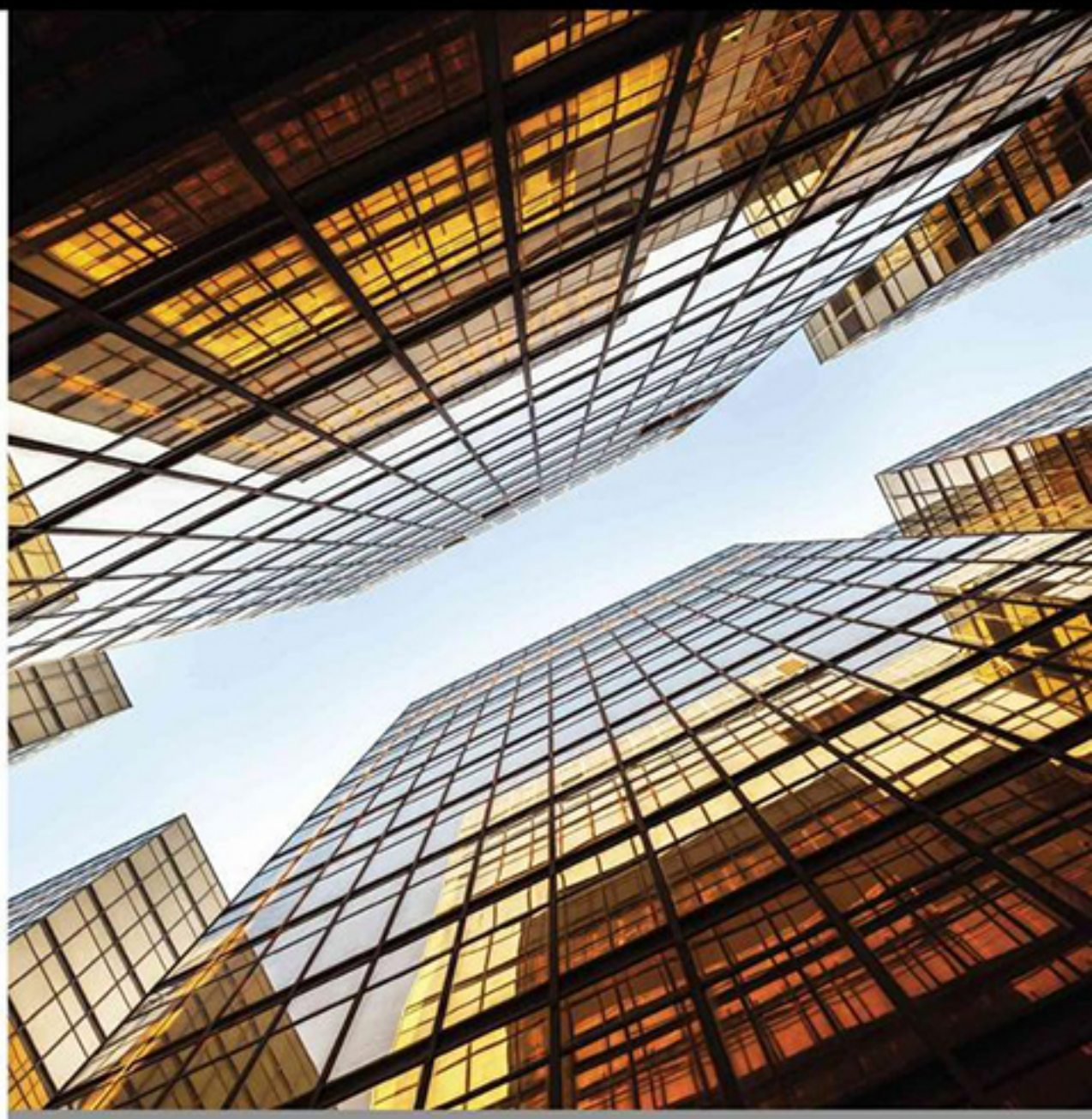
NETWORKING

Guide to Networking Essentials

Seventh Edition

Greg Tomsho



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CENGAGE
Learning

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WCN: 02-200-203

Library of Congress Control Number: 2015949720

ISBN: 978-1-305-10543-0

Cengage Learning
20 Channel Center Street
Boston, MA 02210
USA

Printed in the United States of America
Print Number: 01 Print Year: 2015

Brief Table of Contents

Table of Contents

Introduction

***Guide to Networking Essentials, Seventh Edition*, serves the needs of students,** instructors, aspiring information technology professionals, and others who are interested in learning more about networking technologies but who might have little or no background in this subject matter. This book's extensive and broad coverage of computer networking technologies and network operating systems gives you a solid networking background to pursue a number of certifications, including Network+, CCNA, MCSA, and Security+. In fact, although it's not intended as a certification study book, many instructors use it for Network+ and CCENT test preparation. With the extensive use of tables that compare important properties of networking technologies, this book also makes an excellent reference.

