It sets the value of the `stars` field in the `magnitude` set to `Mintaka`, using a precision of 2.25.
 - C. It sets the value of the `magnitude` field to 2.25 for any item in the `stars` table with the `starname` of `Mintaka`.
 - D. It combines the `stars` and `magnitude=2.25` tables, returning all items for which `starname` is `Mintaka`.

Answers to Review Questions

1. C. The current directory indicator is particularly dangerous in `root`'s `PATH` environment variable because it can be used by unscrupulous local users to trick `root` into running programs of the unscrupulous user's design.
2. A. The `alias` built-in command creates a duplicate name for a (potentially much longer) command. Option A shows the correct syntax for using this built-in command; it causes the new alias `cdpt` to work like the much longer `cd ~/papers/trade`. The `export` command in option B creates an environment variable called `cdpt` that holds the value `cd ~/papers/trade`. This will have no useful effect. Option C, if placed in a `bash` startup script, will cause the user's current directory to shift to `~/papers/trade` immediately after the user logs in. There is no standard `shortcut` command, so option D is meaningless.
3. B. Some programs use the `EDITOR` environment variable as described in option B. Contrary to option A, the `EDITOR` environment variable has nothing to do with command-line editing. The `edit` command doesn't behave as option C suggests. (This command may be configured differently on different systems.) You can create links called `GUI` and `TEXT` to have the `EDITOR` environment variable behave as option D suggests, but this isn't a normal configuration.
4. C. The `PWD` environment variable holds the present working directory. The `PATH` environment variable holds a colon-delimited list of directories in which executable programs are stored so that they may be run without specifying their complete pathnames. There are no standard `CWD` and `PRESENT` environment variables.
5. A. Option A creates the desired environment variable. Option B creates a local variable—but not an environment variable—called `MYVAR`, holding the value `mystuff`. After typing option B, you can also type `export MYVAR` to achieve the desired goal, but option B by itself is insufficient. Option C isn't a valid `bash` shell command. Option D displays the contents of the `MYVAR` variable and also echoes `mystuff` to the screen, but it doesn't change the contents of any environment variable.
6. D. The `~/ .bashrc` file is a non-login `bash` startup script file. As such, it can be used to alter a user's `bash` environment. There is no standard `~/ .startup` file for `bash`, so option A is incorrect. The `/etc/bashrc` file is a global `bash` startup script. Editing it will modify users' `bash` environments, but an individual user should not be able to modify it, so option B is incorrect. There is no standard `/home/ .bashrc` file; this option would only be correct if the user's home directory were set to `/home`, which would almost certainly be an error.
7. A, D. The `env` command displays all defined environment variables, so option A satisfies the question. (In practice, you might pipe the results through `grep` to find the value of a specific environment variable.) The `echo` command, when passed the name of a specific environment variable, displays its current value, so option D is also correct. `DISPLAY` is an environment variable, but it's not a command for displaying environment variables, so option B is incorrect. You can use the `export` command to create an environment variable, but not to display the current settings for one, so option C is incorrect.

8. A. Scripts, like binary programs, normally have at least one executable bit set, although they can be run in certain ways without this feature. There is no standard `/usr/bin/scripts` directory, and scripts can reside in any directory. Scripts are interpreted programs, which means they don't need to be compiled. Typing **bash *scriptname*** will run the script. Viruses are extremely rare in Linux, and because you just created the script, the only ways it could possibly contain a virus would be if your system was already infected or if you wrote it as a virus.
9. C. The `cp` command is the only one called in the script, and that command copies files. Because the script passes the arguments (`$1` and `$2`) to `cp` in reverse order, their effect is reversed—where `cp` copies its first argument to the second name, the `cp1` script copies the second argument to the first name. The `cp` command has nothing to do with compiling C or C++ programs, so neither does the script.
10. C. Conditional expressions return a true or false response, enabling the script to execute one set of instructions or another or to terminate or continue a loop.
11. B, D. Valid shell scripts begin with the characters `#!` and the complete path to a program that can run the script. Options B and D both meet this description, because `/bin/bash` is a shell program that's installed on virtually all Linux systems and `/bin/sh` is usually a link to `/bin/bash` or to some other valid shell. There is no standard `/bin/script` program, so option A is incorrect. Option C is almost correct; `/bin/tcsh` is a valid shell on most systems, but the order of the first two characters is reversed, so this option is incorrect.
12. C. The `bash` scripting language doesn't support a `goto` statement, although some languages (such as BASIC) do. The `for`, `while`, and `until` statements are all valid looping statements in `bash`.
13. A. All SMTP e-mail servers are supposed to accept e-mail to `postmaster`. Linux systems typically do so by using an alias to forward the e-mail to another local user, or occasionally to a user on another computer. Thus, option A is correct. Options B and D both describe non-delivery of the message, in violation of proper e-mail server configuration. Option C is effectively the same as option D unless creation of the `postmaster` account is imminent, and an e-mail server would have no way of knowing this.
14. C. The `Fetchmail` program is a tool for retrieving e-mail from remote POP or IMAP servers and injecting it into a local (or remote) SMTP e-mail queue. As such, it's not an SMTP server, so option C is correct. `Postfix`, `sendmail`, and `Exim` are all popular SMTP e-mail servers for Linux.
15. B. The `-s` option to `mail` sets the message subject line, and `-c` sets carbon copy (`cc:`) recipients. Input redirection (via `<`) reads the contents of a line into `mail` as a message. A `mail` command line normally terminates with the primary recipient. Thus, option B correctly describes the effect of the specified line. Options A, C, and D are all confused in their interpretation of the effects of `mail` parameters. Options B and D also confuse input and output redirection, and option A incorrectly suggests that a script (or the `mail` program) can elevate its run status to `root` privileges.

16. D. SMTP servers accept local e-mail for delivery even if their Internet connections are down. If the SMTP server can't contact recipient servers, the SMTP server holds the e-mail and attempts delivery later, so option D is correct. Because SMTP servers don't check on the availability of remote servers until after e-mail is accepted for delivery, option A is incorrect. Option B can't possibly be correct unless the server has a backup Internet connection, which wasn't specified in the question. Option C isn't correct because the SMTP server will hold the mail and attempt delivery later.
17. B. The `/etc/aliases` file configures system-wide e-mail forwarding. The specified line does as option B describes. A configuration like this one is common. Option A has things reversed. Option C is not a valid conclusion from this evidence alone, although an intruder may conceivably be interested in redirecting `root`'s e-mail; so if `jody` shouldn't be receiving `root`'s e-mail, this should be investigated further. Although the effect of option D (`jody` reading `root`'s e-mail) is nearly identical to the correct answer's effect, they are different; `jody` cannot directly access the file or directory that is `root`'s e-mail queue. Instead, the described configuration redirects `root`'s e-mail into `jody`'s e-mail queue. Thus, option D is incorrect.
18. B. The `CREATE DATABASE` command creates a new database with the specified name. Because SQL commands are case-insensitive, this command may be typed in uppercase or lowercase, and option B is correct. Options A and C both use the incorrect command `NEW` rather than `CREATE`, and option C specifies the database name as `FISH` rather than `fish`. (Database names are case-sensitive.) Option D reverses the order of the `CREATE` and `DATABASE` keywords.
19. A, D. A single database may hold multiple tables, as option A suggests. Option D is also correct; by splitting data across tables (such as into tables describing objects generically and specifically), databases can be more space-efficient. Option B is incorrect because the `DROP` command doesn't combine tables; it *deletes* a table! Option C is incorrect because it reverses the meaning of rows and columns in a SQL table.
20. C. The `UPDATE` command modifies existing database table entries, and in this case it does so as option C describes. Option B also describes an update operation, but in a confused and incorrect way. Options A and D both describe database retrieval operations, but `UPDATE` doesn't retrieve data.

Chapter 10

Securing Your System

THE FOLLOWING LINUX PROFESSIONAL INSTITUTE OBJECTIVES ARE COVERED IN THIS CHAPTER:

- ✓ 1.110.1 Perform security administration tasks (weight: 3)
- ✓ 1.110.2 Set up host security (weight: 3)
- ✓ 1.110.3 Securing data with encryption (weight: 3)





Chances are, you take basic security measures in your daily life—locking the door to your house, avoiding unsafe neighborhoods, keeping valuables out of sight in your car, and so on.

Such measures can minimize the risk of a theft or even personal injury, and similar measures on a computer can help protect the computer from compromise. This chapter covers several security issues: restricting access to the computer by port number, managing the security of individual programs, managing passwords, setting miscellaneous account security options, and using encryption to secure data. Understanding these basics will help you begin to secure your computer.



There is no such thing as a 100 percent secure computer. You can take steps to improve security, but no one step or set of steps will absolutely guarantee that you'll have no problems. You must decide for yourself (or the organization for which you work must decide) just how much effort to put into securing your systems and live with the level of threat that remains. This chapter's security information can help you start securing your system; but if you need more than very basic security, you'll have to learn and do more than I can describe here.

Administering Network Security

Linux systems are often used as server computers, or at least they're connected to the Internet more or less directly. On such systems, network security is particularly important, because incorrectly configured servers can provide miscreants with a way into your system to do whatever damage they like. Several methods of protecting networked computers from unwanted outside access exist. Some of the simplest of these methods involve shutting down or restricting access to network servers by controlling the network ports they use. (Network ports are described in Chapter 8, "Configuring Basic Networking.") You can check for existing network connections, check for open ports (that is, ports that are in use by a server program), use super server restrictions to limit access, and disable servers you're not using.



The popular media uses the term *hacker* to refer to computer criminals. This word has an older meaning, though: It refers to individuals who are skilled with computers (and particularly with programming), who enjoy these activities, and who use their skills to productive and legal ends. Many Linux programmers consider themselves hackers in this positive sense. Therefore, I use another term, *cracker*, to refer to computer criminals.

Using Super Server Restrictions

Many network server programs open network ports and listen for connections directly. Some programs, though, work through an intermediary: a *super server*. This is a program that listens for network connections on behalf of another program and then, when a connection is initiated, hands off control of that connection to the intended server. This activity may sound like pointless complication, but it actually has several advantages over a more direct connection. For instance, using a super server can reduce memory load if the super server handles many small servers that are seldom used—most of the time, only the super server and perhaps one or two of the servers it handles will be in memory. Another advantage is security: You can employ security checks in the super server to protect all the servers that the super server manages. In the following pages, I describe the basics of configuring Linux's two major super servers, `inetd` and `xinetd`, with particular emphasis on their security features. In the case of `inetd`, security is handled by a package called TCP Wrappers. `xinetd`'s security features are built into `xinetd` itself, by contrast.



Whenever possible, apply redundant access controls. For instance, you can use both a server's own security features and TCP Wrappers or `xinetd` to block unwanted access. Doing this helps protect against bugs and misconfiguration—if a problem emerges in the super server configuration, for instance, the secondary block will probably halt the intruder. If you configure the system carefully, such an access will also leave a log file message that you'll see, so you'll be alerted to the fact that the super server didn't do its job.

Configuring `inetd`

The `inetd` package was once the standard super server in Linux, and it's still used on some systems. Over the past decade, though, `xinetd` has gained substantial ground, so your system may use `xinetd` instead. Type `ps ax | grep inetd` to see which super server is running on your system—the output should include a line with either the `inetd` or the `xinetd` command. Some systems run neither super server, though. If your system has `inetd` installed, the next few pages cover it.

Setting Up `inetd`

You control servers that launch via `inetd` through the `/etc/inetd.conf` file or files in `/etc/inetd.d`. The `/etc/inetd.conf` file consists of a series of lines, one for each server. A typical line resembles the following:

```
ftp stream tcp nowait root /usr/sbin/tcpd /usr/sbin/in.ftpd -l
```



This and several subsequent examples refer to `in.ftpd`, an FTP server that was once quite popular but that's being replaced on many systems by other FTP servers. Some of these servers cannot be run from a super server, so using another server may not work in all of these cases.

Instead of using a single monolithic `/etc/inetd.conf` file, recent versions of `inetd` enable you to split the configuration into several files in the `/etc/inetd.d` directory. Doing so enables you to easily add or delete server configurations by adding or deleting their configuration files. For brevity, the following paragraphs refer only to `/etc/inetd.conf`, but the description applies to files in `/etc/inetd.d`, as well.

Each line consists of several fields separated by one or more spaces. The meanings of these fields are as follows:

Service name The first field (`ftp` in the preceding example) is the name of the service as it appears in the `/etc/services` file.

Socket type The socket type entry tells the system what type of connection to expect—a reliable two-way connection (`stream`), a less reliable connection with less overhead (`dgram`), a low-level connection to the network (`raw`), or various others. The differences between these types are highly technical; your main concern in editing this entry should be to correctly type the value specified by the server's documentation.

Protocol This is the TCP/IP transport-layer protocol used, usually `tcp` or `udp`.

Wait/no wait For `dgram` socket types, this entry specifies whether the server connects to its client and frees the socket (`nowait`) or processes all its packets and then times out (`wait`). Servers that use other socket types should specify `nowait` in this field.

User This is the username used to run the server. The `root` and `nobody` users are common choices, but others are possible as well. As a general rule, you should run servers with a low-privilege user whenever possible as a security precaution. Some servers require root access, though. Consult the server's documentation for details.

Server name This is the filename of the server. In the preceding example, the server is specified as `/usr/sbin/tcpd`, which is the TCP Wrappers binary. As described shortly in “Controlling Access via TCP Wrappers,” this program is an important security tool and should usually be included as the means of launching programs via `inetd`.

Parameters Everything after the server name consists of parameters that are passed to the server. If you use TCP Wrappers, you pass the name of the true target server (such as `/usr/sbin/in.ftpd`) in this field, along with its parameters.

The hash mark (`#`) is a comment symbol for `/etc/inetd.conf`. Therefore, if a server is running via `inetd` and you want to disable it, you can place a hash mark at the start of the line. If you want to add a server to `inetd.conf`, you need to create an entry for it. Most servers that can be run from `inetd` include sample entries in their documentation. Many distributions ship with `inetd.conf` files that include entries for common servers as well, although many of them are commented out; remove the hash mark at the start of the line to activate the server.

After modifying `inetd.conf`, you must restart the `inetd` super server. This super server normally runs as a standard SysV server, so you can restart it by typing something similar to the following:

```
# /etc/rc.d/init.d/inetd restart
```

Alternatively, you can tell `inetd` to reload its configuration by passing the SysV startup script the `reload` parameter rather than `restart`. The `restart` option shuts down the server and then starts it again. When you use `reload`, the server never stops running; it just rereads the configuration file and implements any changes. As a practical matter, the two are similar. Using `restart` is more likely to correctly implement changes, but it's also more likely to disrupt existing connections.

Instead of using the SysV startup scripts, you can use `kill` or `killall` (described in Chapter 2, “Managing Software”) to pass the `SIGHUP` signal to `inetd`. This signal causes many servers, including `inetd`, to reload their configuration files. For instance, you can type `kill -HUP pid` if you know the process ID (PID) of `inetd`, or `killall -HUP inetd` to have all instances of `inetd` reload their configuration files. (Ordinarily, only one instance of `inetd` runs on a system.) In practice, this should work very much like the `reload` option to the SysV startup script—in fact, such scripts often use this technique to implement this option.



It's generally wise to disable as many servers as possible in `inetd.conf` (or the `xinetd` configuration files, if you use `xinetd`). As a general rule, if you don't understand what a server does, disable it. This will improve the security of your system by eliminating potentially buggy or misconfigured servers from the equation.

Controlling Access via TCP Wrappers

The TCP Wrappers package provides a program known as `tcpd`. Instead of having `inetd` call a server directly, `inetd` calls `tcpd`, which does two things: It checks whether a client is authorized to access the server, and if the client has this authorization, `tcpd` calls the server program.

TCP Wrappers is configured through two files: `/etc/hosts.allow` and `/etc/hosts.deny`. The first of these specifies computers that are allowed access to the system in a particular way, the implication being that systems not listed are not permitted access. By contrast, `hosts.deny` lists computers that are not allowed access; all others are granted access to the system. If a computer is listed in both files, `hosts.allow` takes precedence.

Both files use the same basic format. The files consist of lines of the following form:

```
daemon-list : client-list
```

The *daemon-list* is a list of servers, using the names for the servers that appear in `/etc/services`. Wildcards are also available, such as `ALL` for all servers.

The *client-list* is a list of computers to be granted or denied access to the specified daemons. You can specify computers by name or by IP address, and you can specify a network by using a leading or trailing dot (`.`) when identifying networks by name or IP address

block, respectively. For instance, `.luna.edu` blocks all computers in the `luna.edu` domain, and `192.168.7.` blocks all computers in the `192.168.7.0/24` network. You can also use wildcards in the *client-list*, such as `ALL` (all computers). `EXCEPT` causes an exception. For instance, when placed in `hosts.deny`, `192.168.7. EXCEPT 192.168.7.105` blocks all computers in the `192.168.7.0/24` network except for `192.168.7.105`.

The man pages for `hosts.allow` and `hosts.deny` (they're actually the same document) provide additional information about more advanced features. You should consult them as you build TCP Wrappers rules.



Remember that not all servers are protected by TCP Wrappers. Normally, only those servers that `inetd` runs via `tcpd` are so protected. Such servers typically include, but are not limited to, Telnet, FTP, TFTP, `rlogin`, `finger`, POP, and IMAP servers. A few servers can independently parse the TCP Wrappers configuration files, though; consult the server's documentation if in doubt.

Configuring *xinetd*

The `xinetd` program is an extended super server. It provides the functionality of `inetd` plus security options that are similar to those of TCP Wrappers. Modern versions of Fedora, Mandriva, Red Hat, SUSE, and a few other distributions use `xinetd` by default. Other distributions may use it in the future. If you like, you can replace `inetd` with `xinetd` on any distribution.

Setting Up *xinetd*

The `/etc/xinetd.conf` file controls `xinetd`. On distributions that use `xinetd` by default, this file contains only global default options and a directive to include files stored in `/etc/xinetd.d`. Each server that should run via `xinetd` then installs a file in `/etc/xinetd.d` with its own configuration options.

Whether the entry for a server goes in `/etc/xinetd.conf` or a file in `/etc/xinetd.d`, it contains information similar to that in the `inetd.conf` file. The `xinetd` configuration file, though, spreads the information across multiple lines and labels it more explicitly. Listing 10.1 shows an example that's equivalent to the earlier `inetd.conf` entry from "Setting Up *inetd*." This entry provides precisely the same information as the `inetd.conf` entry except that it doesn't include a reference to `/usr/sbin/tcpd`, the TCP Wrappers binary. Because `xinetd` includes similar functionality, it's generally not used with TCP Wrappers.

Listing 10.1: Sample *xinetd* Configuration Entry

```
service ftp
{
    socket_type      = stream
    protocol        = tcp
    wait            = no
```

```

    user          = root
    server        = /usr/sbin/in.ftpd
    server_args   = -l
}

```

One additional `xinetd.conf` parameter is important: `disable`. If you include the line `disable = yes` in a service definition, `xinetd` ignores the entry. Some servers install startup files in `/etc/xinetd.d` that have this option set by default; you must edit the file and change the entry to read `disable = no` to enable the server. You can also disable a set of servers by listing their names in the `defaults` section of the main `xinetd.conf` file on a line called `disabled`, as in `disabled = ftp shell`.