The seventh edition builds on the strengths of the sixth edition, giving you easy-to-understand explanations of often difficult concepts and a solid grounding in topics such as routing, switching, IP addressing, and virtualization. Many students are learning computer concepts at the same time they're learning about networking, so the first chapter includes a refresher on computer components and terminology. This new edition covers the latest networking technologies and operating systems, including new Ethernet standards, cloud computing, Windows 10, Windows Server 2016, and recent Linux distributions. In keeping with the latest trends in networking, this edition has updated and expanded coverage on IPv6 operation and addressing, network security, the 802.11 wireless standards, network switches, and routing. A new section on cloud computing explains that many networks are using the "as a" technologies, such as infrastructure as a service and platform as a service.

All new hands-on projects interspersed throughout the chapter text allow you to apply the concepts you learn in the chapter. A new feature of this book, the "Critical Thinking" section, offers challenge labs and case projects at the end of each chapter. Challenge labs give you an opportunity to apply what you have learned from the chapter material and hands-on projects in a format that might require additional research and skills. For case projects, you use your knowledge and critical thinking skills to devise solutions to networking problems.

The simulations in the previous three editions of *Guide to Networking Essentials* are now available on the Cengage Learning Web site at *www.cengagebrain.com*; you can search there by author, title, or ISBN to find the simulations. These simulations with audio narrations give you an innovative tool to help you grasp difficult networking concepts. They cover topics ranging from basic LAN communication to Network Address Translation (NAT) and Internet e-mail operation. Drag-and-drop exercises reinforce concepts of the OSI model and network frame formats. You can find more simulations and visual troubleshooting on the author's Web site at *http://books.tomsho.com*.

Intended Audience

Guide to Networking Essentials, Seventh Edition, is intended for people who are getting started in computer networking and want to gain a solid understanding of a broad range of networking technologies. This book is ideal for would-be information technology professionals who want to pursue certifications in a variety of computer networking fields as well as those in a managerial role who want a firm grasp of networking technology concepts. To understand the material in this book, you should have a background in basic computer concepts and have worked with the Windows operating system. This book is ideal for use in a classroom or an instructor-led training environment and is also an effective learning tool for individual self-paced training.

Coping with Change on the Web

Sooner or later, all the specifics on Web-based resources mentioned in this book will become outdated or be replaced by newer information. In some cases, the URLs listed in this book might lead to their replacements; in other cases, they'll lead nowhere, resulting in the dreaded error message "Server not found."

When that happens, please don't give up! There's always a way to find what you want on the Web, if you're willing to invest some time and energy. Most large or complex Web sites offer a search engine. As long as you can get to the site itself, you can use this tool to help you find what you need. In addition, try using general search tools, such as *www.google.com* or *www.bing.com*, to find related information. The bottom line is if you can't find something where the book says it should be, start looking around. It's likely to be somewhere!

Chapter Descriptions

Here's a summary of the topics covered in each chapter of this book:

- **Chapter 1**, "Introduction to Computer Networks," introduces many of the computer and networking terms and technologies discussed in detail in later chapters.
- In **Chapter 2**, "Network Hardware Essentials," you learn about the basic operation of hubs, switches, access points, network interface cards, and routers.