As with `inetd`, after you make changes to `xinetd`'s configuration, you must restart the super server. You do this by typing a command similar to the one used to restart `inetd`. As with that command, you can use either `reload` or `restart`, with similar effects:

```
# /etc/rc.d/init.d/xinetd restart
```

Also as with `inetd`, you may pass the `SIGHUP` signal to `xinetd` via the `kill` or `killall` command to have it reload its configuration file. This approach may be preferable if you're using a distribution, such as Slackware, that doesn't use a conventional SysV startup script to launch `xinetd`.

Controlling Access via *xinetd*

Security is handled on a server-by-server basis through the use of configuration parameters in `/etc/xinetd.conf` or the server-specific configuration files. Some of these options are similar to the function of `hosts.allow` and `hosts.deny`:

Network interface The `bind` option tells `xinetd` to listen on only one network interface for the service. For instance, you can specify `bind = 192.168.23.7` on a router to have it listen only on the Ethernet card associated with that address. This feature is extremely useful in routers, but it isn't as useful in computers with just one network interface. (You can use this option to bind a server only to the loopback interface, `127.0.0.1`, if a server should be available only locally. You might do this with a configuration tool like the Samba Web Administration Tool, or SWAT.) A synonym for this option is `interface`.

Allowed IP or network addresses You can use the `only_from` option to specify IP addresses, networks (as in `192.168.78.0/24`), or computer names on this line, separated by spaces. The result is that `xinetd` will accept connections only from these addresses, similar to TCP Wrappers' `hosts.allow` entries.

Disallowed IP or network addresses The `no_access` option is the opposite of `only_from`; you list computers or networks here that you want to blacklist. This is similar to the `hosts.deny` file of TCP Wrappers.

Access times The `access_times` option sets times during which users may access the server. The time range is specified in the form `hour:min-hour:min`, using a 24-hour clock. Note that this option only affects the times during which the server will *respond*. If the

`xinetd access_times` option is set to 8:00–17:00 and somebody logs in at 4:59 p.m. (one minute before the end time), that user may continue using the system well beyond the 5:00 p.m. cutoff time.

You should enter these options into the files in `/etc/xinetd.d` that correspond to the servers you want to protect. Place the lines between the opening brace (`{`) and closing brace (`}`) for the service. If you want to restrict *all* your `xinetd`-controlled servers, you can place the entries in the `defaults` section in `/etc/xinetd.conf`.



Some servers provide access control mechanisms similar to those of TCP Wrappers or `xinetd`. For instance, Samba provides `hosts allow` and `hosts deny` options that work much like the TCP Wrappers file entries. These options are most common on servers that are awkward or impossible to run via `inetd` or `xinetd`.

Configuring a Firewall

Although the LPI Level 1 exam objectives don't mention firewalls, you should be familiar with the concept. A *firewall* is a computer that restricts access to other computers or software that runs on a single computer to protect it alone. Broadly speaking, two types of firewalls exist: *packet-filter firewalls*, which work by blocking or permitting access based on low-level information in individual data packets (such as source and destination IP addresses and ports), and *proxy filters*, which partially process a transaction (such as a Web page retrieval) and block or deny access based on high-level features in this transaction (such as the filename of an image in the Web page).

In Linux, the kernel includes packet-filter firewall capabilities, which can be programmed via the `iptables` program. You can set up rules by typing **`iptables`** followed by various options that define specific restrictions, such as limits on the IP addresses that may access a specific network port. Creating an effective firewall requires learning `iptables` in detail and writing a script that calls this program repeatedly to set up specific rules.

Many distributions make things easier by providing a generic firewall script that you can configure using a GUI tool. These tools are generally designed for protecting a single computer against unwanted outside access. Check your distribution's GUI system administration options for a firewall configuration tool. You may be able to set security based on a few levels (high, medium, and low security, for instance) or in a somewhat more refined manner.

Linux can also function as a firewall computer that protects an entire network; however, such a configuration is likely to require in-depth knowledge of `iptables`, as well as topics such as configuring Linux as a router.

Disabling Unused Servers

Quite a few server programs ship with most Linux distributions, which can be a great advantage—you don't need to hunt for servers you want to run. On the other hand, this very advantage can be a drawback—if you're not careful, you can end up running a server and not even realize it's installed! For this reason, you should periodically search for servers and shut down any that you find that aren't really necessary. You must begin this task by locating unwanted servers. Several tools to do so exist, such as `netstat`, `lsof`, and remote network scanners. You can also search your local configuration files for clues about what may be running. Disabling unused servers can be done by uninstalling the package or by reconfiguring the server.

Using `netstat`

One way to begin diagnosing network security is to look for network activity or open ports on a computer. One tool that can help in this respect is `netstat`. This program is the Swiss Army knife of network status tools; it provides many different options and output formats to deliver information about routing tables, interface statistics, and so on. For spotting unnecessary servers, you can use `netstat` with its `-a` and `-p` options, as shown here:

```
# netstat -ap
Active Internet connections (servers and established)
Proto Recv-Q Send-Q Local Address           Foreign Address         State↗
PID/Program name
tcp        0      0 *:ftp                  *:*                     LISTEN↗
690/inetd
tcp        0      0 tee1a.rodbooks.com:ssh nessus.rodbooks.:39361 ESTABLISHED↗
787/sshd
```



I've trimmed most of the entries from this output to make it manageable as an example. Also, `netstat` can be run as an ordinary user, but it may not return as much information. Specifically, only root and a process's owner see the PID and program name of a process.

This version of the `netstat` command shows active network connections, which can reveal the presence of servers that are running on your computer. The `Local Address` and `Foreign Address` columns specify the local and remote addresses, including both the host-name or IP address and the port number or associated name from `/etc/services`. The first of the two entries shown here isn't actively connected, so the local address, the foreign address, and the port number are all listed as asterisks (*). This entry does specify the local port, though: `ftp`. This line indicates that a server is running on the `ftp` port (TCP port 21). The `State` column specifies that the server is listening for a connection. The final column in this output, under the `PID/Program name` heading, indicates that the process with a process

ID (PID) of 690 is using this port. In this case, it's `inetd`. In other words, this server is running and listening for connections, but nobody is currently connected to it.

The second output line indicates that a connection has been established between `tee1a.rodsbooks.com` and `nessus.rodsbooks.com` (the second hostname is truncated). The local system (`tee1a`) is using the `ssh` port (TCP port 22), and the client (`nessus`) is using port 39361 on the client system. The process that's handling this connection on the local system is `sshd`, running as PID 787.

It may take some time to peruse the output of `netstat`, but doing so will leave you with a much improved understanding of your system's network connections. If you spot servers listening for connections that you didn't realize were active, you should investigate the matter further. Some servers may be innocent or even necessary. Others may be pointless security risks. The upcoming section "Disabling Unused Servers" describes how to shut down servers you don't want to have running.



When you use the `-p` option to obtain the name and PID of the process using a port, the `netstat` output is wider than 80 columns. You may want to open an extra-wide `xterm` window to handle this output or redirect it to a file that you can study in a text editor capable of displaying more than 80 columns. To quickly spot servers listening for connections, type `netstat -lp` rather than `netstat -ap`. The result will show all servers that are listening for connections, omitting client connections and specific server instances that are already connected to clients.

Exercise 10.1 demonstrates the use of `netstat` to monitor network port use.

EXERCISE 10.1

Monitor Network Port Use

To get started with `netstat`, follow these steps:

1. Log into the Linux system as a normal user. (Acquiring root privileges will produce more complete output, as described earlier, but isn't strictly necessary for this exercise.)
2. Launch an `xterm` from the desktop environment's menu system, if you used a GUI login method.
3. Type `netstat -ap | less`, and page through the output. Chances are, you'll see quite a few entries for servers that are listening for connections and for established connections to local servers or from local clients to remote servers. Pay particular attention to servers that are listening for new connections—that is, those that list LISTEN in the State column of the output.
4. Type `netstat -ap | grep ssh` to find connections involving SSH. Depending on your configuration and the servers you have running, you may see no output or many lines of output.

EXERCISE 10.1 (continued)

5. In another login session or xterm window, initiate an SSH connection to another computer. For instance, type `ssh remote.tuna.edu` to connect to `remote.tuna.edu`.
6. Type `netstat -ap | grep ssh` in your original session (not in your SSH connection). Compare the output to that which you obtained in step 4. The output should have an additional line, reflecting the session you initiated in step 5.
7. Log out of the SSH session you initiated.
8. Type `netstat -ap | grep ssh` again. The output should be missing the line for the session you've now closed.

If you're using a multi-user system, additional SSH sessions may come and go during the course of this lab, reflecting the activities of other users.

Using lsof

The `lsof` program nominally lists open files. It can be used to identify what files are open in a directory, find who's accessing them, and so on. The definition of *file* used by `lsof` is broad, though; it includes network connections. Thus, you can use `lsof` instead of `netstat` for some tasks, including locating servers that are in use. In its most basic form in this role, you should pass the `-i` parameter to `lsof`:

```
# lsof -i
COMMAND      PID        USER      FD  TYPE  DEVICE  SIZE  NODE  NAME
ssh          2498      rodsmith   3u  IPv4  3292662      TCP  *
nessus.rodbooks.com:53106->seeker.rodbooks.com:ssh (ESTABLISHED)
exim4        4827      Debian-exim  5u  IPv4  3369596      TCP  *:smtp (LISTEN)
sshd         4997        root       3u  IPv4  13273        TCP  *:ssh (LISTEN)
```

As in the output of `netstat` shown earlier, this output is truncated for brevity's sake. This example shows two types of connections. The first non-header line, which begins with `ssh`, shows an outgoing connection from `nessus.rodbooks.com` (the system on which the command was typed) to the `ssh` port on `seeker.rodbooks.com`. Such connections are identified by the existence of two hostnames in the `NAME` column and by the keyword `ESTABLISHED` in the same column. The next two lines, which begin with `exim4` and `sshd`, show two servers that are listening for connections on the `smtp` and `ssh` ports, respectively. These lines are identified by the fact that the `NAME` column takes the form `*:service (LISTEN)`, where *service* is the service name or port number. Other columns in the output reveal additional information, such as the `PID` and username associated with the port access.



If you type **lsuf -i** as an ordinary user, you'll only see your own network connections; thus, in order for this command to be a useful diagnostic for system security, you must run it as root.

You can restrict the output of **lsuf** by including an address after the **-i** option. The address takes the following form:

```
[46] [protocol] [@hostname|hostaddr] [:service|port]
```

The digit 4 or 6 represents an IPv4 or IPv6 connection, the *protocol* is the protocol type (TCP or UDP), the *hostname* or *hostaddr* is the computer hostname or IP address associated with the remote system, the *service* is a service name (from `/etc/services`), and the *port* is the port number. For instance, suppose you want to verify that no FTP server is running on a computer. You can search for any connections associated with the FTP port:

```
# lsuf -i :ftp
```

Alternatively, you can replace `ftp` with `21`, because `21` is the port number associated with the FTP port. (Table 8.2 in Chapter 8 summarizes the common network port numbers.) In either case, this command returns a list of all processes associated with FTP connections, both incoming and outgoing. If no such connections exist, the command returns no output; the system simply produces a new command prompt. Be sure to note which output lines are linked with server as opposed to client processes. Even if you're not running an FTP server locally, the preceding command may produce dozens of lines of output if users on the computer are making use of FTP clients.

To perform a general audit of your system's network connections, you should type **lsuf -i** by itself, without restricting the output. You'll probably want to pipe the output through `less` or use an `xterm`'s scroll buffer to review the output. Piping the output through `grep` to search for the string `LISTEN` can be a shortcut to find active servers:

```
# lsuf -i | grep LISTEN
```

Paging through the raw output (without using `grep` to search for `LISTEN`) will provide you with a better idea of your system's overall network use. You could conceivably spot something suspicious, such as an outgoing network connection to a sensitive computer that the client shouldn't be contacting. This network activity may indicate active cracking attempts by a user of the client, intrusion by an outsider, or the work of an automated worm or Trojan horse program.

If you identify programs that shouldn't be running, such as unnecessary servers, you can use the command name, PID, and other information to help shut them down. The upcoming section "Disabling Unused Servers" describes how to do this in more detail.

Using Remote Network Scanners

Network scanners, such as Nmap (<http://www.insecure.org/nmap/>) or Nessus (<http://www.nessus.org>), can scan for open ports on the local computer or on other computers. The more sophisticated scanners, including Nessus, check for known vulnerabilities, so they can tell you if a server may be compromised should you decide to leave it running.



Network scanners are used by crackers to locate likely target systems, as well as by network administrators for legitimate purposes. Many organizations have policies forbidding the use of network scanners except under specific conditions. Therefore, you should check these policies and obtain explicit permission, signed and in writing, to perform a network scan. Failure to do so could cost you your job or even result in criminal charges, even if your intentions are honorable.

Nmap is capable of performing a basic check for open ports. Pass the `-sT` parameter and the name of the target system to it, as shown here:

```
$ nmap -sT seeker.rodsbooks.com
Starting Nmap 4.53 ( http://insecure.org ) at 2008-09-04 15:38 EDT
Interesting ports on seeker.rodsbooks.com (192.168.1.6):
Not shown: 1704 closed ports
PORT      STATE SERVICE
22/tcp    open  ssh
80/tcp    open  http
2049/tcp  open  nfs
3306/tcp  open  mysql

Nmap done: 1 IP address (1 host up) scanned in 0.100 seconds
```



As with the output of `netstat` and `lsof` shown earlier, this output has been trimmed for brevity's sake.

This output shows four open ports: 22, 80, 2049, and 3306, used by `ssh`, `http`, `nfs`, and `mysql`, respectively. If you weren't aware that these ports were active, you should log into the scanned system and investigate further, using `netstat`, `lsof`, or `ps` to locate the programs using these ports and, if desired, shut them down. The `-sT` option specifies a scan of TCP ports. A few servers, though, run on UDP ports, so you need to scan them by typing `nmap -sU hostname`. (This usage requires root privileges, unlike scanning TCP ports.)

Nmap is capable of more sophisticated scans, including "stealth" scans that aren't likely to be noticed by most types of firewalls, ping scans to detect which hosts are active, and more. The Nmap man page provides details. Nessus, which is built atop Nmap, provides a

GUI and a means of performing automated and still more sophisticated tests. Nessus comes as separate client and server components; the client enables you to control the server, which does the actual work.

When you use a network scanner, you should consider the fact that the ports you see from your test system may not be the same as those that might be visible to an attacker. This issue is particularly important if you're testing a system that resides behind a firewall from another system that's behind the same firewall. Your test system is likely to reveal accessible ports that would not be accessible from the outside world. On the other hand, a cracker on your local network would most likely have access similar to your own, so you shouldn't be complacent because you use a firewall. Nonetheless, firewalls can be important tools for hiding servers without shutting them down.



You can use a standalone Linux boot CD-ROM to perform security checks on a network. Tools intended for this purpose, such as BackTrack (<http://www.remote-exploit.org/backtrack.html>), provide easy access to Nmap and other network security tools, enabling quick checks of network security even if no computer on that network regularly runs Linux.

Examining Configuration Files

Most Linux server packages include configuration files. Thus, you may be able to spot installed but unwanted servers by looking for their configuration files. On most systems, two classes of files are important: those controlling SysV startup scripts and those controlling your super server. Slackware is a bit odd because it doesn't use SysV startup scripts *per se*; instead, it uses one startup script for each runlevel. For Slackware, therefore, you must skim the relevant runlevel startup script looking for suspicious calls.

SysV startup scripts are described in detail in Chapter 5, "Booting Linux and Editing Files," so review that chapter for details of how they're managed. Generally speaking, you'll look in `/etc/rc?.d`, `/etc/init.d/rc?.d`, or `/etc/rc.d/rc?.d`, where `?` is your default runlevel number, for scripts whose names take the form `S##server`, where `##` is a number and `server` is the name of the server. If you find such a script for a server you know you don't want to run, you should disable it using your SysV startup script editing tools, as described in Chapter 5.

Be aware that many SysV startup scripts start entire subsystems that aren't directly network-related. Thus, you'll probably see SysV startup scripts that you don't recognize. You shouldn't automatically disable these scripts, because they may be necessary even if you don't recognize the name. If in doubt, leave it in place until you can research the matter further.



Try doing a Web search on the name of the SysV startup script (minus the `S` and sequence number), possibly in conjunction with "Linux" or "startup script." Chances are, you'll find a helpful reference.

The other major configuration-file class you should examine is the super server configuration. Thus, you should check your `inetd` or `xinetd` configuration files for unwanted servers. Also, unlike SysV startup scripts, super servers only launch network servers. Therefore, you should take a more aggressive approach to disabling entries you don't recognize from your super server configuration than you do with SysV startup scripts.

On some older systems, `/etc/inittab` deserves examination. This file, described in Chapter 5, controls some of the earliest stages of the startup process. Of greatest interest from a security point of view is the fact that older `/etc/inittab` installations started the processes used to accept text-mode logins, as well as similar processes used to accept logins via dial-up modems and RS-232 serial ports. These processes are called `getty` or some variant of this, such as `mingetty`. Ordinarily, a Linux machine must have at least one such process running, and it's controlled via an `/etc/inittab` entry such as the following:

```
1:2345:respawn:/sbin/mingetty --noclear tty1
```

The first character of this line (1) specifies the virtual terminal (VT) it controls. Most Linux distributions include similar lines for the first six VTs, and there's usually no need to adjust these lines. Lines that begin with `S#`, where `#` is a number, control login via RS-232 serial ports and modems:

```
S0:2345:respawn:/usr/sbin/mgetty -F -s 57600 /dev/ttyS0
```

If you want to use a modem with the computer but don't want to enable remote logins via the modem, you should ensure that `/etc/inittab` does *not* have such lines.

Modern systems that lack `/etc/inittab` or have only very basic `/etc/inittab` files typically move these functions into other files, such as SysV startup scripts or files in `/etc/event.d`. You won't ordinarily need to modify such configurations, but you may want to check to be sure your system isn't listening for dial-up modem connections unnecessarily. Files called `/etc/event.d/tty#` control local login access, whereas `/etc/event.d/ttyS#` files control RS-232 serial or modem access.

Uninstalling or Reconfiguring Servers

Once you've identified an unnecessary server, your task becomes one of shutting it down. Broadly speaking, two options exist:

- You can disable the server by changing its SysV configuration or disabling it in your system's super server. Consult Chapter 5 and the preceding sections on `inetd` and `xinetd` for details on how to perform these tasks. Disabling the server in this way has the advantage that you can easily reactivate the server in the future if you decide to do so. It has the disadvantage that the server's files will continue to consume disk space, and the server might be *accidentally* reactivated in the future.
- You can completely uninstall the server using your distribution's package management tools or by otherwise deleting its files. Chapter 2, "Managing Software," describes this task. Completely uninstalling software has the advantage of reducing the risk of accidental reactivation, but it has the drawback that you won't be able to easily reactivate the server intentionally should you decide to do so.

Overall, completely removing the server is generally preferable unless you merely want to temporarily disable a server. If you decide to reactivate the server in the future, you can always re-install it.

Administering Local Security

Security isn't limited to networking—local security issues can be as much of a threat as remote intruders. Thus, you should attend to some local security matters: securing passwords, limiting root access to the computer, setting user limits, and tracking down SUID/SGID files.

Securing Passwords

A default Linux configuration relies heavily on passwords. Users' passwords are their keys into the system, and if users are careless with their passwords, security breaches can result. Understanding these risks is critical to maintaining system security, but this is one task for which you *must* enlist the help of your users; after all, they're the ones who are in possession of their passwords! You should also be aware of some of the tools Linux provides to help keep passwords secure. (Most of the details concerning password-related commands are described in Chapter 7, "Administering the System.")

Password Risks

Passwords can end up in crackers' hands in various ways, and you must take steps to minimize these risks. Steps you can take to improve your system's security include the following:

Use strong passwords. Users should employ good passwords, as described shortly in "Choosing a Good Password." This practice won't eliminate all risk, though.

Change passwords frequently. You can minimize the chance of damage due to a compromised password by changing passwords frequently. Some Linux tools can help to enforce such changes, as described briefly in "Tools for Managing Passwords" and in more detail in Chapter 7.

Use shadow passwords. If a cracker who's broken into your system through an ordinary user account can read the password file, or if one of your regular users is a cracker who has access to the password file, that individual can run any of several password-cracking programs on the file. For this reason, you should use shadow passwords stored in `/etc/shadow` whenever possible. Most Linux distributions use shadow passwords by default. If yours doesn't, consult the upcoming section "Tools for Managing Passwords" for information about enabling this feature.

Keep passwords secret. You should remind your users not to reveal their passwords to others. Such trust is sometimes misplaced, and sometimes even a well-intentioned password recipient may slip up and let the password fall into the wrong hands. This can happen by

writing the password down, storing it in electronic form, or sending it by e-mail or other electronic means. Users shouldn't e-mail their own passwords even to themselves, because e-mail can be intercepted.

Use secure remote login protocols. Certain remote login protocols are inherently insecure; all data traverse the network in an unencrypted form. Intervening computers can be configured to snatch passwords from such sessions. Because of this, it's best to disable Telnet, FTP, and other protocols that use cleartext passwords in favor of protocols that encrypt passwords, such as SSH.

Be alert to shoulder surfing. If your users log in using public terminals, as is common on college campuses, in Internet cafes, and the like, it's possible that others will be able to watch them type their passwords (a practice sometimes called *shoulder surfing*). Users should be alert to this possibility and minimize such logins if possible.

Use each password on just one system. If one computer's password database is compromised, and if users of that system reuse their passwords on other systems, those other systems can be compromised. For this reason, it's best to use each password just once. Unfortunately, the proliferation of Web sites that require passwords for access makes this rule almost impossible to enforce, at least without violating the rule of not writing the password down. (Modern Web browsers can remember passwords for you, but this is done by storing them in a file—essentially, writing them down.) A reasonable compromise might be to use one password for the least-sensitive Web sites (such as online newspapers) and unique passwords for sensitive Web sites (such as banking sites) and login accounts.

Be alert to social engineering. Crackers often use *social engineering* to obtain passwords. This practice involves tricking individuals into giving up their passwords by pretending to be a system administrator or by otherwise misleading victims. Amazingly, a large percentage of people fall for this ploy. A related practice is *phishing*, in which an attacker puts up a fake Web site or sends an e-mail pretending to be from somebody else. The victim is then lured into revealing sensitive data (such as credit card numbers).

Some of these steps are things you can do, such as replacing insecure remote login protocols with encrypted ones. Others are things your users must do. This illustrates the importance of user education, particularly on systems with many users.

Choosing a Good Password

As a general rule, people tend to be lazy when it comes to security. In computer terms, this means users tend to pick passwords that are easy to guess, and they change those passwords infrequently. Both these conditions make a cracker's life easier, particularly if the cracker knows the victim. Fortunately, Linux includes tools to help make your users select good passwords and change them regularly.

Common (and therefore poor) passwords include those based on the names of family members, friends, and pets; favorite books, movies, television shows, or the characters in any of these; telephone numbers, street addresses, or Social Security numbers; or other meaningful personal information. Any single word that's found in a dictionary (in *any*

language) is a poor choice for a password. The best possible passwords are random collections of letters, digits, and punctuation. Unfortunately, such passwords are difficult to remember. A reasonable compromise is to build a password in two steps: First, choose a base that's easy to remember but difficult to guess. Second, modify that base in ways that increase the difficulty of guessing the password.

One approach to building a base is to use two *unrelated* words, such as *bun* and *pen*. You can then merge these two words (bunpen). Another approach, and one that's arguably better than the first, is to use the first letters of a phrase that's meaningful to the user. For instance, the first letters of "yesterday I went to the dentist" become yiwttd. In both cases, the base should not be a word in any language. As a general rule, the longer the password, the better. Older versions of Linux had password length limits of eight characters, but those limits have been lifted by the use of the MD5 password hash, which is the standard on modern Linux distributions. Many Linux systems require passwords to be at least four to six characters in length; the `passwd` utility won't accept anything shorter than the distribution's minimum.

With the base in hand, it's time to modify it to create a password. The user should apply at least a couple of several possible modifications:

Adding numbers or punctuation The single most important modification is to insert random numbers or punctuation in the base. This step might yield, for instance, bu3npe&n or y#i9wttd. As a general rule, add at least two symbols or numbers.

Mixing case Linux uses case-sensitive passwords, so jumbling the case of letters can improve security. Applying this rule might produce Bu3nPE&n and y#i9WttD, for instance.

Reversing order A change that's very weak by itself but that can add somewhat to security when used in conjunction with the others is to reverse the order of some or all letters. You might apply this to just one word of a two-word base. This could yield Bu3nn&EP and DttW9i#y, for instance.

Your best tool for getting users to pick good passwords is to educate them. Tell them that passwords can be guessed by malicious individuals who know them or even who target them and look up personal information in telephone books, on Web pages, and so on. Tell them that, although Linux encrypts its passwords internally, programs exist that feed entire dictionaries through Linux's password encryption algorithms for comparison to encrypted passwords. If a match is found, the cracker has found the password. Therefore, using a password that's not in a dictionary, and that isn't a simple variant of a dictionary word, improves security substantially. Tell your users that their accounts might be used as a first step toward compromising the entire computer or as a launching point for attacks on other computers. Explain to your users that they should *never* reveal their passwords to others, even people claiming to be system administrators—this is a common scam, but real system administrators don't need users' passwords. You should also warn them not to use the same password on multiple systems because doing so quickly turns a compromised account on one system into a compromised account on all the systems. Telling your users these things will help them understand the reasons for your concern, and it's likely to help motivate at least some of them to pick good passwords.

If your users are unconcerned after being told these things (and in any large installation, some will be), you'll have to rely on the checks possible in `passwd`. Most distributions' implementations of this utility require a minimum password length (typically four to six characters). They also usually check the password against a dictionary, thus weeding out some of the absolute worst passwords. Some require that a password contain at least one or two digits or punctuation.



Password-cracking programs, such as Crack (<http://www.crypticide.com/alecm/security/>), are easy to obtain. You might consider running such programs on your own encrypted password database to spot poor passwords, and in fact, this is a good policy in many cases. It's also grounds for dismissal in many organizations and can even result in criminal charges being brought, at least if done without authorization. If you want to weed out bad passwords this way, discuss the matter with your superiors and obtain written permission from a person with the authority to grant it before proceeding. Take extreme care with the files involved, too; it's best to crack the passwords on a computer with *no* network connections.

Another password security issue is password changes. Frequently changing passwords minimizes the window of opportunity for crackers to do damage; if a cracker obtains a password but it changes before the cracker can use it (or before the cracker can do further damage using the compromised account), the password change has averted disaster. As described shortly, you can configure accounts to require periodic password changes. When so configured, an account will stop accepting logins after a time if the password isn't changed periodically. (You can configure the system to warn users when this time is approaching.) This is a very good option to enable on sensitive systems or those with many users. Don't set the expire time too low, though—if users have to change their passwords too frequently, they'll probably just switch between a couple of passwords, or pick poor ones. Precisely what “too low” a password change time is depends on the environment. For most systems, one to six months is probably a reasonable change time, but for some it may be longer or shorter.

Tools for Managing Passwords

Most Linux distributions use shadow passwords by default, and for the most part, this chapter is written with the assumption that this feature is active. In addition to providing extra security by moving hashed passwords out of the world-readable `/etc/passwd` file and into the more secure `/etc/shadow` file, shadow passwords add extra account information.

One of the advantages of shadow passwords is that they support password aging and account expiration features. These features enable you to enforce password changes at regular intervals or to automatically disable an account after a specified period of time. You can enable these features and set the times using the `chage` command, which is described in more detail in Chapter 7.

The `usermod` utility, described in Chapter 7, can be used to adjust some shadow password features, such as account expiration dates. The `chage` command is more thorough with respect to account security features, but `usermod` can adjust more non-security account features.

Limiting *root* Access

Because `root` can do anything on a Linux computer, access to that account must of course be limited. On a system with a single administrator, this can be accomplished by having the administrator set a unique `root` password that nobody else knows. This user can then log in directly as `root` or use `su` to acquire root privileges. The `su` command's name stands for *switch user*, and it's used to change a user's apparent identity. Typing `su` alone results in a prompt for the root password. If the user types that password correctly, the session effectively becomes a root session. You can also type a username after `su` to acquire that user's privileges. When `root` does so, no password is required. (This is sometimes handy for investigating problems reported by a single user.) To run a single program with root privileges, use `-c` to specify the program name, as in `su -c "lsdf -i"` to run `lsdf -i` as `root`.

Logging in directly as `root` is generally discouraged for several reasons: No record of who typed the password appears in log files; the `root` password can be intercepted in various ways; and if the user leaves the terminal, a passerby can hijack the computer. Using `su` is somewhat better than a direct login from a security point of view, because use of `su` generally leaves a trace in system logs of who became `root`.

A method of acquiring `root` access that is somewhat more secure than either direct logins or `su` is `sudo`. This program runs a single command as `root`; for instance, to run `lsdf -i` as `root`, you type

```
$ sudo lsdf -i
[sudo] password for georgia:
```

In this example, the computer prompts for the *user's* (*georgia's*) password, not for the `root` password. The idea behind `sudo` is that you first configure the computer to accept certain users as `sudo` users. Those users may then use *their own* passwords to perform superuser tasks, even if those users don't have the `root` password. You can even fine-tune what tasks users may perform. This is done via the `/etc/sudoers` configuration file. You must edit this configuration file via `visudo`, which is a variant of `Vi` (described in Chapter 5) that's used only to edit `/etc/sudoers`.

The `/etc/sudoers` file consists of two types of entries: aliases and user specifications. Aliases are basically variables; you can use them to define groups of commands, groups of users, and so on. User specifications link users to machines and commands (possibly using aliases for some or all options). Thus, you can configure `sudoers` such that `georgia` can run network programs with root privileges but not account maintenance tools, whereas `george` can run account maintenance tools but not network programs.

Your default `/etc/sudoers` file probably includes several examples. Consider the following lines:

```
## Storage
Cmd_Alias STORAGE = /sbin/fdisk, /sbin/sfdisk, /sbin/parted,
/sbin/partprobe, /bin/mount, /bin/umount

## Processes
Cmd_Alias PROCESSES = /bin/nice, /bin/kill, /usr/bin/kill, /usr/bin/killall

%sys ALL = STORAGE, PROCESSES
%disk ALL = STORAGE
%wheel ALL=(ALL) ALL
```

This example defines two command aliases, `STORAGE` and `PROCESSES`, each of which stands in for a set of commands. Users who are members of the `sys` group may use both sets of commands; users who are members of the `disk` group may use the `STORAGE` commands but not the `PROCESSES` commands; and members of the `wheel` group may use all commands, whether or not they're explicitly mentioned in `/etc/sudoers`.

Some distributions, such as Ubuntu, make heavy use of `sudo`; these distributions are designed to be administered exclusively via `sudo`, and they set up an `/etc/sudoers` file that provides at least one user with easy access to all system utilities. Other distributions don't rely on `sudo` this way, although you can tweak your `sudo` configuration to enable administration via `sudo` if you like.

Setting Login, Process, and Memory Limits

Sometimes you may want to impose limits on how many times users may log in, how much CPU time they can consume, how much memory they can use, and so on. Imposing such limits is best done through a Pluggable Authentication Modules (PAM) module called `pam_limits`. Most major Linux distributions use this module as part of their standard PAM configuration, so chances are you won't need to add it; however, you will still need to configure `pam_limits`. You do so by editing its configuration file, `/etc/security/limits.conf`. This file contains comments (denoted by a hash mark, `#`) and limit lines that consist of four fields:

```
domain type item value
```

Each of these fields specifies a particular type of information:

The domain The *domain* describes the entity to which the limit applies. It can be a username; a group name, which takes the form `@groupname`; or an asterisk (*) wildcard, which matches everybody.

Hard or soft limits The *type* field specifies the limit as hard or soft. A hard limit is imposed by the system administrator and cannot be exceeded under any circumstances,

whereas a **soft** limit may be temporarily exceeded by a user. You can also use a dash (-) to signify that a limit is both hard and soft.

The limited item The *item* field specifies what type of item is being limited. Examples include *core* (the size of core files), *data* (the size of a program's data area), *fsize* (the size of files created by the user), *nofile* (the number of open data files), *rss* (the resident set size), *stack* (the stack size), *cpu* (the CPU time of a single process in minutes), *nproc* (the number of concurrent processes), *maxlogins* (the number of simultaneous logins), and *priority* (the process priority). The *data*, *rss*, and *stack* items all relate to memory consumed by a program. These and other measures of data capacity are measured in kilobytes.

The value The final field specifies the value that's to be applied to the limit.

As an example, consider a system on which certain users should be able to log in and perform a limited number of actions but not stay logged in indefinitely and consume vast amounts of CPU time. You can use a configuration like this one:

```
@limited hard cpu 2
```

This configuration applies a hard CPU limit of two minutes to the `limited` group. Members of this group can log in and run programs; but if one of those programs consumes more than two minutes of CPU time, it will be terminated.



CPU time and total system access time are two entirely different things. CPU time is calculated based on the amount of time the CPU is actively processing a user's data. Idle time (for instance, when a user's shell is active but no CPU-intensive tasks are running) doesn't count. Thus, a user can log in and remain logged in for hours even with a very low hard CPU time limit. This limit is intended to prevent problems caused by users who run very CPU-intensive programs on systems that shouldn't be used for such purposes.

Another way to set limits on system resource use is via the `ulimit` command. This command is a bash built-in command, so it only affects bash and programs launched from it. The `ulimit` syntax is as follows:

```
ulimit [options [limit]]
```

The *options* define what is being limited:

Core file limits The `-c` option limits the size of *core dumps*, which are files created for debugging purposes in certain types of program crashes.

File limits The `-f` option limits the size of files that may be created by the shell, and `-n` limits the number of open file descriptors. (Most systems don't honor the `-n` limits, though.)

Process limits The `-u` option limits the number of processes a user may run, and `-t` limits the total CPU time in seconds.

Memory limits The `-v` option sets the total amount of virtual memory available to the shell, `-s` sets the maximum stack size, `-m` sets the maximum resident set size, `-d` limits programs' data set size, and `-l` sets the maximum size that may be locked into memory.

Hard and soft limits The `-H` and `-S` options modify other options, causing them to be set as *hard* or *soft* limits, respectively. Hard limits may not be subsequently increased, but soft limits may be. If neither option is provided, `ulimit` sets both the hard and soft limits for the feature specified.

Current settings Passing `-a` causes `ulimit` to report its current settings.

The *limit* is typically a numeric value associated with the limit. The `ulimit` command is often found in system or user bash startup scripts, typically as `ulimit -c 0`, in order to prevent creation of core files, which can sometimes clutter a filesystem. If your users perform software development, you may want to ensure that you do *not* set this limit, or at least set it as a soft limit (as in `ulimit -Sc 0`) so users may override it when necessary.



Because `ulimit` is a bash built-in command, its utility as a system security tool is limited. If users have access to GUI login tools or can log into the system in any way that bypasses bash (such as via SSH, depending on how it's configured), restrictions imposed by `ulimit` become meaningless. Thus, you should treat `ulimit` as a way to prevent problems because of accidental, rather than intentional, abuse of the system.

One particularly radical approach to security is to use the `/etc/nologin` file. If this file is present, only `root` may log into the computer. In many respects, this is like setting critical system limits to 0 for all other users. This file is most likely to be useful on dedicated server systems that have no regular console or remote shell users.

Locating SUID/SGID Files

Chapter 4, “Managing Files,” describes the SUID and SGID bits. In brief, these are special flags that may be applied to executable program files, causing Linux to treat the program as if it were run by the program file's owner (for SUID) or by the file's group (for SGID) rather than by the individual who actually ran the program. For instance, if a program's SUID bit is set, and if the program file is owned by `bruce`, the program, when run by anybody, will be able to access all the files owned by `bruce` and otherwise behave as if `bruce` had run it.

The SUID and SGID bits are frequently associated with the `root` account in order to enable them to perform tasks that require special privilege. For instance, the `passwd` program (described in Chapter 7) is SUID `root` because only `root` may modify the Linux password database. Thus, for an ordinary user to change a password, some mechanism must exist to run a process as `root`. That mechanism, in the case of `passwd`, is the SUID bit.

The problem with all of this is that the SUID and SGID bits can be security risks. For instance, suppose the `rm` program's SUID bit was set. This program is normally owned by `root`, so setting the SUID bit on `rm` would mean that any user could delete any file on the

system. Although no Linux distribution sets the SUID bit on `rm` by default, the SUID bit can be set inappropriately. This can happen by accident (say, a mistyped command by `root`), by malice (if a cracker gains access to the system), or because of a more subtle misconfiguration by the distribution maintainer (the SUID bit set unnecessarily on a program for which it's less blatantly inappropriate than `rm`). Even if the SUID or SGID bit is set appropriately, a bug in the program can become more serious because the bug executes as `root`. If the bug enables users to write files, for example, any user can exploit the bug to overwrite critical system configuration files. For these reasons, you should periodically review your system to find all the SUID programs and, if appropriate, change their configuration.