- **Chapter 3**, "Network Topologies and Technologies," discusses logical and physical topologies and the LAN technologies that use them.
- **Chapter 4**, "Network Media," covers the cables and connectors required to connect network devices, including structured cabling techniques, and describes wireless networking.
- In **Chapter 5**, "Network Protocols," you learn about the purpose and operation of network protocols, focusing on the TCP/IP protocol suite. Special emphasis is given to the TCP/IP layered model and the protocols that work at each layer.
- In **Chapter 6**, "IP Addressing," you learn about IPv4 addressing, including address classes, public and private addresses, subnetting, and Network Address Translation. New expanded coverage on IPv6 addressing and operation has been added to reflect the growing importance of this protocol.
- **Chapter 7**, "Network Reference Models and Standards," discusses the OSI model's seven-layer architecture and gives you an overview of the IEEE 802 networking standards.
- **Chapter 8**, "Network Hardware in Depth," delves into the hardware components of networks discussed in Chapter 2, giving you more in-depth coverage of each type of device.
- In **Chapter 9**, "Introduction to Network Security," you learn about network security policies, securing access to equipment and data, network security devices (such as firewalls and intrusion detection systems), and malware.
- In **Chapter 10**, "Wide Area Networking and Cloud Computing," you learn how to use WAN technologies, such as frame relay and SONET, to create networks that can extend across your town or across the country. In addition, you're introduced to remote access protocols and cloud computing concepts, such as IaaS and PaaS.
- In **Chapter 11**, "Network Operating System Fundamentals," you learn about network operating system features and the most common types of services provided by server OSs. This chapter also covers virtualization and using virtual machines in data centers and on the desktop. Finally, you learn how to plan for an OS installation and perform postinstallation tasks.
- **Chapter 12**, "Network Management and Administration," discusses everyday tasks that network and server administrators perform, including working with user and group accounts, creating and managing file shares, monitoring system performance and reliability, and using fault-tolerance and backup solutions.
- **Chapter 13**, "Troubleshooting and Support," discusses what you can do to prevent network downtime, data loss, and system failures. In addition, you learn about the problem-solving process, several different approaches to solving network problems, the tools for troubleshooting networks, and disaster recovery procedures.
- **Appendix A**, "Network Troubleshooting Guide," summarizes advice on how to recognize, isolate, and diagnose trouble on a network, whether it's related to media, hardware, or software.

Features

To help you understand networking concepts thoroughly, this book incorporates many features designed to enhance your learning experience:

- *Chapter objectives*—Each chapter begins with a detailed list of the concepts to be mastered. This list is a quick reference to the chapter's contents and a useful study aid.
- *A requirements table*—At the beginning of each chapter is a table listing the hands-on projects along with their requirements and estimated time of completion.
- *Hands-on projects*—Although understanding the theory behind networking technology is important, nothing can improve on real-world experience. Projects are interspersed throughout each chapter to give you hands-on experience.
- *Screen captures, illustrations, and tables*—Numerous screen captures and illustrations of concepts help you visualize network setups, theories, and architectures and see how to use tools. In addition, tables summarize details in an at-a-glance format and give you comparisons of both practical and theoretical information; they can be used for a quick review. Because most school labs use Windows OSs, these products have been used for most screenshots and hands-on projects.
- *Simulations*—In many chapters, you'll see references to simulations, which are available online at *www.cengagebrain.com*; you can search by the book's author, title, or ISBN. These simulations demonstrate concepts such as basic LAN communication, Ethernet switches, routing, Network Address Translation, Internet e-mail operation, and more.
- *Chapter summary*—Each chapter ends with a summary of the concepts introduced in the chapter. These summaries are a helpful way to recap the material covered in the chapter.
- *Key terms*—All terms in the chapter introduced with bold text are gathered together in the Key Terms list at the end of the chapter. This list gives you an easy way to check your understanding of important terms and is a useful reference.
- *Review questions*—The end-of-chapter assessment begins with review questions that reinforce the concepts and techniques covered in each chapter. Answering these questions helps ensure that you have mastered important topics.
- *Critical Thinking sections*—The end-of-chapter Critical Thinking section gives you more opportunities for hands-on practice with challenge labs, which enable you to use the knowledge you've gained from reading the chapter and performing hands-on projects to solve more complex problems without step-by-step instructions. This section also includes case projects that ask you to evaluate a hypothetical situation and decide on a course of action to propose a solution. These valuable tools help you sharpen decision-making, critical thinking, and troubleshooting skills—all important aspects of network administration.

Text and Graphics Conventions

Additional information and exercises have been added to this book to help you better understand what's being discussed in the chapter. Icons throughout the book alert you to these additional materials:

Tips offer extra information on resources, how to solve problems, and time-saving shortcuts.

Notes present additional helpful material related to the subject being discussed.

The Caution icon identifies important information about potential mistakes or hazards.

Each hands-on project in this book is preceded by this icon.

Simulation icons refer you to simulations that reinforce the concepts being discussed.

This icon marks end-of-chapter labs that challenge you to apply what you've learned without step-by-step instructions.

Case Project icons mark the end-of-chapter case projects, which are scenario-based assignments that ask you to apply what you have learned in the chapter.

Instructor Companion Site

Everything you need for your course in one place! This collection of book-specific lecture and class tools is available online via *www.cengage.com/login*. Access and download PowerPoint presentations, images, the Instructor's Manual, and more. In addition, the author maintains a Web site at *http://books.tomsho.com* with lab notes, errata, additional exercises, the latest lab setup guide, and hints and tips for teaching with this book.