To do this, you can use the `find` command, which is described in detail in Chapter 4. In particular, you can use the `-perm mode` option, which searches for files with the specified permission mode. To search for SUID and SGID files, you should pass a *mode* of `+6000`. The symbolic representation for the SUID and SGID bits is `6000`, and the plus sign (+) tells `find` to locate any file with any of the specified bits set. (You could search for SUID files alone by passing `+4000` or SGID alone by passing `+2000`.) You may also want to pass `-type f`, which restricts the search to regular files. (Directories use the SUID and SGID bits differently, as described in Chapter 4.) Thus, to search the entire computer for SUID and SGID programs, you type this:

```
# find / -perm +6000 -type f
```

The result is a list of files, one per line, that have either the SUID or the SGID bits set. Programs that are likely to be present in this list include `su`, `ping`, `mount`, `passwd`, `umount`, and `sudo`. These programs all have a legitimate need to be so configured. Most systems have additional SUID and SGID programs. If you have doubts about whether the program really needs this status, you should investigate further. Try verifying the package integrity using your package management tools and perform a Web search on the program name and “SUID” or “SGID,” as appropriate. You can also try changing the SUID status of the program using `chmod`, as described in Chapter 4, and see if it still works as it should when run by a normal user.



Programs that are SUID or SGID root but that shouldn't be can be a sign of system compromise. Crackers might reconfigure programs this way in order to more easily do their dirty work. Thus, if you find such programs, investigate the overall integrity of the system. On the other hand, if a distribution maintainer set the SUID or SGID bit unnecessarily, this isn't cause for concern about a break-in, although you may want to fix the matter. Likewise, accidental misconfiguration by you or another administrator isn't cause for massive system upheaval—but you'll need to dig a bit deeper to ascertain whether such a change was accidental or a sign of a deeper problem.

Configuring SSH

In the past, Telnet has been the remote text-mode login protocol of choice on Linux and Unix systems. Unfortunately, Telnet is severely lacking in security features. Thus, in recent years SSH has grown in popularity, and it is in fact the preferred remote login tool. SSH can also handle file transfer tasks similar to those of FTP. For these reasons, knowing how to configure SSH can be very helpful. This task requires knowing a bit about SSH generally and about the SSH configuration file under Linux. As is usual in this chapter, I conclude the look at SSH with information about the security implications of running the server.



SSH is complex enough that I can't cover more than its basics in this chapter. Consult OpenSSH's documentation or a book on the topic, such as *SSH, The Secure Shell: The Definitive Guide, Second Edition*, by Daniel J. Barrett, Richard Silverman, and Robert G. Byrnes (O'Reilly, 2005), for more details.

SSH Basics

Linux supports remote login access through several different servers, including Telnet, Virtual Network Computing (VNC), and even X. Unfortunately, most of these methods suffer from a major drawback: They transfer all data over the network in unencrypted form. This fact means that anybody who can monitor network traffic can easily snatch sensitive data, often including passwords. (VNC and a few other protocols encrypt passwords but not other data.) This limitation puts a serious dent in the utility of these remote login tools; after all, if using a remote access protocol means you'll be giving away sensitive data or compromising your entire computer, it's not a very useful protocol.



Non-encrypting remote access tools are particularly risky for performing work as root, either by logging in directly as root or by logging in as an ordinary user and then using `su`, `sudo`, or other tools to acquire root privileges.

SSH was designed to close this potentially major security hole by employing strong encryption techniques for all parts of the network connection. SSH encrypts the password exchange and all subsequent data transfers, making it a much safer protocol for remote access.

In addition to encryption, SSH provides file transfer features and the ability to *tunnel* other network protocols—that is, to enable non-encrypted protocols to piggyback their data over an SSH connection, thus delivering SSH's encryption advantages to other protocols. This feature is frequently employed in conjunction with X, enabling encrypted remote GUI access, as described in Chapter 6, “Configuring the X Window System, Localization, and Printing.”

Of course, SSH's advantages don't come without a price. The main drawback of SSH is that the encryption and decryption consume CPU time. This fact slows down SSH connections compared to those of direct connections and can degrade overall system performance. This effect is modest, though, particularly for plain text-mode connections. If you tunnel a protocol that transfers much more data, such as X, you may see a greater performance drop when using SSH. Even in this case, the improved security is generally worth the slight speed cost.

Several SSH servers are available for Linux, but the most popular by far is the OpenSSH server (<http://www.openssh.org>). This program was one of the first open-source implementations of the SSH protocol, which was developed by the commercial SSH Communications Security (<http://www.ssh.com>), whose server is now sold under the name SSH Tectia. OpenSSH, SSH Tectia, and other SSH products can interoperate with one another, assuming they're all configured to support at least one common level of the SSH protocol. OpenSSH 5.1, the latest version as I write, supports SSH levels 1.3, 1.5, and 2.0, with 2.0 being the preferred level because of known vulnerabilities in the earlier versions.



OpenSSH is closely associated with the OpenBSD OS, so its Web site has an OpenBSD bias. If you visit the site, you may want to click the Linux link under the For Other OS's heading. You can find Linux-compatible source code and binaries from that site, and OpenSSH now ships with most Linux distributions.

OpenSSH may be launched via either a super server (`inetd` or `xinetd`) or a SysV startup script. The latter method is preferred, because the server may need to perform CPU-intensive tasks upon starting, so if it's started from a super server, OpenSSH may be sluggish to respond to connection requests, particularly on systems with weaker CPUs. Most distributions deliver SysV startup scripts with their SSH packages. If you make changes to your SSH configuration, you may need to pass the `reload` or `restart` option to the startup script, as in `/etc/init.d/sshd reload`. (Chapter 5 covers SysV startup scripts in more detail.) However it's launched, the OpenSSH server binary name is `sshd`—the same as the binary name for SSH Tectia.

Setting SSH Options for Your System

For the most part, SSH works reasonably well when it's first installed, so you may not need to make any changes to its configuration. If you do need to make changes, though, these are mostly handled through the main SSH configuration file, `/etc/ssh/sshd_config`. You can also edit some additional files to limit access to the SSH server or to change how SSH manages the login process.

Configuring Basic SSH Features

The `/etc/ssh/sshd_config` file consists mainly of option lines that take the following form:

Option value



Don't confuse the `sshd_config` file with the `ssh_config` file. The former controls the OpenSSH server, whereas the latter controls the SSH client program, `ssh`.

In addition to configuration lines, the `sshd_config` file holds comments, which are denoted by hash marks (`#`). Most sample configuration files include a large number of SSH options that are commented out; these lines specify the default values, so uncommenting the lines without otherwise changing them will have no effect. If you want to change an option, uncomment the line and change it. Most options' default values are suitable for most systems. The following list includes some that you may want to check and, perhaps, change:

Protocol This option specifies the protocol levels OpenSSH understands. Possible values are 1 and 2. You can configure OpenSSH to support both protocols by separating them by a comma, as in `1,2` or `2,1`, which are equivalent. Given the fact that OpenSSH protocol level 1 has been compromised, the safest configuration is to set `Protocol 2`. This limits the server's ability to communicate with older clients, though.

PermitRootLogin By default, this option is set to `yes`, which enables OpenSSH to accept direct logins by `root`. This is safer than a similar configuration under Telnet, but for a bit of added security, set this value to `no`. The result will be that anybody wanting to perform remote work as `root` will need to first log in as an ordinary user, which means that an intruder who has somehow acquired the `root` password will also need a regular username and its password.

X11Forwarding This option specifies whether or not OpenSSH's X tunneling features should be active. If you want to enable remote users to run X programs via SSH, you must set this option to `yes`. Doing so can slightly degrade security of the client's X display, though, depending on certain other options; hence the conservative default value of `no`.

For information about additional options, consult the man page for `sshd_config`. If you make changes to the SSH configuration, remember to restart it using the server's SysV startup script.

SSH Keys

Part of SSH's security involves *encryption keys*. Each server system and each user has a unique number, or key, for identification purposes. In fact, SSH uses a security system that involves two keys: a *public key* and a *private key*. These two keys are mathematically linked in such a way that data encrypted with a particular public key may be decrypted only with the matching private key. When establishing a connection, each side sends its public key to the other. Thereafter, each side encrypts data with the other side's public key, ensuring that the data can be decrypted only by the intended recipient. In practice, this is just the first step of the process, but it's critical. What's more, SSH clients typically retain the public keys of servers they've contacted. This enables them to spot changes to the public key. Such changes can be signs of tampering.

Most OpenSSH server SysV startup scripts include code that looks for stored public and private keys and, if they're not present, generates them. In total, four to six keys are needed: public and private keys for two or three encryption tools SSH supports. These keys are normally stored in `/etc/ssh` and are called `ssh_host_rsa_key` and `ssh_host_dsa_key` for private keys, with `.pub` filename extensions added for public keys. Some systems add `ssh_host_rsa1_key` and its associated public key. If your system doesn't have these keys, and you can't get the SSH server to start up, you can try generating the keys with the `ssh-keygen` command:

```
# ssh-keygen -q -t rsa1 -f /etc/ssh/ssh_host_key -C '' -N ''
# ssh-keygen -q -t rsa -f /etc/ssh/ssh_host_rsa_key -C '' -N ''
# ssh-keygen -q -t dsa -f /etc/ssh/ssh_host_dsa_key -C '' -N ''
```

Each of these commands generates both a private key (named in the `-f` parameter) and a public key (with the same name but with `.pub` appended).

Don't run these `ssh-keygen` commands if the SSH key files already exist. Replacing the working files will cause clients who've already connected to the SSH server to complain about the changed keys and possibly refuse to establish a connection.



Be sure the private keys are suitably protected; if an intruder obtains one of these keys, the intruder can impersonate your system. Typically, these files should have 0600 (`-rw-----`) permissions and be owned by root. The public key files (with `.pub` filename extensions) should be readable by all users, though.

When you configure a client system, you may want to consider creating a global cache of host keys. As already noted, the `ssh` program records host keys for each individual user. (It stores these in the `~/.ssh/known_hosts` file.) When you set up the client, you can populate the global `ssh_known_hosts` file, which is normally stored in `/etc` or `/etc/ssh`. Doing so ensures that the public key list is as accurate as the sources you use to populate the global file. It also eliminates confirmation messages when users connect to the hosts whose keys you've selected to include in the global file.

How do you create this file? One simple way is to copy the file from a user account that's been used to connect to the servers you want to include. For instance, you can type `cp /home/ecernan/.ssh/known_hosts /etc/ssh/ssh_known_hosts` to use `ecernan`'s file. You may want to manually review this file before copying it. It consists of one line per host. Each line begins with a hostname, IP address, or both, and continues with the key type and the key. You can ignore most of this information, but pay attention to the hostnames and IP addresses. Ensure that the list includes all the SSH servers your client is likely to want to use and that it does *not* include inappropriate or unnecessary servers. You can remove lines in your text editor, if necessary. To add entries, use the account whose file you're copying to connect to the system you want to add. Chances are, `ssh` will display a warning about connecting to an unknown system. Confirm that you want to do so. Once you do this and reload the file, you should see an entry for the server.



OpenSSH 4.0 and later support hashing of hostnames in the known hosts file. When this feature is enabled, the hostname is *hashed* (that is, encrypted using a one-way encryption algorithm) and stored in hashed form. The idea is that you'll still be able to authenticate SSH servers to which you connect, because a hash of the typed hostname will match a hash of the stored hostname; but if an intruder steals your known hosts file, the intruder will be unable to determine the identities of the computers to which you've been connecting.

Controlling SSH Access

You can limit who may access an SSH server in various ways. The most obvious and basic method is via password authentication. The usual SSH authentication method is to employ a username and password, much as Telnet does. (The `ssh` client program sends the username automatically or as part of the command line, so you won't see a username prompt when logging in via `ssh`.)

Beyond password authentication, SSH supports several other types of limitations:

TCP Wrappers If you run SSH from a super server, or if the server was compiled with TCP Wrappers support, you can use the `/etc/hosts.allow` and `/etc/hosts.deny` files to limit access by IP address. Note that if you launch SSH via a SysV startup script, this approach works only if the server was compiled to support it. This support may or may not be present in your distribution's standard SSH package.

Firewalls As with all servers, you can restrict access by using a firewall. SSH uses TCP port 22. Technically, this isn't an SSH feature, but it's certainly useful for protecting an SSH server.

`/etc/nologin` If this file is present, SSH honors it. As described earlier, this file's presence means that only `root` may log in. Ordinarily, the file's contents are displayed as an error message; however, OpenSSH doesn't do this.

Copying Files via SSH

Most users employ the `ssh` client program, which provides remote login access—type `ssh othersystem` to log into `othersystem` using the same username you're using on the client system; or add a username, as in `ssh user@othersystem`, to log in using another username.

SSH includes a file-copying command, too: `scp`. This command works much like the `cp` command for copying files locally; however, you must specify the target computer, and optionally the username, just before the target filename. For instance, to copy the file `masterpiece.c` to the `lisa` account on `leonardo.example.com`, you would type

```
$ scp masterpiece.c lisa@leonardo.example.com:
```

The colon (`:`) that terminates this command is extremely important; if you omit it, you'll find that `scp` works like `cp`, and you'll end up with a file called `lisa@leonardo`

.example.com. If you want to rename the file, you can do so by including the new name following the colon.

Configuring Logins without Passwords

If you use SSH a lot, or if you use it in automated tools, you'll no doubt become annoyed by the need to type a password with every connection. There is a way around this requirement: You can set up the SSH client with keys and give the public key to the server computer. With this configuration, the SSH client computer can identify itself, possibly obviating the need for you to type a password.



Configuring SSH to operate without the use of passwords is convenient, but it does increase security risks. If somebody you don't trust ever gains access to your account on the SSH client system, that person will be able to log into the SSH server system as you without the benefit of your password. Thus, you should create a password-less login only from a client that's very well protected, if at all. Configuring access to the root account in this way is particularly risky.

To configure SSH to not require a password, follow these steps:

1. Log into the SSH client system as the user who will be performing remote access.
2. Type the following command to generate a version 2 SSH key:


```
$ ssh-keygen -q -t rsa -f ~/.ssh/id_rsa -C '' -N ''
```
3. Step 2 generates two files: `id_rsa` and `id_rsa.pub`. Transfer the second of these files to the SSH server computer in any way that's convenient—via floppy disk, by using `scp`, or by any other means. Copy the file under a temporary name, such as `temp.rsa`.
4. Log into the SSH server system. If you use SSH, you'll need to type your password.
5. Add the contents of the file you've just transferred to the end of the `~/.ssh/authorized_keys` file. (This file is sometimes called `~/.ssh/authorized_keys2`, so you should check to see which is present. If neither is present, you may need to experiment.) Typing `cat ~/temp.rsa >> ~/.ssh/authorized_keys` should do this job, if you stored the original file as `~/temp.rsa`.

If you now log out of the SSH server system and try to log in again via SSH from the client, you shouldn't be prompted for a password; the two computers handle the authentication automatically. If this doesn't work, chances are the `~/.ssh/authorized_keys` file needs another name, as described earlier. You may also want to check that the file includes a line matching the contents of the original public-key file on the client. Some older clients may require you to specify that you use version 2 of the SSH protocol by including the `-2` option:

```
$ ssh -2 server
```

Using *ssh-agent*

Another SSH authentication option is to use the `ssh-agent` program. This program requires a password to initiate connections, so it's more secure than configuring logins without passwords; however, `ssh-agent` remembers your password, so you need only type it once per local session. To use `ssh-agent`, follow these steps:

1. Follow the procedure for enabling no-password logins described in “Configuring Logins without Passwords,” but with one change: Omit the `-N ''` option from the `ssh-keygen` command in step 2. You'll be asked for a passphrase at this step. This passphrase will be your key for all SSH logins managed via `ssh-agent`.
2. On the SSH client system, type `ssh-agent /bin/bash`. This launches `ssh-agent`, which in turn launches `bash`. You'll use this `bash` session for subsequent SSH logins.
3. In your new shell, type `ssh-add ~/.ssh/id_rsa`. This adds your RSA key to the set that's managed by `ssh-agent`. You'll be asked to type your SSH passphrase at this time.

From this point on, whenever you use SSH to connect to a remote system to which you've given your public key, you won't need to type a password. You *will*, however, have to repeat steps 2 and 3 whenever you log out, and the benefits will accrue only to the shell launched in step 2 or any shells you launch from that one.

If you make heavy use of this facility, you can insert `ssh-agent` into your normal login procedure. For instance, you can edit `/etc/passwd` so that `ssh-agent /bin/bash` is your login shell. For a GUI login, you can rename your normal GUI login script (for instance, change `~/.xsession` to `~/.xsession-nossh`) and create a new GUI login script that calls `ssh-agent` with the renamed script as its parameter. Either action inserts `ssh-agent` at the root of your user process tree so that any call to SSH uses `ssh-agent`.

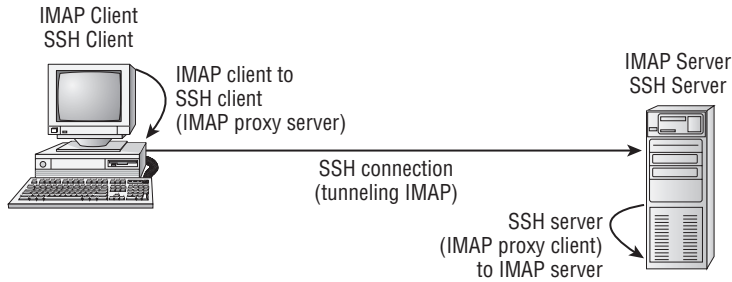
Using SSH Login Scripts

Ordinarily, an SSH text-mode login session runs the user's configured shell, which runs the shell's defined login scripts. The OpenSSH server also supports its own login script, `sshr` (normally stored in `/etc` or `/etc/ssh`). The OpenSSH server runs this script using `/bin/sh`, which is normally a symbolic link to `bash`, so you can treat it as an ordinary `bash` script.

Setting Up SSH Port Tunnels

SSH has the ability to extend its encryption capabilities to other protocols, but doing so requires extra configuration. The way this is done is known as *tunneling*. Chapter 6 described a special type of SSH tunneling involving X, but the process can work for other protocols.

The basic idea behind an SSH tunnel is illustrated in Figure 10.1. The server computer runs two server programs: a server for the tunneled protocol (Figure 10.1 uses the Internet Mail Access Protocol, IMAP, as an example) and an SSH server. The client computer also runs two clients: one for the tunneled protocol and one for SSH. The SSH client also listens for connections for the tunneled protocol; it's effectively both a client and a server. When the SSH client receives a connection from the tunneled protocol's client, the result is that the tunneled protocol's connection is encrypted using SSH, tunneled to the SSH server, and then directed to the target server. Thus, data pass over the network in encrypted form, even if the target protocol doesn't support encryption.

FIGURE 10.1 An SSH tunnel extends SSH's encryption benefits to other protocols.

Of course, all of this requires special configuration. The default configuration on the server enables tunneling; but to be sure, check the `/etc/ssh/sshd_config` file on the server for the following option:

```
AllowTcpForwarding no
```

If this line is present, change `no` to `yes`. If it's not present, or if it's already set to `yes`, you shouldn't need to change your SSH server configuration.

On the client side, you must establish a special SSH connection to the server computer. You do this with the normal `ssh` client program, but you must pass it several parameters. An example will help illustrate this use of `ssh`:

```
# ssh -N -f -L 142:mail.luna.edu:143 benf@mail.luna.edu
```

The `-N` and `-f` options tell `ssh` to not execute a remote command and to execute in the background after asking for a password, respectively. These options are necessary to create a tunnel. The `-L` option specifies the local port on which to listen, the remote computer to which to connect, and the port on the remote computer to which to connect. This example listens on the local port 142 and connects to port 143 on `mail.luna.edu`. (You're likely to use the same port number on both ends; I changed the local port number in this example to more clearly distinguish between the local and remote port numbers.) The final parameter (`benf@mail.luna.edu` in this example) is the remote username and computer to which the tunnel goes. Note that this computer need not be the same as the target system specified via `-L`.