- *Electronic Instructor's Manual*—The Instructor's Manual that accompanies this book includes additional instructional material to assist in class preparation, including suggestions for classroom activities, discussion topics, and additional quiz questions.

- *Solutions Manual*—The instructor's resources include solutions to all end-of-chapter material, including review questions and case projects.
- *Cengage Learning Testing Powered by Cognero*—This flexible, online system allows you to do the following:
  - Author, edit, and manage test bank content from multiple Cengage Learning solutions.
  - Create multiple test versions in an instant.
  - Deliver tests from your LMS, your classroom, or wherever you want.
- *PowerPoint presentations*—This book comes with Microsoft PowerPoint slides for each chapter. They're included as a teaching aid for classroom presentation, to make available to students on the network for chapter review, or to be printed for classroom distribution. Instructors, please feel free to add your own slides for additional topics you introduce to the class.
- *Figure files*—All the figures and tables in the book are reproduced in bitmap format. Similar to the PowerPoint presentations, they're included as a teaching aid for classroom presentation, to make available to students for review, or to be printed for classroom distribution.

Contact the Author

I would like to hear from you. Please e-mail me at *NetEss@tomsho.com* with any problems, questions, suggestions, or corrections. I even accept compliments! This book has staying power, so I wouldn't be surprised to see an eighth edition in the future. Your comments and suggestions are invaluable for shaping the next edition's content. In addition, please visit my Web site at *http://books.tomsho.com*, where you can find lab notes, errata, and other information related to this book and my other titles. You can also submit comments and suggestions.

Acknowledgments

I would like to thank the team at Cengage Learning for this opportunity to improve and expand on the fifth edition of this book. This team includes Kristin McNary, Product Team Manager; Michelle Ruelos Cannistraci, Senior Content Developer; Brooke Greenhouse, Senior Content Project Manager; and Serge Palladino and John Freitas, Manuscript Quality Assurance, for testing projects and labs for accuracy. Thanks especially to my development editor, Lisa Lord, for her excellent guidance in creating a polished product. Additional praise and special thanks goes to my beautiful wife, Julie; our daughters, Camille and Sophia; and our son, Michael. They all deserve medals for their patience and support while going husbandless and fatherless during the development of this book.

Before You Begin

The importance of a solid lab environment can't be overstated. This books contains hands-on projects that require a variety of network equipment and software. Most of the hands-on projects use a PC with Windows 10 installed. However, other versions of Windows (such as Windows 7 and Windows 8.1) can be used with modifications to the steps. Using virtualization can simplify the lab environment. For example, you can use VMware Player, VMware Workstation, VirtualBox, and other products to install Windows and Linux in a virtual machine, regardless of the OS running on your physical computer. The following section lists the requirements and gives you ideas for how to best configure your lab environment.

Lab Setup Guide

Both the hands-on projects and challenge labs have setup requirements. Some labs require two or three computers, called "lab computers," that you connect to hubs and routers to create small test networks. Lab computers use Windows 10 (but earlier versions can be substituted) and should be physical computers that have easy access to power, a NIC, and other ports. Many other labs simply require a computer that's connected to a network in a classroom setting, with access to the Internet. Students must have administrator access to these computers, and the use of virtual machines is recommended. An instructor computer is also required for some labs. The instructor computer can also be set up as a virtual machine and must be accessible to student computers on the network.

Student Computers (Net-*XX*)

- Use of virtual machines recommended
- Windows 10 Enterprise or Education Edition
- Computer name: Net-*XX* (replacing *XX* with a student number, such as 01, 02, and so forth)
- Administrator account: NetAdmin with the password Password01 set to never expire
- Workgroup name: NetEss
- Memory: 1 GB required, 2 GB or more recommended
- Hard disk 1: 60 GB or more (Windows installed on this drive); a second NTFS-formatted partition assigned drive letter D is preferable but not required.
- Hard disk 2: Unallocated 60 GB or more
- IP address via DHCP server or static if required on your network
- Wireshark installed (a free protocol analyzer from *www.wireshark.org*)
- Internet access

Instructor Computer (Net-Instr)

- Same requirements as Net-*XX* except for the following:
  - Computer name: Net-Instr
  - No second hard disk required
- Create a shared folder named NetDocs, giving the NetAdmin user Read and Change sharing permissions and Modify NTFS permissions. You access this share by using \\net-instr\netdocs in Chapter 1.

Lab Computers (Three Computers Minimum)

- Windows 10 Enterprise or Education Edition (or other versions, including Windows 7 and Windows 8.1; however step-by-step instructions are written for Windows 10)
- Computer names: Computer1, Computer2, Computer3
- Administrator account: NetAdmin with the password Password01 set to never expire
- Workgroup name: NetEss
- Memory: 1 GB required, 2 GB or more recommended
- Hard disk 1: 60 GB or more (Windows installed on this drive)
- IP address: Set to use DHCP, but no DHCP server should be present, so APIPA addresses are assigned.
- Wireshark installed (a free protocol analyzer from *www.wireshark.org*)
- No Internet access

Network Equipment for Lab Computers (for Each Group of Three Computers)

- Two 10/100 hubs
- Two 10/100 switches
- One WPA 802.11 b/g/n SSID NetEss; open security
- 802.11 b/g/n NICs (USB Wi-Fi NICs are ideal)
- Five patch cables and one crossover cable

Additional Supplies and Tools

- RJ-45 crimping tool
- Punchdown tool
- Cable stripper
- Cat 5e or higher cable
- Cat 5e or higher patch panel
- RJ-45 plugs (at least four per student)
- A Cisco switch with Cisco IOS for configuring VLANs (for Challenge Lab 8-3)
- A Cisco router with CISCO IOS (for Challenge Lab 8-4)
- Network diagram software, such as Visio, or online diagramming software, such as *www.gliffy.com*
- A Fedora Linux Live DVD or ISO file or an Ubuntu Linux DVD or ISO file
- Windows Server 2012 R2 ISO file (downloaded from the Microsoft evaluation center) for Hands-On Project 11-9
- A shared printer (optional)
- NetInfo and Simple Server Monitor (downloaded and installed by students or the instructor)
- VMware Player (downloaded and installed by students or the instructor)

You can find additional lab setup instructions and videos on the author's Web site at *http://books.tomsho.com*. Click the menu item Networking Essentials 7th Edition. You can also find videos by the author on YouTube at *https://www.youtube.com/user/gtomshobooks*. More information is available on the author's Amazon page at *https://www.amazon.com/author/gregtomsho*, Facebook page at *www.facebook.com/gtomshobooks*, and Twitter (@gtomshobooks).

chapter 1

Introduction to Computer Networks

After reading this chapter and completing the exercises, you will be able to:

- Describe basic computer components and operations
- Explain the fundamentals of network communication
- Define common networking terms
- Compare different network models

In only a few decades, computer networks have evolved from being a complex technology accessible to only the most tech-savvy users to being part of most people's everyday lives. Computer networks can be found in almost every business, school, and home. Their use is available to anyone with a computer and a network connection, but installation and upkeep of all but the smallest networks still require considerable know-how. This chapter starts you on the path toward acquiring the skills to manage a large corporate network or simply configure a home network with a wireless router.

This chapter begins by discussing the computer and its role in a network to give you a foundation for the topics in this book. Next, you examine the components of a network and the fundamentals of communication between computers. Many new terms are introduced and defined, and the varied types of networks and network servers you might encounter are described.

An Overview of Computer Concepts

The hands-on projects in this book require setting up your lab environment so that it's ready to go, so make sure you read and follow the step-by-step instructions in the "Before You Begin" section of the Introduction, which help you set up your lab for all projects in this book.

The hands-on projects in this book contain information about how networks work that's best understood by hands-on experience. If you can't do some of the projects, you should at least read through each one to make sure you don't miss important information. Table 1-1 summarizes what you need for the hands-on projects in this chapter.

Table 1-1 Hands-on project requirements

Hands-on project	Requirements	Time required	Notes
Hands-On Project 1-1: Examining a Computer's Boot Procedure	Net-*XX*	10 minutes	A Windows 10 computer configured as described in "Before You Begin" Must be able to access the BIOS setup screen
Hands-On Project 1-2: Upgrading a Stand-alone Computer to a Networked Computer	Net-*XX*, a NIC, a patch cable, and a hub or switch	30 minutes	A lab computer set up as described in "Before You Begin"
Hands-On Project 1-3: Viewing Network Software Layers	Net-*XX*	10 minutes	
Hands-On Project 1-4: Using `ipconfig`, `ping`, and `arp`	Net-*XX*	15 minutes	
Hands-On Project 1-5: Exploring Peer-to-Peer Networking	Net-*XX*	15 minutes	
Hands-On Project 1-6: Creating a Shared Folder	Net-*XX*	15 minutes	
Hands-On Project 1-7: Transferring a Document to Another Computer	Net-*XX*	15 minutes	A share named NetDocs on the instructor's computer (Net-Instr)
Hands-On Project 1-8: Looking Up Computer and Networking Acronyms	Net-*XX*	20 minutes	Internet access