If you want SSH on the client system to listen to a privileged port (that is, one numbered below 1024), you must execute the `ssh` program as root, as shown in the preceding example. If listening to a non-privileged port is acceptable, the `ssh` client can be run as a normal user.

With the tunnel established, you can use the client program to connect to the local port specified by the first number in the `-L` parameter (port 142 in the preceding example). For instance, this example is intended to forward IMAP traffic, so you'd configure a mail reader on the client to retrieve IMAP e-mail from port 142 on `localhost`. When

the e-mail reader does this, SSH kicks in and forwards traffic to the SSH server, which then passes the data on to the local port 143, which is presumably running the real IMAP server. All of this is hidden from the e-mail reader program; as far as it's concerned, it's retrieving e-mail from a local IMAP server.

SSH Security Considerations

SSH is intended to solve security problems rather than create them. Indeed, on the whole using SSH is superior to using Telnet for remote logins, and SSH can also take over FTP-like functions and tunnel other protocols. Thus, SSH is a big security plus compared to using less-secure tools.

Like all servers, though, SSH can be a security liability if it's run unnecessarily or inappropriately. Ideally, you should configure SSH to accept only protocol level 2 connections and to refuse direct root logins. If X forwarding is unnecessary, you should disable this feature. If possible, use TCP Wrappers or a firewall to limit the machines that can contact an SSH server. As with all servers, you should keep SSH up to date; there's always the possibility of a bug causing problems.

You should consider whether you really need a remote text-mode login server. Such a server can be a great convenience—often enough to justify the modest risk involved. For extremely high-security systems, though, using the computer exclusively from the console may be an appropriate approach to security.

One unusual security issue with SSH is its keys. As noted earlier, the private-key files are extremely sensitive and should be protected from prying eyes. Remember to protect the backups of these files, as well—don't leave a system backup tape lying around where it can be easily stolen.

Using GPG

SSH is designed to encrypt interactive login sessions and file transfers. Sometimes, though, another type of encryption is desirable: You may want to encrypt e-mail messages or files sent to another person via some other means. E-mail was never designed as a secure data transfer tool, and most e-mail messages pass through several e-mail servers and network routers. A compromise at any one of these points enables a cracker to sniff e-mail traffic and extract sensitive data, such as credit card or Social Security numbers. Encrypting your e-mail keeps such details private.

The usual tool for encrypting e-mail is the GNU Privacy Guard (GPG or GnuPG; <http://www.gnupg.org>) package. This package is an open source re-implementation of the proprietary Pretty Good Privacy (PGP). In addition to encrypting entire messages, GPG enables you to digitally “sign” messages. Used in this way, messages can be read by recipients who lack the GPG software or appropriate keys; but those who have these tools can verify that the contents haven't been tampered with.

Generating and Importing Keys

To begin using GPG, you should first install the software. Chances are, your distribution includes it as a standard package, so you can install it that way. Once this is done, you must generate keys. GPG keys are conceptually similar to SSH keys: You need a private key (a.k.a. a secret key) and a public key. As the names imply, the private key is kept private, but the public key is publicly available. You can sign your messages with your private key, and readers can verify it with your public key; or you can encrypt a message with another user's public key, and it can be decrypted only with that user's private key.

To generate keys, you use the `gpg` program with its `--gen-key` option:

```
$ gpg --gen-key
```

The program will ask you a series of questions. In most cases, answering with the defaults should work well, although you may have to type in your full name and e-mail address. The keys are stored in the `~/.gnupg` directory.

Once you've generated your keys, you can *export* your public key:

```
$ gpg --export name > gpg.pub
```

This command saves the public key associated with *name* in the file `gpg.pub`. You can use your e-mail address as *name*. (If you create additional public keys or add others' public keys, you can specify their names to export those keys.) You can then make your key available to others so that they may encrypt e-mail messages sent to you or verify your signed messages. Adding the `--armor` option produces ASCII output, which may be preferable if you intend to e-mail the public key. You can make the file accessible on your Web site, transfer it as an e-mail attachment, or distribute it in various other ways.

To encrypt e-mail you send to others, you must obtain their public keys. Ask your correspondents how to obtain them. Once you've done so, you can add their keys to your *keyring* (that is, the set of keys GPG maintains):

```
$ gpg --import filename
```

This command adds *filename* to your set of public keys belonging to other people.



Although public keys are, by definition, public, there are security concerns relating to them. Specifically, you should be sure you use a *legitimate* public key. Hypothetically, a miscreant could publish a fake public key in order to obtain sensitive communications or fake a signed e-mail. For instance, George might distribute a fake GPG public key that claimed to be from Harold. George could then either sign messages claiming to be from Harold or intercept e-mail sent to Harold that was encrypted using the fake key. Thus, you should use as secure a communication method as possible to distribute your public key and to receive public keys from others.

Once you've created your own key and, perhaps, imported keys from others, you can see what keys are available by using the `--list-keys` option to `gpg`:

```
$ gpg --list-keys
/home/gjones/.gnupg/pubring.gpg
-----
pub   1024D/190EDB2E 2008-09-05
uid           George A. Jones <gjones@example.com>
sub   2048g/0D657AC8 2008-09-05

pub   1024D/A8B2061A 2008-09-05
uid           Jennie Martin <jennie@luna.edu>
sub   2048g/4F33EF6B 2008-09-05
```

The `uid` lines contain identifiers you'll use when encrypting or decrypting data, so you should pay particular attention to that information.

Encrypting and Decrypting Data

To encrypt data, you use `gpg` with its `--out` and `--encrypt` options and, optionally, `--recipient` and `--armor`:

```
$ gpg --out encrypted-file --recipient uid --armor --encrypt original-file
```

You can use the UID from a `gpg --list-keys` output, or just the e-mail address portion, as the `uid` in this command. If you haven't signed the recipient's key, you'll have to verify that you want to use that key. The result is a new file, *encrypted-file*, which holds an encrypted version of *original-file*. If you omit the `--armor` option, the resulting file is a binary file; if you send it as e-mail, you'll need to send it as an attachment or otherwise encode it for transmission over the text-based e-mail system. If you include the `--armor` option, the output is ASCII, so you can cut-and-paste the encrypted message into an e-mail or send it as an attachment.

If you receive a message or file that was encrypted with your public key, you can reverse the encryption by using the `--decrypt` option:

```
$ gpg --out decrypted-file --decrypt encrypted-file
```

You'll be asked to enter your passphrase. The result should be a decrypted version of the original file.

In practice, GPG can be even easier to use than this description may make you think. GPG is primarily used to secure and verify e-mail, so most Linux e-mail clients provide GPG interfaces. These options call `gpg` with appropriate options to encrypt, sign, or decrypt messages. Details vary from one e-mail client to another, so you should consult your e-mail client's documentation for details.

Signing Messages and Verifying Signatures

As noted earlier, GPG can be used to sign messages so that recipients know they come from you. To do so, use the `--sign` or `--clearsign` option to `gpg`:

```
$ gpg --clearsign original-file
```

The `--sign` option creates a new file with the same name as the original, but with `.gpg` appended to the filename. This file is encrypted using your private key, so that it may only be decrypted with your public key. This means that anybody with your public key may read the message, but anybody who can read it knows it's from you. The `--clearsign` option works similarly, but it leaves the message text unencrypted and only adds an encrypted signature that can only be verified using your public key. The `--clearsign` option creates a file with a name that ends in `.asc`.

If you receive a signed message, you can verify the signature using the `--verify` option to `gpg`:

```
$ gpg --verify received-file
```

If any of the keys in your keyring can decode the message or verify the signature, `gpg` displays a `Good signature` message. To read a message that was encrypted via the `--sign` option, you must decrypt the message via the `--decrypt` option, as described earlier.

Summary

Maintaining system security is both important and time-consuming. A great deal of security emphasis is on network security, and for this, configuring your super server and disabling unused servers will go a long way. Attending to passwords and performing miscellaneous tasks to keep your local accounts from becoming security risks are also important security tasks.

Encryption is a hot topic in security. SSH is a protocol and tool that can handle many network encryption tasks by encrypting two-way connections between computers. Typically used as a remote login protocol, SSH can also be used to transfer files or encrypt other protocols. When you want to encrypt data sent to another individual via a tool such as e-mail, you can do so with the help of GPG. This package enables you to encrypt individual files, which can then be attached to or embedded in e-mail messages and decrypted by the recipient.

Exam Essentials

Identify the purpose of a super server. Super servers, such as `inetd` and `xinetd`, manage incoming network connections for multiple servers. They can add security and convenience features, and they can help minimize the memory load imposed by seldom-accessed servers.

Explain the function of super server port access controls. Super servers or programs called by them (such as TCP Wrappers) can restrict access to ports for the servers they manage. These restrictions occur at a higher level than a firewall's restrictions, and they apply only to the servers managed by the super server.

Summarize the tools you can use to identify the servers running on a computer. The `netstat` and `lsof` programs both provide options to list all (or a subset of) the open network connections, as well as programs that are listening for connections. Remote network scanners, such as Nmap, can probe another computer for open network ports. Perusal of local configuration files can also provide clues to what's running on a computer.

Describe why SUID and SGID programs are potentially risky. The set user ID (SUID) and set group ID (SGID) bits tell Linux to run the program as the user or group that owns the file. This is particularly risky when `root` owns the program file because it essentially elevates all users to `root` for the purposes of running the file, making bugs in the program more dangerous and raising the possibility of a clever user abusing the program to acquire full `root` privileges or otherwise wreaking havoc.

Explain why shadow passwords are important. Shadow passwords store password hashes in a file that can't be read by ordinary users, thus making it harder for miscreants on the local system to read the hashed passwords and use brute-force attacks to discover other users' passwords. Modern Linux distributions use shadow passwords by default.

Explain how to generate a good password. Ideally, passwords should be random. Failing that, one good approach is to generate a base that's hard to guess and then modify it by adding digits and punctuation, changing the case of some characters, and changing letter order.

Explain why SSH is the preferred remote text-mode login tool. The Secure Shell (SSH) protocol provides encryption for all traffic, including both the password exchange and all subsequent data exchanges, whereas older tools, such as Telnet, do not. This makes SSH much safer (if not 100 percent safe) for the exchange of sensitive data, particularly over untrusted networks such as the Internet.

Identify the most important SSH configuration file. The SSH server is controlled through the `/etc/ssh/sshd_config` file. The SSH client configuration file is `/etc/ssh/ssh_config`; don't confuse the two.

Describe the function of GPG. GPG enables public-key encryption of individual files or e-mail messages. You can use GPG to encrypt sensitive data for transmission over e-mail or other insecure means.

Review Questions

1. Typing `lsuf -i | grep LISTEN` as root produces three lines of output, corresponding to the `sendmail`, `sshd`, and `proftpd` servers. What can you conclude about the security of this system?
 - A. Everything's OK; the presence of `sshd` ensures that data are being encrypted via SSH.
 - B. The `sendmail` and `sshd` servers are OK, but the FTP protocol used by `proftpd` is insecure and should never be used.
 - C. The `sendmail` server should be replaced by Postfix or `qmail` for improved security, but `sshd` and `proftpd` are fine.
 - D. No conclusion can be drawn without further information; the listed servers may or may not be appropriate or authentic.
2. As part of a security audit, you plan to use Nmap to check all the computers on your network for unnecessary servers. Which of the following tasks should you do prior to running your Nmap check?
 - A. Back up `/etc/passwd` on the target systems to eliminate the possibility of its being damaged.
 - B. Obtain the root passwords to the target systems so that you can properly configure them to accept the Nmap probes.
 - C. Obtain written permission from your boss to perform the Nmap sweep.
 - D. Configure `/etc/sudoers` on the computer you intend to use for the sweep, to give yourself the ability to run Nmap.
3. Your login server is using PAM, and you want to limit users' access to system resources. Which configuration file will you need to edit?
 - A. `/etc/limits.conf`
 - B. `/etc/pam/limits.conf`
 - C. `/etc/security/limits.conf`
 - D. `/etc/security/pam/limits.conf`
4. Which of the following tools might you use to check for open ports on a local computer? (Select all that apply.)
 - A. Nmap
 - B. `netstat`
 - C. `lsuf`
 - D. `portmap`

5. Which of the following commands will locate all program files on a computer on which the SUID bit is set?
- A. `find / -type SUID`
 - B. `find / -perm +4000 -type f`
 - C. `find / -perm +SUID -type f`
 - D. `find / -type +4000`
6. The `/etc/sudoers` file on a computer includes the following line. What is its effect?
`%admin ALL=(ALL) ALL`
- A. Members of the `admin` group may run all programs with `root` privileges by using `sudo`.
 - B. Users in the `admin` user alias, defined earlier in the file, may run all programs with `root` privileges by using `sudo`.
 - C. The `admin` user alias is defined to include all users on the system.
 - D. The `admin` command alias is defined to include all commands.
7. Which command would you type, as `root`, to discover all the open network connections on a Linux computer?
- A. `lsof -c a`
 - B. `netstat -ap`
 - C. `ifconfig eth0`
 - D. `nmap -sT localhost`
8. A server/computer combination appears in both `hosts.allow` and `hosts.deny`. What's the result of this configuration when TCP Wrappers runs?
- A. TCP Wrappers refuses to run and logs an error in `/var/log/messages`.
 - B. The system's administrator is paged to decide whether to allow access.
 - C. `hosts.deny` takes precedence; the client is denied access to the server.
 - D. `hosts.allow` takes precedence; the client is granted access to the server.
9. When is the `bind` option of `xinetd` most useful?
- A. When you want to run two servers on one port
 - B. When you want to specify computers by name rather than IP address
 - C. When `xinetd` is running on a system with two network interfaces
 - D. When resolving conflicts between different servers
10. You've discovered that the Waiter program (a network server) is running inappropriately on your computer. You therefore locate its SysV startup script and shut it down by removing that script from your default runlevel. How can you further improve security? (Select all that apply.)
- A. By blocking the Waiter program's port using a firewall rule
 - B. By reading the Waiter program's documentation to learn how to run it in stealth mode
 - C. By tunneling the Waiter program's port through SSH
 - D. By uninstalling the Waiter package

11. You want to use `xinetd` access controls to limit who may access a server that's launched via `xinetd`. Specifically, only users on the 192.168.7.0/24 network block should be able to use that server. How may you do this?
 - A. Enter `hosts_allow = 192.168.7.0/24` in the `/etc/xinetd.d` configuration file for the server in question.
 - B. Enter `only_from = 192.168.7.0/24` in the `/etc/xinetd.d` configuration file for the server in question.
 - C. Enter `server : 192.168.7.`, where `server` is the server's name, in the `/etc/hosts.allow` file.
 - D. Enter `server : 192.168.7.`, where `server` is the server's name, in the `/etc/hosts.deny` file.
12. Of the following, which is the best password?
 - A. Odysseus
 - B. iA710ci^My
 - C. pickettomato
 - D. Denver2Colorado
13. Which of the following types of attacks involves sending bogus e-mail to lure unsuspecting individuals into divulging sensitive financial or other information?
 - A. Phishing
 - B. Script kiddies
 - C. Spoofing
 - D. Ensnaring
14. Ordinary users report being unable to log onto a computer, but `root` has no problems doing so. What might you check for to explain this situation?
 - A. A misbehaving `syslogd` daemon
 - B. A `login` process that's running as `root`
 - C. The presence of an `/etc/nologin` file
 - D. The presence of an SUID bit on `/bin/login`
15. Which servers might you consider retiring after activating an SSH server? (Select all that apply.)
 - A. SMTP
 - B. Telnet
 - C. FTP
 - D. NFS

16. You find that the `ssh_host_dsa_key` file in `/etc/ssh` has `0666 (-rw-rw-rw-)` permissions. Your SSH server has been in operation for several months. Should you be concerned?
- A. Yes
 - B. No
 - C. Only if the `ssh_host_dsa_key.pub` file is also world-readable
 - D. Only if you're launching SSH from a super server
17. For best SSH server security, how should you set the `Protocol` option in `/etc/ssh/sshd_config`?
- A. `Protocol 1`
 - B. `Protocol 2`
 - C. `Protocol 1,2`
 - D. `Protocol 2,1`
18. Why is it unwise to allow `root` to log on directly using SSH?
- A. Somebody with the `root` password but no other password can then break into the computer.
 - B. The `root` password should never be sent over a network connection; allowing `root` logins in this way is inviting disaster.
 - C. SSH stores all login information, including passwords, in a publicly readable file.
 - D. When logged on using SSH, `root`'s commands can be easily intercepted and duplicated by undesirable elements.
19. You've downloaded a GPG public key from a Web site, into the file `fredkey.pub`. What must you do with this key to use it?
- A. Type `inspect-gpg fredkey.pub`.
 - B. Type `gpg --readkey fredkey.pub`.
 - C. Type `import-gpg fredkey.pub`.
 - D. Type `gpg --import fredkey.pub`.
20. You want to send an encrypted message to an e-mail correspondent. You both have GPG. What do you need to exchange before you can send your encrypted message?
- A. Your correspondent must obtain your GPG public key.
 - B. Your correspondent must obtain your GPG private key.
 - C. You must obtain your correspondent's GPG public key.
 - D. You must obtain your correspondent's GPG private key.

Answers to Review Questions

1. D. The server names alone are insufficient to determine if they're legitimate. The computer in question may or may not need to run any of these servers, and their presence may or may not be intentional, accidental, or the sign of an intrusion. Contrary to option A, the mere presence of an SSH server does not ensure security. Although, as option B asserts, FTP is not a secure protocol, it's still useful in some situations, so the mere presence of an FTP server is not, by itself, grounds for suspicion. Similarly, in option C, although some administrators prefer Postfix or qmail to `sendmail` for security reasons, `sendmail` isn't necessarily bad, and the names alone don't guarantee that the `sshd` and `proftpd` servers are legitimate.
2. C. Although Nmap and other port scanners are useful security tools, they're also used by crackers, and many organizations have policies restricting their use. Thus, you should always obtain permission to use such tools prior to using them. A port scanner can't cause damage to `/etc/passwd`, so there's no need to back it up, contrary to option A. A port scanner also doesn't need the `root` password on a target system to operate, so you don't need this information. In fact, asking for it could be seen as extremely suspicious! Although you could use `sudo` to run Nmap, there's no need to do so to perform a TCP scan, and you can perform a UDP scan by running Nmap as `root` in other ways (such as via a direct login or by using `su`). Thus, option D isn't strictly necessary, although you might want to tweak `/etc/sudoers` as a matter of system policy.
3. C. The `/etc/security/limits.conf` file holds the configuration settings that allow you to limit users' access. The other options listed don't give the correct path to this file.
4. A, B, C. Nmap is usually used to perform scans of remote computers, but it can scan the computer on which it's run, as well. The `netstat` and `lsof` utilities can both identify programs that are listening for connections (that is, open ports) on the local computer. The `portmap` program is used by the Network File System (NFS) and some other servers, but it's not used to identify open ports.
5. B. The `-perm` option to `find` locates files with the specified permissions, and `+4000` is a permission code that matches SUID files. The `-type f` option restricts matches to files in order to avoid false alarms on directories. Options A, C, and D use these options incorrectly.
6. A. Option A correctly describes the meaning of the specified line. A percent sign (%) identifies a Linux group name, and the remainder of the line tells `sudoers` to enable users of that group to run all programs as `root` by using `sudo`.
7. B. The `netstat` command can do what is described in the question. To do so, the `-ap` options to the command are good choices, so option B is correct. Although `lsof` can also accomplish the job, the `-c a` option is incorrect; this option restricts output to processes whose names begin with `a`. Thus, option A is incorrect. Option C's `ifconfig` command doesn't display open network connections, so it's incorrect. Although option D's `nmap` command will locate ports that are open on the `localhost` interface, it doesn't locate all open *connections*, nor does it locate connections on anything but the `localhost` interface.

8. D. TCP Wrappers uses this feature to allow you to override broad denials by adding more specific explicit access permissions to `hosts.allow`, as when setting a default deny policy (`ALL : ALL`) in `hosts.deny`.
9. C. The `bind` option of `xinetd` lets you tie a server to just one network interface rather than link to them all. It has nothing to do with running multiple servers on one port, specifying computers by hostname, or resolving conflicts between servers.
10. A, D. Using a firewall rule to block Waiter's port, as in option A, can increase security by providing redundancy; if Waiter is accidentally run in the future, the firewall rule will block access to its port. Uninstalling the program, as in option D, improves security by reducing the risk that the program will be accidentally run in the future. Most programs don't have a "stealth" mode, so option B is incorrect. (Furthermore, *reading* the documentation isn't enough; to improve security, you must change some configuration.) Tunneling Waiter's connections might have some benefit in some situations, but this configuration requires setup on both client and server computers and by itself leaves the server's port open, so option C is incorrect.
11. B. Option B correctly describes how to accomplish this goal. Option A is incorrect because the `hosts_allow` option isn't a legal `xinetd` configuration file option. Option C correctly describes how to configure the described restriction using TCP Wrappers, which is generally used with `inetd`, but it's not the way this is done using `xinetd`. Option D also describes a TCP Wrappers description, but it reverses the meaning.
12. B. Ideally, passwords should be completely random but still memorable. Option B's password was generated from a personally meaningful acronym and then modified to change the case of some letters and add random numbers and symbols. This creates a password that's close to random but still memorable. Option A uses a well-known mythological figure, who is likely to be in a dictionary. Option C uses two common words, which is arguably better than option A, but not by much. Option D uses two closely related words separated by a single number, which is also a poor choice for a password.
13. A. Phishing involves sending bogus e-mail or setting up fake Web sites that lure unsuspecting individuals into divulging sensitive financial or other information. Script kiddies are intruders who use root kits. Spoofing involves pretending data is coming from one computer when it's coming from another. Ensnaring isn't a type of attack.
14. C. The `/etc/nologin` file, if present, prevents logins from ordinary users; only `root` may log in. You might set this file when performing maintenance and then forget to remove it, thus explaining the symptoms in the question. The `syslogd` daemon mentioned in option A records system messages and is unlikely to produce the specified symptoms. The login process ordinarily runs as `root` and is normally SUID `root`, so options B and D are also incorrect.
15. B, C. SSH is most directly a replacement for Telnet, but SSH also includes file-transfer features that enable it to replace FTP in many situations. SSH is not a direct replacement for either SMTP or NFS.
16. A. The `ssh_host_dsa_key` file holds one of three critical private keys for SSH. The fact that this key is readable (and writeable!) to the entire world is disturbing. In principle, a miscreant who has acquired this file might be able to redirect traffic and masquerade as your system, duping users into delivering passwords and other sensitive data.

17. B. SSH protocol level 2 is more secure than protocol level 1; thus, option B (specifying acceptance of level 2 only) is the safest approach. Option A is the *least* safe approach because it precludes the use of the safer level 2. Options C and D are exactly equivalent in practice; both support both protocol levels.
18. A. Allowing only normal users to log in via SSH effectively requires two passwords for any remote `root` maintenance, improving security. SSH encrypts all connections, so it's unlikely that the password, or commands issued during an SSH session, will be intercepted. (Nonetheless, some administrators prefer not to take even this small risk.) SSH doesn't store passwords in a file.
19. D. Option D provides the correct command to import `fredkey.pub` prior to use. The `inspect-gpg` and `import-gpg` commands of options A and C are fictitious; and there is no `--readkey` option to `gpg`, as option B suggests.
20. C. The usual method of sending encrypted messages with GPG entails the sender using the recipient's public key to encrypt the message. Thus, option C is correct. Option A would be correct if your correspondent needed to send you an encrypted message, but the question only specifies your sending the encrypted message. Options B and D both entail delivery of private keys, which is inadvisable at best, because private keys in the wrong hands permit the holder to impersonate the person who owns the keys.

Appendix

A

About the Companion CD

IN THIS APPENDIX:

- What you'll find on the CD
- System requirements
- Using the CD
- Troubleshooting





What You'll Find on the CD

The following sections are arranged by category and summarize the software and other goodies you'll find on the CD. If you need help with installing the items provided on the CD, refer to the installation instructions in the "Using the CD" section of this appendix.

Some programs on the CD might fall into one of these categories:

Shareware programs are fully functional, free, trial versions of copyrighted programs. If you like particular programs, register with their authors for a nominal fee and receive licenses, enhanced versions, and technical support.

Freeware programs are free, copyrighted games, applications, and utilities. You can copy them to as many computers as you like—for free—but they offer no technical support.

GNU software is governed by its own license, which is included inside the folder of the GNU software. There are no restrictions on distribution of GNU software. See the GNU license at the root of the CD for more details.

Trial, demo, or evaluation versions of software are usually limited either by time or by functionality (such as not letting you save a project after you create it).

Sybex Test Engine

For Windows

The CD contains the Sybex test engine, which includes all of the assessment test and chapter review questions in electronic format, as well as two bonus exams located only on the CD.

PDF of the Book

For Windows

We have included an electronic version of the text in .pdf format. You can view the electronic version of the book with Adobe Reader.

Adobe Reader

For Windows

We've also included a copy of Adobe Reader so you can view PDF files that accompany the book's content. For more information on Adobe Reader or to check for a newer version, visit Adobe's website at www.adobe.com/products/reader/.

Electronic Flashcards

For PC, Pocket PC, and Palm

These handy electronic flashcards are just what they sound like. One side contains a question or fill-in-the-blank question, and the other side shows the answer.

System Requirements

Make sure your computer meets the minimum system requirements shown in the following list. If your computer doesn't match up to most of these requirements, you may have problems using the software and files on the companion CD. For the latest and greatest information, please refer to the ReadMe file located at the root of the CD-ROM.

- A PC running Microsoft Windows 98, Windows 2000, Windows NT4 (with SP4 or later), Windows Me, Windows XP, or Windows Vista
- An Internet connection
- A CD-ROM drive

Using the CD

To install the items from the CD to your hard drive, follow these steps:

1. Insert the CD into your computer's CD-ROM drive. The license agreement appears.



Windows users: The interface won't launch if you have autorun disabled. In that case, click Start > Run (for Windows Vista, Start > All Programs > Accessories > Run). In the dialog box that appears, type *D:\Start.exe*. (Replace *D* with the proper letter if your CD drive uses a different letter. If you don't know the letter, see how your CD drive is listed under My Computer.) Click OK.

2. Read the license agreement, and then click the Accept button if you want to use the CD. The CD interface appears. The interface allows you to access the content with just one or two clicks.

Troubleshooting

Wiley has attempted to provide programs that work on most computers with the minimum system requirements. Alas, your computer may differ, and some programs may not work properly for some reason.

The two likeliest problems are that you don't have enough memory (RAM) for the programs you want to use or you have other programs running that are affecting installation or running of a program. If you get an error message such as "Not enough memory" or "Setup cannot continue," try one or more of the following suggestions and then try using the software again:

Turn off any antivirus software running on your computer. Installation programs sometimes mimic virus activity and may make your computer incorrectly believe that it's being infected by a virus.

Close all running programs. The more programs you have running, the less memory is available to other programs. Installation programs typically update files and programs; so if you keep other programs running, installation may not work properly.

Have your local computer store add more RAM to your computer. This is, admittedly, a drastic and somewhat expensive step. However, adding more memory can really help the speed of your computer and allow more programs to run at the same time.

Customer Care

If you have trouble with the book's companion CD-ROM, please call the Wiley Product Technical Support phone number at (800) 762-2974. Outside the United States, call +1 (317) 572-3994. You can also contact Wiley Product Technical Support at <http://sybex.custhelp.com>. John Wiley & Sons will provide technical support only for installation and other general quality-control items. For technical support on the applications themselves, consult the program's vendor or author.

To place additional orders or to request information about other Wiley products, please call (877) 762-2974.



Glossary

Numbers

8.3 filename A filename that consists of no more than eight characters plus an optional dot (.) and three-character extension. This file-naming limit exists in DOS and the original File Allocation Table (FAT) filesystem it uses.

A

access control list (ACL) A security system that provides a list of usernames or groups and their permissions to access a resource. ACLs are expanding and supplementing traditional Unix-style permissions on new filesystems. Ext2fs, ext3fs, ext4fs, ReiserFS, JFS, and XFS all support ACLs natively.

account Stored information and a reserved directory that allows one individual to use a computer. The term is often used and thought of as if it were a distinct virtual component of a computer that a person can use, as in “Sam logged into his account,” or “Miranda’s account isn’t working.”

ACL See *access control list (ACL)*.

active partition The partition that’s marked as bootable in the Master Boot Record (MBR). Some boot loaders, such as the standard DOS/Windows boot loader, boot the active partition.

Address Resolution Protocol (ARP) A protocol used to learn a network hardware address based on an IPv4 address. See also *Neighbor Discovery Protocol (NDP)*.

Advanced Linux Sound Architecture (ALSA) One of two major sets of sound drivers in Linux. Added as a standard part of the 2.6.x kernel series, but available as an add-on package for earlier kernels. See also *Open Sound System (OSS)*.

Advanced Package Tools (APT) A package management tool that’s most often used atop Debian packages, although a version for RPM also exists. APT enables package installation and updates from Internet repositories, including automatic dependency resolution.

Advanced Technology Attachment (ATA) A type of interface for hard disks, CD-ROM drives, tape drives, and other mass-storage devices. Also often referred to as *EIDE*. The older parallel ATA (PATA) is being supplanted by the newer serial ATA (SATA). The term *ATA* alone may refer to either, but more commonly it refers to PATA.

ALSA See *Advanced Linux Sound Architecture (ALSA)*.

American Standard Code for Information Interchange (ASCII) An encoding method for alphanumeric data, commonly used for text files. ASCII is a common code, but because it lacks characters used by many non-English languages, other encoding methods, such as UTF-8, are slowly supplanting it.

anti-aliasing A technique for rendering fonts that uses shades of gray along curved or angled edges in order to improve the legibility and aesthetic appeal of individual characters.

Apache The most commonly used Web server package for Linux.

APT See *Advanced Package Tools (APT)*.

ARP See *Address Resolution Protocol (ARP)*.

ASCII See *American Standard Code for Information Interchange (ASCII)*.

ATA See *Advanced Technology Attachment (ATA)*.

B

backport The practice of moving more advanced features into less advanced versions of a package. This has been common to add hardware support from development kernels into stable kernels.

Basic Input/Output System (BIOS) A low-level software component included on a computer's motherboard in read-only memory (ROM) form. The CPU runs BIOS code when it first starts up, and the BIOS is responsible for locating and booting an OS or OS loader.

baud A measure of data transmission speed, commonly used over serial lines, corresponding to the number of signal elements transmitted per second. This term is often used as a synonym for "bits per second"; but many modems encode more than one bit per signal element, so the two aren't always synonymous.

Berkeley Internet Name Domain (BIND) A common Domain Name System (DNS) server for Linux.

BIND See *Berkeley Internet Name Domain (BIND)*.

BIOS See *Basic Input/Output System (BIOS)*.

bitmap font A font whose characters are defined in terms of the activation or inactivation of individual pixels. Bitmap fonts are quick to display but inflexible. See also *scalable font*.

boot loader A program that directs the boot process. The BIOS calls the boot loader, which loads the Linux kernel or redirects the boot process to another boot loader. Also known as a *boot manager*.

boot manager See *boot loader*.

broadband 1. High-speed (greater than 200Kbps) Internet connections delivered to homes and small businesses. 2. Networking technologies that support simultaneous transmission of data, voice, and video.

broadcast A type of network communication in which one computer sends a message to many computers (typically all the computers on the sender's local network segment).

build number A number identifying minor changes made to a binary package by its maintainer rather than changes implemented by the program's author, which are reflected in the version number.

C

C library (libc) Standard programming routines used by many programs written in the C programming language. The most common Linux C library is also referred to as *GNU libc (glibc)*.

cathode ray tube (CRT) A type of computer display that uses a glass screen with an electron gun that shoots charged particles at the screen to make images. CRTs are similar to conventional television sets. CRTs have been largely replaced by LCD monitors.

central processing unit (CPU) The main chip on a computer; it handles the bulk of its computational tasks.

CGI See *Common Gateway Interface (CGI)*.

checksum A simple file integrity check in which the values of individual bits or bytes are summed up and compared to a stored value for a reference version of the file.

chroot jail A method of running a program (particularly a server) so that its access to the computer is limited to a particular directory tree. A chroot jail is a useful security measure for certain types of servers.

CHS geometry See *cylinder/head/sector (CHS) geometry*.

CIDR See *classless inter-domain routing (CIDR)*.

classless inter-domain routing (CIDR) A method of breaking IP addresses into subnets for routing purposes that doesn't rely on the traditional Class A/B/C distinctions. CIDR is more flexible than the class system but requires certain Internet routers to have larger routing tables.

client 1. A program that initiates data transfer requests using networking protocols. 2. A computer that runs one or more client programs.

CMOS See *complementary metal oxide semiconductor (CMOS)*.

command completion A feature of many Linux shells that simplifies typing long commands. Pressing the Tab key causes the shell to search for possible commands or filenames that would complete the command. If only one command or filename matches the characters typed so far, the shell completes the entry. If not, the shell enters the characters up to the point where the user must specify another character.

Common Gateway Interface (CGI) A system for running scripts or programs from a Web server at the request of Web clients.

Common Unix Printing System (CUPS) A printing system for Linux and other Unix-like systems. CUPS adds several features that had been missing from the earlier BSD LPD and LPRng printing systems.

complementary metal oxide semiconductor (CMOS) A part of the BIOS that gives the user the ability to control key chipset features, such as enabling or disabling built-in ports.

conditional expression A construct of computer programming and scripting languages used to express a condition, such as the equality of two variables or the presence of a file on a disk. Conditional expressions enable a program or script to take one action in one case and another action in the other case.

Coordinated Universal Time (UTC) A time closely related to *Greenwich Mean Time (GMT)*.

CPU See *central processing unit (CPU)*.

cracker An individual who breaks into computers. Crackers may do this out of curiosity, out of malice, for profit, or for other reasons.

cron job A program or script that's run at a regular interval by the cron daemon. See also *system cron job* and *user cron job*.

CRT See *cathode ray tube (CRT)*.

CUPS See *Common Unix Printing System (CUPS)*.

cylinder/head/sector (CHS) geometry A method of hard disk addressing in which a triplet of numbers (a cylinder, a head, and a sector) is used to identify a specific sector. CHS geometry addressing contrasts with *linear block addressing (LBA)*.

D

daemon A program that runs constantly, providing background services. Linux servers are typically implemented as daemons, although there are also non-server daemons, such as *crond*, the cron daemon.

Data Display Channel (DDC) A protocol that enables a computer to query a monitor for its maximum horizontal and vertical refresh rates and other vital statistics.

DDC See *Data Display Channel (DDC)*.

Debian package A package file format that originated with the Debian distribution but is now used on several other distributions. Debian packages feature excellent dependency tracking and easy installation and removal procedures.

default route The route that network packets take if a more specific route doesn't direct them in some other way. The default route typically involves a gateway or router system that can further redirect the packets.

dependency A requirement of one software package that another one be installed. For instance, most Linux programs include a dependency on the C library.

desktop environment A set of programs that provide a friendly graphical environment for a Linux user.

DHCP See *Dynamic Host Configuration Protocol (DHCP)*.

DHCP lease A temporary assignment of an IP address to a DHCP client by a DHCP server. Clients must periodically renew their DHCP leases or risk losing the right to use the address.

digital subscriber line (DSL) A type of broadband network access provided over telephone lines. Several subtypes of DSL exist, including Asymmetric DSL (ADSL) and Symmetric DSL (SDSL).

direct memory addressing (DMA) A means of transferring data between devices (such as sound cards or SCSI host adapters) and memory without directly involving the CPU.

disk quota A limit on the amount of disk space that an individual or group may use.

DMA See *direct memory addressing (DMA)*.

DNS See *Domain Name System (DNS)*.

domain name A name assigned to a group of computers, such as `example.com`. Individual computers have hostnames that include the domain name, such as `jupiter.example.com`.

Domain Name System (DNS) A distributed set of computers that run servers to convert between computer names (such as `ns.example.com`) and IP addresses (such as `192.168.45.204`). DNS servers are organized hierarchically and refer requests to systems responsible for successively more specific domains.

dot file A Linux or Unix file whose name begins with a dot (`.`). Most Linux shells and programs hide such files from the user by default; therefore, user configuration files usually come in this form so as to be unobtrusive in directory listings.

dotted quad A method of referring to an IP address or netmask that uses four 1-byte numbers separated by dots (`.`), as in `192.168.72.27` or `255.255.255.0`.

DSL See *digital subscriber line (DSL)*.

Dynamic Host Configuration Protocol (DHCP) A protocol used on local networks for dissemination of network configuration information. A single DHCP server can maintain information for many DHCP clients, reducing overall configuration effort.

dynamic library A type of library that's stored as a separate file from an executable program but that's loaded along with the main program file. Dynamic libraries save disk space and RAM compared to static libraries. See also *library* and *static library*.

E

EEPROM See *electronically erasable programmable read-only memory (EEPROM)*.

EHCI See *Enhanced Host Controller Interface (EHCI)*.

electronically erasable programmable read-only memory (EEPROM) A type of data storage chip that retains data when power has been turned off but that can be erased and rewritten electronically. Frequently used to store a computer's or plug-in card's BIOS.

encryption key A number that's used in conjunction with an algorithm to scramble data in a way that can be descrambled only with the use of the same or a related number.

Enhanced Host Controller Interface (EHCI) A type of controller for USB 2.0 ports.

environment variable A setting that's available to any program running in a session. Environment variables can define features such as the terminal type being used, the path to search for executable programs, and the location of an X server for GUI programs.

export 1. As a noun, a directory that's shared via the Network File System (NFS) server. 2. As a verb, the act of sharing a directory via NFS.

ext2 See *Second Extended File System (ext2fs or ext2)*.

ext2fs See *Second Extended File System (ext2fs or ext2)*.

ext3 See *Third Extended File System (ext3fs or ext3)*.

ext3fs See *Third Extended File System (ext3fs or ext3)*.

ext4 See *Fourth Extended File System (ext4fs or ext4)*.

ext4fs See *Fourth Extended File System (ext4fs or ext4)*.

extended partition A type of disk partition used on x86 systems. Extended partitions are placeholders for one or more logical partitions.

Extents File System (XFS) One of several journaling filesystems for Linux. XFS was developed by Silicon Graphics (SGI) for its IRIX OS and then ported to Linux.

F

FAT See *File Allocation Table (FAT)*.

FHS See *Filesystem Hierarchy Standard (FHS)*.

File Allocation Table (FAT) 1. A type of filesystem used as a native filesystem by DOS and Windows and also supported as a non-native filesystem by Linux and most other OSs. 2. On the FAT filesystem, a data structure after which the filesystem is named.

file globbing The process of wildcard expansion—for instance, matching the existing file `glossary.txt` when the string `glos*.txt` is typed. Also called *globbing*.

file server A computer or program that delivers files to other computers via network protocols upon request. Examples of file-server programs include NFS, Samba, and FTP.

file type code A special code that identifies the type of a file, such as a regular file, a directory, or a device file.

filesystem 1. The low-level data structures recorded on a disk in order to direct the placement of file data. The filesystem determines characteristics like the maximum partition size, the file-naming rules, and what extra data (time stamps, ownership, and so on) may be associated with a file. 2. The overall layout of files and directories on a computer. For instance, a Linux filesystem includes a root directory (`/`), several directories under this (`/usr`, `/var`, `/boot`, and others), subdirectories of these, and so on.

Filesystem Hierarchy Standard (FHS) A standard that defines the names and contents of critical directories in a Linux filesystem (meaning 2).

Filesystem Standard (FSSTND) An early attempt to define the names and contents of critical directories in a Linux filesystem (meaning 2). The FSSTND has been supplanted by the FHS.

firewall 1. A program or kernel configuration that blocks access to specific ports or network programs on a computer. 2. A computer that's configured as a router and that includes firewall software that can restrict access between the networks it manages.

font server A program that provides font bitmaps to client programs on the same or other computers. The font server may work directly from font bitmaps, or it may generate the bitmaps from outline fonts such as PostScript Type 1 or TrueType fonts.

font smoothing See *anti-aliasing*.

Fourth Extended File System (ext4fs or ext4) The fourth version of the popular Linux filesystem. Ext4fs adds the ability to handle larger files and filesystems, as well as various performance enhancements, to the ext3fs feature set.

frame In networking, a data packet associated with network hardware (such as Ethernet) as opposed to the software (such as TCP/IP).

free software Software that is distributed under a license, such as the *GPL*, that permits copying and modification under liberal terms. See also *open source*.

Free Software Foundation (FSF) A non-profit organization based in Cambridge Massachusetts dedicated to the promotion of what it calls *free software*.

FSF See *Free Software Foundation (FSF)*.

FSSTND See *Filesystem Standard (FSSTND)*.

full duplex A mode of communication in which data can be transferred in two directions at the same time.

function In the context of programming or scripting, a section of code that can be called by name from other sections of code in order to perform some specific task or set of computations.

G

General Public License (GPL) A common free software license, created and favored by the Free Software Foundation.

GID See *group ID (GID)*.

gigabit Ethernet A variety of Ethernet that can transfer 1,000 megabits (1 gigabit) per second.

glibc See *GNU C library (glibc)*.

globbing See *file globbing*.

GMT See *Greenwich Mean Time (GMT)*.

GNOME See *GNU Network Object Model Environment (GNOME)*.

GNU See *GNU's Not Unix (GNU)*.

GNU C library (glibc) A specific type of C library used on Linux systems since the late 1990s. See also *C library (libc)*.

GNU Network Object Model Environment (GNOME) A common desktop environment for Linux, headquartered at <http://www.gnome.org>.

GNU Privacy Guard (GPG or GnuPG) Software for encrypting data using public-key/private-key technology. Frequently used for encrypting e-mail that carries sensitive data.

GNU's Not Unix (GNU) A project sponsored by the *Free Software Foundation* to create a free implementation of Unix. Linux relies heavily on GNU software—so much so that some people prefer the term *GNU/Linux* to *Linux*.

GnuPG See *GNU Privacy Guard (GPG or GnuPG)*.

GPG See *GNU Privacy Guard (GPG or GnuPG)*.

GPL See *General Public License (GPL)*.

Grand Unified Boot Loader (GRUB) A popular boot loader for Linux. GRUB can boot a Linux kernel or redirect the boot process to another boot loader in a non-Linux partition, thus booting other OSs. Similar to the competing *Linux Loader (LILO)*. See also *boot loader*.

graphical user interface (GUI) A method of human/computer interaction characterized by a graphical display, a mouse to move a pointer around the screen, and the ability to perform actions by pointing at objects on the screen and clicking a mouse button.

Greenwich Mean Time (GMT) The time in Greenwich, England, unadjusted for Daylight Saving Time. Linux systems use this time internally and adjust to local time by knowing the system's time zone. See also *Coordinated Universal Time (UTC)*.

group A collection of users. Files are owned by a user and a group, and group members may be given access to files independent of the owner and all other users. This feature may be used to enhance collaborative abilities by giving members of a group read/write access to particular files while still excluding those who aren't members of the group. It can also be used by system administrators to control access to system files and resources.

group administrator A person with administrative authority over a group. A group administrator can add or delete members from a group and perform similar administrative tasks.

group ID (GID) A number associated with a particular group. Similar to a *user ID (UID)*.

GRUB See *Grand Unified Boot Loader (GRUB)*.

GUI See *graphical user interface (GUI)*.

H

hacker 1. An individual who is skilled at using or programming computers and who enjoys using these skills in constructive ways. Many Linux programmers consider themselves hackers in this sense of the term. 2. A cracker (see also *cracker*). This use of the term is more prevalent in the mass media, but it's frowned upon in the Linux community.

half-duplex A type of data transmission in which data can be sent in only one direction at a time.

hard link A directory entry for a file that has another directory entry. All hard links are equally valid ways of accessing a file, and all must be deleted in order to delete a file. See also *soft link*.

hardware address A code that uniquely identifies a single network interface. This address is built into the device itself rather than assigned in Linux.

hardware clock A clock that's built into x86 (and most other computers') hardware. The hardware clock maintains the time when the system is powered down. See also *software clock*.

hash An encryption method in which a file or string is encoded in a manner that cannot be reversed. Hashes are commonly used for password storage and as a more secure variant on checksums, among other things. See also *checksum*.

header In e-mail, a line that contains information about a message's delivery path, sender, recipient, or other meta-information.

header file File that contains interface definitions for software routines contained in a library. Program source code that uses a library must refer to the associated header files.

here document A form of redirection, denoted by <<, which takes the following lines of input to be passed to a program as standard input. Most often used to pass fixed input to a program as standard input in scripts, obviating the need for separate support files.

HFS See *Hierarchical File System (HFS)*.

Hierarchical File System (HFS) A filesystem used on Mac OS.

high-level formatting A type of disk formatting that writes the data that define a filesystem. Also called *making a filesystem*. See also *low-level formatting*.

hostname A computer's human-readable name, such as `persephone.example.com`.

hot-pluggable Hardware that can be safely added or removed while the computer is powered up and running. USB and FireWire are examples of protocols that support hot-plugging hardware.

HTTP See *Hypertext Transfer Protocol (HTTP)*.

hub A type of network hardware that serves as a central exchange point in a network. Each computer has a cable that links to the hub, so all data pass through the hub. Hubs echo all data they receive to all the other computers to which they connect. See also *switch*.

hung Term used to describe a program that's stopped responding to user input, network requests, or other types of input to which it should respond. Hung processes sometimes consume a great deal of CPU time.

Hypertext Transfer Protocol (HTTP) A protocol used for transferring Web pages from a Web server to a Web browser.

I

ICMP See *Internet Control Message Protocol (ICMP)*.

incremental backup A type of backup in which only files that have changed since the last backup are backed up. This is used to reduce the time required to back up a computer, at the cost of potentially greater restoration complexity.

Industry Standard Architecture (ISA) The expansion bus used on the original IBM PC. Most manufacturers began dropping ISA from their motherboards around 2001. ISA is inferior to PCI in most respects.

inode A filesystem data structure that contains critical information about the file, such as its size and location on the disk.

Internet Control Message Protocol (ICMP) A type of network packet that's commonly used to signal error conditions, such as corrupted packets.

Internet Printing Protocol (IPP) A protocol for printing on a network. Used by CUPS on Linux.

Internet Protocol (IP) An internet-layer protocol that's an important part of the TCP/IP network stack because it handles data packet exchange based on low-level addressing.

interrupt request (IRQ) A method by which peripherals (SCSI host adapters, sound cards, and so on) signal that they require attention from the CPU. An IRQ also refers to a specific interrupt signal line. The original x86 architecture supported 16 IRQs (8 on very old systems), numbered 0–15; but IRQs 2 and 9 are linked, so in practice, there are only 15 IRQs. Many of these are used by basic hardware like floppy disks. Recent x86 systems support more than 16 IRQs.

IP See *Internet Protocol (IP)*.

IP address A computer's numeric TCP/IP address, such as 192.168.45.203.

IP masquerading See *Network Address Translation (NAT)*.

IPP See *Internet Printing Protocol (IPP)*.

IPv6 The “next-generation” Internet Protocol. This upgrade to TCP/IP allows for a theoretical maximum of approximately 3.4×10^{38} addresses, as opposed to the 4 billion addresses possible with the IPv4 that's in common use in 2009.

IRQ See *interrupt request (IRQ)*.

ISA See *Industry Standard Architecture (ISA)*.

ISO-9660 The most common filesystem on CD-ROM and related optical media. ISO-9660 is often paired with *Rock Ridge extensions* or a *Joliet* filesystem in order to support long filenames and other features.

J

JFS See *Journalized File System (JFS)*.

Joliet A filesystem commonly used on CD-ROMs and related optical media. Joliet supports Microsoft-style long filenames and is almost always used in conjunction with an ISO-9660 filesystem.

journal An advanced filesystem feature that records data about pending disk operations. See also *journaling filesystem*.

Journaled File System (JFS) One of several journaling filesystems for Linux. JFS was developed by IBM for its AIX OS. A subsequent implementation was created for OS/2, and Linux's JFS is derived from this code.

journaling filesystem A type of filesystem that maintains a record of its operations. Such filesystems can typically recover quickly after a power failure or system crash. Common Linux journaling filesystems are ext3fs, ReiserFS, JFS, and XFS. See also *filesystem*.

K

K Desktop Environment (KDE) A common desktop environment for Linux, headquartered at <http://www.kde.org>.

KDE See *K Desktop Environment (KDE)*.

kernel The core of a computer operating system. Technically, Linux is a kernel; everything else in a Linux computer runs atop the Linux kernel.

kernel module A driver or other kernel-level program that may be loaded or unloaded as required.

kernel ring buffer A record of recent messages generated by the Linux kernel. Immediately after a Linux system boots, this buffer contains the bootup messages generated by drivers and major kernel subsystems. This buffer may be viewed with the `dmesg` command.

L

LBA See *logical block addressing (LBA)*.

LCD See *liquid crystal display (LCD)*.

libc See *C library (libc)*.

library A collection of code that's potentially useful to many programs. This code is stored in special files to save disk space and RAM when running programs that use the library. See also *static library* and *dynamic library*.

LILO See *Linux Loader (LILO)*.

linear block addressing (LBA) See *logical block addressing (LBA)*.

link A way of providing multiple names to reference a single file. Links are created with the `ln` command.

Linux 1. The open source OS kernel originally developed by Linus Torvalds and since then maintained and expanded by a large team of programmers. 2. An OS based on the Linux kernel, particularly if it follows the Unix model. Most Linux OSs rely heavily on software from the GNU project, so some people prefer the term *GNU/Linux*.

Linux Loader (LILO) A popular Linux boot loader. Can boot a Linux kernel or redirect the boot process to another boot loader in a non-Linux partition, thus booting other OSs. Similar to the competing *Grand Unified Boot Loader (GRUB)*. See also *boot loader*.

liquid crystal display (LCD) A type of flat-panel display that's common on laptops and has recently become standard on desktop systems. LCDs are lightweight and consume little electricity, but they're more expensive to produce than are conventional CRT monitors.

load average A measure of the demands for CPU time by running programs. A load average of 0 means no demand for CPU time; 1 represents a single program placing constant demand on the CPU; and values higher than 1 represent multiple programs competing for CPU time. The `top` and `uptime` commands both provide load average information.

localhost A name for the local computer.

log file A text file, maintained by the system as a whole or by an individual server, in which important system events are recorded. Log files typically include information about user logins, server access attempts, and automatic routine maintenance.

log file rotation A routine maintenance process in which the computer suspends recording data in log files, renames them, and opens new log files. This process keeps log files available for a time, but ultimately it deletes them, preventing them from growing to consume all available disk space. Also called *log rotation*.

log rotation See *log file rotation*.

logical block addressing (LBA) A method of accessing data on a disk that uses a single sector number to retrieve data from that sector. LBA contrasts with cylinder/head/sector (CHS) addressing. Some sources refer to LBA as *linear* block addressing.

logical partition A type of x86 hard disk partition that has no entry in the primary partition table. Instead, logical partitions are carried within an extended partition.

loop A programming or scripting construct enabling multiple executions of a segment of code. Typically terminated through the use of a conditional expression.

loopback address A name that refers to a network interface or address that points back to the computer itself. This is typically the 127.0.0.1 IP address.

low-level formatting Creating data structures on a disk that define the locations of individual sectors and tracks. Hard disks are low-level formatted at the factory and should not normally be low-level formatted by end users. Floppy disks may need to be low-level formatted by end users via the Linux `fdformat` command. See also *high-level formatting*.

M

MAC address See *Media Access Control (MAC) address*.

machine name The portion of a hostname that identifies a computer on a network, as opposed to the network as a whole (for instance, `ginkgo` is the machine name portion of `ginkgo.example.com`). The machine name is sometimes used in reference to the entire hostname.

major version number The first number in a program's version number. For instance, if a program's version number is 1.2.3, the major version number is 1.

master boot record (MBR) The first sector of a hard disk. The MBR contains code that the BIOS runs during the boot process as well as the primary partition table.

MBR See *master boot record (MBR)*.

Media Access Control (MAC) address A low-level address associated with a piece of network hardware. The MAC address is usually stored on the hardware itself, and it's used for local network addressing only. Addressing between networks (such as on the Internet) uses higher-level addresses, such as an IP address.

mode The permissions of a file. In conjunction with the file's owner and group, the mode determines who may access a file and in what ways.

mode lines Definition of the timings required by particular video resolutions running at particular refresh rates.

modem Short for *modulator/demodulator*. A device for transferring digital data over an analog transmission medium. Traditionally, the analog transmission medium has been the normal telephone network, but the word *modem* is increasingly being applied to devices used for broadband Internet access.

module A kernel driver or other kernel component that's stored in a separate file. Linux can load modules on demand or on command, saving RAM when modules aren't in use and reducing the size of the kernel.

module stack A set of modules that build up to provide some set of features. For instance, to deliver sound, you may need to load several sound driver modules that make up a module stack.

mount 1. The process of adding a filesystem (meaning 1) to a directory tree. 2. A command of the same name that performs this task.

mount point A directory to which a new filesystem (meaning 1) is attached. Mount points are typically empty directories before their host filesystems are mounted.

mounted The status of a filesystem that has been linked to a directory tree using the `mount` command.

multi-head display A display that's made up of two or more physical monitors that together show a wider view on a larger virtual workspace.

multicast A method of sending network data to multiple remote sites. Multicasts differ from broadcasts in that multicasts are more focused, whereas broadcasts are typically sent to all the computers on a network.

N

NAT See *Network Address Translation (NAT)*.

NDP See *Neighbor Discovery Protocol (NDP)*.

Neighbor Discovery Protocol (NDP) A protocol used to learn a network hardware address based on an IPv6 address. See also *Address Resolution Protocol (ARP)*.

netmask See *network mask*.

Network Address Translation (NAT) A technique in which a router can "hide" a whole network from view, making all the systems look like one computer to the outside world.

Network File System (NFS) A file-sharing protocol used among Linux and Unix computers.

network mask A bit pattern that identifies the portion of an IP address that's an entire network and the part that identifies a computer on that network. The pattern may be expressed in dotted quad notation (as in 255.255.255.0) or as the number of network bits following an IP address and a slash (as in 192.168.45.203/24). The network mask is also referred to as the *netmask* or *subnet mask*.

network stack See *protocol stack*.

Network Time Protocol (NTP) A network protocol and server enabling one computer to set its clock based on the value maintained by another clock.

New Technology File System (NTFS) The favored filesystem on Windows NT/200x/XP/Vista systems. Linux supports NTFS, but this support is limited.

NFS See *Network File System (NFS)*.

NTFS See *New Technology File System (NTFS)*.

NTP See *Network Time Protocol (NTP)*.

O

OHCI See *Open Host Controller Interface (OHCI)*.

Open Host Controller Interface (OHCI) A common hardware standard for managing USB 1.x ports.

open relay An SMTP mail server that's configured to relay mail from anywhere to anywhere. Open relays are frequently abused by spammers to obfuscate their messages' true origins.

Open Sound System (OSS) One of two common sound systems for Linux, the other being the *Advanced Linux Sound Architecture (ALSA)*. OSS is available in all versions of the Linux kernel, but ALSA is preferred in the 2.6.x kernel series.

open source A broad set of software licenses, or the software that uses them, that permits redistribution and copying under liberal terms. The open source definition is somewhat broader than that of *free software*.

OSS See *Open Sound System (OSS)*.

outline font See *scalable font*.

P

package A collection of files stored in a single carrier file, ready for installation using a package management system such as RPM or the Debian package system.

packet A limited amount of data collected together with addressing information and sent over a network.

packet filter firewall A type of firewall that operates on individual network data packets, passing or rejecting packets based on information such as the source and destination addresses and ports.

packet sniffer A program that monitors network traffic at a low level, enabling diagnosis of problems and capturing data. Packet sniffers can be used both for legitimate network diagnosis and for data theft.

parallel ATA (PATA) The traditional form of ATA interface, in which several bits are transferred at once. See also *serial ATA (SATA)*.

PATA See *parallel ATA (PATA)*.

path A colon-delimited list of directories in which program files may be found. (Similar lists define the locations of directories, fonts, and other file types.)

PCI See *Peripheral Component Interconnect (PCI)*.

PCL See *Printer Control Language (PCL)*.

Peripheral Component Interconnect (PCI) An expansion bus capable of much higher speeds than the older ISA bus. Modern computers usually include several PCI slots.

permission bit A single bit used to define whether a given user or class of users has a particular type of access to a file. For instance, the owner's execute permission bit determines whether the owner can run a file as a program. The permission bits together make up the file's mode.

phishing The process of sending bogus e-mail or putting up fake Web sites with the goal of collecting sensitive personal information (such as credit card numbers).

pipe A method of executing two programs so that one program's output serves as the second program's input. Piped programs are separated in a Linux shell by a vertical bar (|).

pipeline See *pipe*.

Plug and Play (PnP) A set of hardware standards enabling automated, or at least software-based, configuration of hardware. This term applies mostly to ISA devices, although PCI and other devices are sometimes described as being PnP devices.

PnP See *Plug and Play (PnP)*.

Point-to-Point Protocol (PPP) A method of initiating a TCP/IP connection between two computers over an RS-232 serial line or modem. See also *PPP over Ethernet (PPPoE)*.

port See *port number*.

port number A number that identifies the program from which a data packet comes or to which it's addressed. When a program initiates a network connection, it associates itself with one or more ports, enabling other computers to uniquely address the program.

POST See *power-on self-test (POST)*.

PostScript A programming language used on many high-end printers. PostScript is optimized for displaying text and graphics on the printed page. The Linux program Ghostscript converts from PostScript to bitmapped formats understood by many low-end and mid-range printers.

PostScript Printer Definition (PPD) A configuration file that provides information on a printer's capabilities—its paper size, whether it prints in color, and so on.

PostScript Type 1 An outline font format associated with PostScript but useable under Linux with or without a PostScript printer. See also *TrueType*.

power-on self-test (POST) A series of basic hardware checks performed by the BIOS when the computer is first powered on and before the boot loader or OS boots. The POST can detect some, but not all, serious hardware problems before the OS boots.

PPD See *PostScript Printer Definition (PPD)*.

PPP See *Point-to-Point Protocol (PPP)*.

PPP over Ethernet (PPPoE) A variant of the Point-to-Point Protocol (PPP) that's optimized for use over Ethernet rather than RS-232 serial connections. PPPoE is used by some DSL providers.

PPPoE See *PPP over Ethernet (PPPoE)*.

primary partition A type of *x86* partition that's defined in a data structure contained in the hard disk's partition table in the MBR. An *x86* computer can host only four primary partitions per hard disk.

print queue A storage place for files waiting to be printed.

Printer Control Language (PCL) A language developed by Hewlett-Packard for controlling printers. (Many of Hewlett-Packard's competitors now use PCL.) PCL is most commonly found on mid-range laser printers, but some ink-jet printers also support the language. Several PCL variants exist, the most common ranging from PCL 3 to PCL 6.

printer driver A software component that converts printable data generated by an application into a format that's suitable for a specific model of printer. In Linux, printer drivers usually reside in Ghostscript, but some applications include a selection of printer drivers to print directly to various printers.

private key One of two keys used in certain types of cryptography. The private key should be carefully guarded against theft. See also *encryption key* and *public key*.

privileged port A port (see *port number*) that's numbered less than 1024. Linux restricts access to such ports to *root*. In networking's early days, any program running on a privileged port could be considered trustworthy because only programs configured by professional system administrators could be run on such ports. Today, that's no longer the case. See also *unprivileged port*.

process A piece of code that's maintained and run by the Linux kernel separately from other pieces of code. Most processes correspond to programs that are running. One program can be run multiple times, resulting in several processes.

protocol stack A collection of drivers, kernel procedures, and other software that implements a standard means of communicating across a network. Two computers must support compatible protocol stacks to communicate. The most popular protocol stack today is TCP/IP. Also called a *network stack*.

public key One of two keys used in certain types of cryptography. The public key is frequently given to the other side in a communication link. See also *encryption key* and *private key*.

R

random access A method of access to a storage device (RAM, hard disk, and so on) by which information may be stored or retrieved in an arbitrary order with little or no speed penalty. See also *sequential access*.

RAM See *random access memory (RAM)*.

random access memory (RAM) Memory that can be randomly accessed. More specifically, RAM can be read and written with ease and makes up the bulk of the memory in modern computers.

real-time clock (RTC) See *software clock*.

recursive lookup A method of name resolution in which the DNS server queries a series of DNS servers, each of which has information about more and more specific networks, in order to locate the IP address associated with a hostname.

redirection A procedure in which a program's standard output is sent to a file rather than to the screen or in which the program's standard input is obtained from a file rather than from the keyboard. See also *standard input* and *standard output*.

regular expression A method of matching textual information that may vary in important ways but that contains commonalities. The regular expression captures the commonalities and uses various types of wildcards to match variable information.

ReiserFS One of several journaling filesystems for Linux. Developed from scratch for Linux.

release number See *build number*.

Rock Ridge extensions A set of extensions to the ISO-9660 filesystem that enable storage of Unix-style long filenames, ownership, permissions, and other filesystem features on an ISO-9660 filesystem. See also *ISO-9660* and *Joliet*.

root directory The directory that forms the base of a Linux filesystem (meaning 2). All other directories are accessible from the root directory, either directly or via intermediate directories.

root filesystem See *root directory*.

root kit A set of scripts and other software that enable *script kiddies* to break into computers.

root servers A set of DNS servers that deliver information to other DNS servers about top-level domains (.com, .net, .us, and so on). DNS servers consult the root DNS servers first when performing full recursive DNS lookups.

RPM See *RPM Package Manager (RPM)*.

RPM Package Manager (RPM) A package file format and associated utilities designed by Red Hat but now used on many other distributions as well. RPM features excellent dependency tracking and easy installation and removal procedures.

RTC See *real-time clock (RTC)*.

runlevel A number associated with a particular set of services that are being run. Changing runlevels changes services or can shut down or restart the computer.

S

Samba A server that implements the SMB/CIFS file-sharing protocols for Linux.

SAS See *Serial Attached SCSI (SAS)*.

SATA See *Serial ATA (SATA)*.

scalable font A font whose characters are defined in terms of a series of lines and curves. Scalable fonts are easily scaled to fit any display, printer, or other output device, but this scaling operation consumes CPU time. Also known as an *outline font*. See also *bitmap font*.

script kiddies Individuals with little knowledge or skill who break into computers using scripts created by others. Such break-ins often leave obvious traces, and script kiddies frequently cause collateral damage that produces system instability.

SCSI See *Small Computer System Interface (SCSI)*.

Second Extended File System (ext2fs or ext2) The most common filesystem (meaning 1) in Linux from the mid-1990s through approximately 2001.

Secure Shell (SSH) A remote login protocol and program that uses encryption to ensure that intercepted data packets cannot be used by an interloper. Generally regarded as the successor to Telnet on Linux systems.

sendmail A popular SMTP mail server for Linux and Unix.

sequential access A method of accessing a storage medium. Requires reading or writing data in a specific order. The most common example is a tape; to read data at the end of a tape, you must wind past the interceding data. See also *random access*.

Serial ATA (SATA) A type of ATA interface that uses serial data transfer rather than the parallel data transfers used in older forms of ATA. See also *parallel ATA (PATA)*.

Serial Attached SCSI (SAS) A type of SCSI interface that uses serial data transfer rather than the parallel data transfers used in older forms of SCSI.

set group ID (SGID) A special type of file permission used on a program file to make the program run with the permissions of its group. (Normally, the user's group permissions are used.)

set user ID (SUID) A special type of file permission used on a program file to make the program run with the permissions of its owner rather than those of the user who runs the program.

SGID See *set group ID (SGID)*.

shareable files Files that can be reasonably shared with another computer, as in users' home directory files and program files in `/opt` or `/usr`.

shared library See *dynamic library*.

shell A program that provides users with the ability to run programs, manipulate files, and so on.

shell history A log of commands typed at a shell. The shell history enables easy repetition of a previously typed command.

shell script A program written in a language that's built into a shell.

signal In reference to processes, a code that the kernel uses to control the termination of the process or to tell it to perform some task. Signals can be used to kill processes.

Simple Mail Transfer Protocol (SMTP) The most common push mail protocol on the Internet. SMTP is implemented in Linux by servers such as sendmail, Postfix, Exim, and qmail.

skeleton directory A directory, typically `/etc/skel`, that holds files that should be copied to each new user's home directory as the user's account is created.

Small Computer System Interface (SCSI) An interface standard for hard disks, CD-ROM drives, tape drives, scanners, and other devices.

smart filter A program, run as part of a print queue, that determines the type of a file and passes it through appropriate programs to convert it to a format the printer can handle.

smart relay A mail server configuration that involves sending all outgoing mail to a specific upstream mail server rather than directly to the destination system. Such configurations are common on small networks in which the ISP blocks direct SMTP connections to any but its own mail server as an anti-spam measure or when you want one of your own systems to handle all of a network's outgoing mail as a tracking measure.

SMTP See *Simple Mail Transfer Protocol (SMTP)*.

social engineering The practice of convincing individuals to disclose sensitive information without arousing suspicion. Social engineers may pretend to be system administrators to ask for passwords, for instance. See also *phishing*.

socket A programming construct enabling connection to network connection endpoints (the combination of IP addresses and port numbers).

soft link A type of file that refers to another file on the computer. When a program tries to access a soft link, Linux passes the contents of the linked-to file to the program. If the linked-to program is deleted, the soft link stops working. Deleting the soft link doesn't affect the original file. Also referred to as a *symbolic link*. See also *hard link*.

software clock A type of clock maintained by a running Linux system and used by most software programs that must refer to the time. See also *hardware clock*.

software modem A modem that implements key functionality in software that must be run by the host computer. These modems require special drivers, which are uncommon in Linux.

source code The version of a program written by a human and typically stored in plain-text (ASCII) file format. Source code is converted to a binary form that a computer can run by a compiler.

spool directory A directory in which print jobs, mail, or other files wait to be processed. Spool directories are maintained by specific programs, such as the printing system or SMTP mail server.

SQL See *Structured Query Language (SQL)*.

squashing In the context of the NFS file server, this refers to changing the effective UID or GID of an access request to limit the system's vulnerability. The `root` account on the client is often squashed to the `nobody` account on the server.

SSH See *Secure Shell (SSH)*.

standard error An output stream that's reserved for high-priority messages, such as errors. See also *standard output*.

standard input The default method of delivering input to a program. It normally corresponds to the keyboard at which you type.

standard output The default method of delivering purely text-based information from a program to the user. It normally corresponds to a text-mode screen, `xterm` window, or the like. See also *standard error*.

stateful packet inspection A firewall tool in which a packet's state (that is, whether it's marked to begin a transaction, to continue an existing exchange, and so on) is considered in the filtering process.

static file A file that seldom changes. Partitions that hold nothing but static files may be mounted read-only to minimize the risk of accidental or malicious changes to the partition's files.

static library A type of library that's compiled into the program's main executable file. This contrasts with a *dynamic library*.

sticky bit A special file permission bit that's most commonly used on directories. When set, only a file's owner may delete the file, even if the directory in which it resides can be modified by others.

stratum In the context of the Network Time Protocol (NTP), the distance of a server from an atomic clock or other original time source. Stratum 0 servers are such sources but can't be contacted directly except by a stratum 1 server. Stratum 2 servers set their clocks from stratum 1 servers, stratum 3 servers set their clocks from stratum 2 servers, and so on.

stream Text or other input or output as processed by a program. Examples include files, keyboard input, and output to a screen.

Structured Query Language (SQL) A language designed for interacting with databases.

subdomain A subdivision of a domain. A subdomain may contain computers or subdomains of its own.

subnet mask See *network mask*.

SUID See *set user ID (SUID)*.

super server A server that listens for network connections intended for other servers and launches those servers. Examples on Linux are `inetd` and `xinetd`.

superblock A filesystem (meaning 1) data structure that holds critical information about the filesystem, such as its size and revision number.

superuser A user with extraordinary rights to manipulate critical files on the computer. The superuser's username is normally `root`.

swap file A disk file configured to be used as *swap space*.

swap partition A disk partition configured to be used as *swap space*.

swap space Disk space used as an extension to a computer's RAM. Enables a system to run more programs or to process larger data sets than would otherwise be possible.

switch A type of network hardware that serves as a central exchange point in a network. Each computer has a cable that links to the switch, so all data pass through the switch. A switch usually sends data only to the computer to which the packets are addressed. See also *hub*.

symbolic link See *soft link*.

system clock See *hardware clock*.

system cron job A cron job that handles system-wide maintenance tasks, like log rotation or deletion of unused files from `/tmp`. See also *user cron job*.

System V (SysV) A form of AT&T Unix that defined many of the standards used on modern Unix systems and Unix clones, such as Linux.

SysV See *System V (SysV)*.

SysV startup script A type of startup script that follows the System V startup standards. Such a script starts one service or related set of services.

T

tarball A package file format based on the `tar` utility. Tarballs are easy to create and are readable on any version of Linux and on most non-Linux systems. They contain no dependency information, and the files they contain aren't easy to remove once installed.

TCP See *Transmission Control Protocol (TCP)*.

TCP/IP See *Transmission Control Protocol/Internet Protocol (TCP/IP)*.

terminal program A program that's used to initiate a simple text-mode connection between two computers, especially via a modem or RS-232 serial connection.

terminated In the context of SCSI devices, refers to the presence of a resistor pack that prevents signals from bouncing back from the end of a SCSI chain. The devices on both ends of a SCSI chain must be terminated, but other devices must not be terminated.

Third Extended File System (ext3fs or ext3) A variant of the *Second Extended Filesystem (ext2 or ext2fs)* that adds a journal to reduce startup times after a power failure or system crash. See also *journaling filesystem*.

Transmission Control Protocol (TCP) A major transport-layer protocol type in modern networking. TCP supports error correction and other features that are helpful in maintaining a link between two computers.

Transmission Control Protocol/Internet Protocol (TCP/IP) The most important protocol stack in common use today, and the basis for the Internet.

TrueType A font format developed by Apple and dominant in the Mac OS and Windows worlds. TrueType support in Linux is provided by certain font servers, by XFree86 4.x, by X.org-X11, and by Xfs. See also *PostScript Type 1*.

trusted hosts A security system in which the server trusts a specified set of clients to manage key aspects of the security. The trusted hosts model is used by NFS and some other Linux servers but is risky on the Internet at large.

tunnel The process of using one protocol to carry another protocol's traffic. Tunneling enables you to gain the advantages of one protocol when using another. For instance, the *Secure Shell (SSH)* may be used to tunnel various other protocols, thus adding encryption to a non-encrypted protocol.

twisted-pair A type of wiring in which pairs of wires are wrapped around each other (and typically enclosed in a plastic sheath). Twisted-pair cabling is commonly used for Ethernet and certain other network cabling. Many telephone wires also use twisted-pair cabling.

U

UDF See *Universal Disc Format (UDF)*.

UDP See *User Datagram Protocol (UDP)*.

UHCI See *Universal Host Controller Interface (UHCI)*.

UID See *user ID (UID)*.

umask See *user mask (umask)*.

Unicode A standard for representing text in numerous alphabets and other writing systems. See also *Unicode Transformation Format (8-bit)*.

Unicode Transformation Format (8-bit) A variable-length encoding format for *Unicode*. UTF-8 is slowly supplanting ASCII as a standard encoding method.

Universal Disc Format (UDF) A next-generation optical disc filesystem, frequently used on DVD-ROMs.

Universal Host Controller Interface (UHCI) A common hardware standard for managing USB 1.x ports.

Universal Serial Bus (USB) A type of interface for low- to medium-speed external devices, such as keyboards, mice, cameras, modems, printers, scanners, and removable disk drives. USB 2.0 increases the speed to the point that USB is useable for hard disks in less-demanding applications.

unprivileged port A port (see *port number*) that's numbered greater than 1024. Such ports may be accessed by any user and so are commonly used by client programs and by a few servers that may legitimately be run by ordinary users. See also *privileged port*.

unshareable file A file that should not be shared with other computers. Examples include system-specific configuration files (such as most of */etc*) and system-specific queue directories in certain subdirectories of */var*.

USB See *Universal Serial Bus (USB)*.

USB hub A piece of hardware that enables connecting multiple USB devices to a single USB connector on a computer.

user cron job A cron job created by an individual user to handle tasks for that user, such as running a CPU-intensive job late at night when other users won't be disturbed by the job's CPU demands. See also *system cron job*.

User Datagram Protocol (UDP) A transport-layer protocol used on the TCP/IP stack. UDP is a simple and efficient protocol, but it lacks error checking and other advanced features that can be helpful in maintaining a connection.

user ID (UID) A number associated with a particular account. Linux uses the UID internally for most operations, and it converts to the associated username only when interacting with people.

user mask (umask) A bit pattern representing the permission bits that are to be removed from new files as they're created by processes.

username The name associated with an account, such as theo or miranda. Linux usernames are case sensitive and may be from 1 to 32 characters in length, although they're usually entirely lowercase and no longer than 8 characters.

UTC See *Coordinated Universal Time (UTC)*.

UTF-8 See *Unicode Transformation Format (8-bit)*.

V

variable In computer programming or scripting, a placeholder for data. Variables may change from one run of a program to another, or even during a single run of a program.

variable file A file whose data may change at any time. Examples include user data files and queues maintained by servers.

virtual filesystem A filesystem that doesn't correspond to a real disk partition, removable disk, or network export. A common example is /proc, which provides access to information about the computer's hardware.

W

widget A control or decoration in a GUI display, such as a button or menu.

widget set A collection of programming tools that help programmers create GUI displays, such as dialog boxes, menus, and scroll bars.

wildcard A character or group of characters that, when used in a shell as part of a filename, matches more than one character. For instance, b??k matches book, back, and buck, among many other possibilities.

window manager A program that provides decorative and functional additions to the plain windows provided by X. Linux supports dozens of window managers.

Y

Yellow Dog Updater, Modified (YUM) A package management tool associated with RPM packages. YUM enables direct package installation and updates from network repositories, including dependency resolution.

YUM See *Yellow Dog Updater, Modified (YUM)*.

X

X See *X Window System*.

X core fonts Fonts managed by the X server.

X Display Manager Control Protocol (XDMCP) A protocol for managing X connections across a network. XDMCP is also used for displaying a local GUI login screen for Linux workstations. Common XDMCP servers for Linux include the X Display Manager (XDM), the GNOME Display Manager (GDM), and the KDE Display Manager (KDM).

X logical font description (XLFD) A format for describing X core fonts. Programs use the XLFD when telling X to display a font, and the XLFD also appears in X core font configuration files.

X server A program that implements X for a computer; especially the component that interacts most directly with the video hardware.

X Window System The GUI environment for Linux. A network-aware, cross-platform GUI that relies on several additional components (such as a window manager and widget sets) to provide a complete GUI experience. See also *X server*, *XFree86*, and *X.org-X11*.

XDMCP See *X Display Manager Control Protocol (XDMCP)*.

XFree86 A set of X servers and related utilities for Linux and other OSs. Abandoned on most distributions in favor of X.org-X11.

XFS See *Extents File System (XFS)*.

XLFD See *X logical font description (XLFD)*.

X.org-X11 The most common X server for Linux. Derived from XFree86.

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