At the heart of a computer network is the computer. Networks were created to facilitate communication between computing devices, which ultimately facilitates communication between people. So to better understand networks, how they work, and how to support them, you must have a solid understanding of computer operations. In fact, most of the devices you encounter when working with a network involve a computer. The most obvious are network servers and workstations that run operating systems, such as Windows, Linux, UNIX, and Mac OS X. Not as obvious are devices such as routers and switches, which move network data from computer to computer and network to network. These complex devices are also computers, although they're specialized computers for performing specific tasks. The next sections discuss the basic functions of a computer and its associated components, along with computer hardware, the boot procedure, and the basic functions of an operating system (OS). Networking is the focus of this book, but your grasp of the fundamentals of computer components and operations helps you understand networking components and operations.

Basic Functions of a Computer

A computer's functions and features can be grouped into the three basic tasks all computers perform: input, processing, and output. Information is input to a computer from a device such as a keyboard or from a storage device such as a hard drive; the central processing unit (CPU) processes the information, and then output is usually created. The following example illustrates this process:

- *Input*—A user running a word-processing program types the letter A on the keyboard, which results in sending a code representing the letter A to the computer.
- *Processing*—The computer's CPU determines what letter was typed by looking up the keyboard code in a table.
- *Output*—The CPU sends instructions to the graphics card to display the letter A, which is then sent to the computer monitor.

Some components of computers are designed to perform only one of these three functions; others are designed to perform two or all three functions. For example, a standard keyboard and mouse perform input functions, and storage devices, such as hard drives, perform both input (when files are read from the drive) and output (when files are written to the drive). Network cards can perform all three functions. A network card is an output device when data is sent from the computer to the network and an input device when data comes from the network to the computer. In addition, many network cards have rudimentary processors that perform actions on incoming and outgoing data to help supplement the computer's main CPU.

Input Components Before a computer can do any processing, it requires input, commonly from user-controlled devices, such as keyboards, microphones, Webcams, and scanners. External interfaces, such as serial, FireWire, and USB ports, can also be used to get input from external devices.

Input is also generated by storage devices, such as hard disks and CDs/DVDs that store programs and data files containing computer instructions and data. For example, a spreadsheet program, such as Microsoft Excel, might contain instructions for the CPU to calculate formulas for adding the values of two columns of data and a spreadsheet file called `MyBudget.xls` containing the numbers and formulas the spreadsheet program should use. Both the program (Microsoft Excel) and the data file (`MyBudget.xls`) are used as input to the CPU, which then processes the program instructions and data.

A spreadsheet program normally starts when a user double-clicks the spreadsheet program icon or the icon representing the spreadsheet data file. These actions are instigated by user input. Sometimes, however, your computer seems to start performing actions without user input. For example, you might have noticed that your hard drive sometimes shows activity without any obvious action from you to initiate it. However, inputs to a computer can include timers that cause programs to run periodically and data arriving from network cards, for example, that cause a program or process to run. So although it sometimes seems as though your computer has a mind of its own, computers don't actually do anything without first getting input to jolt them into action.

Processing Components A computer's main processing component is the CPU, which executes instructions from computer programs, such as word-processing programs and Web browsers. It also runs the instructions making up the OS, which provides a user interface and the environment in which applications run. Aside from the CPU, computers usually include ancillary processors associated with input/output (I/O) devices, such as graphics cards. These processors are often referred to as "onboard processors." The processor on a graphics card, called a "graphics processing unit (GPU)," takes a high-level graphics instruction, such as "draw a circle," and performs the calculations needed to draw the circle on a display device. With an onboard GPU, the main CPU doesn't have to handle many of the complex calculations graphical applications require, thereby improving overall system performance. Other devices, such as network interface cards and disk controller cards, might also include onboard processors.

CPUs are usually composed of two or more processors, called **cores**, in one package. A **multicore CPU** is like a person with two brains. With only one brain, you could add four numbers, but you would probably do it in three sequential summing operations: Add the first number to the second number, take the first sum and add it to the third number, and add that sum to the fourth number to arrive at the final sum. If you had two brains, you'd still need three summing operations, but two could be done simultaneously: The first brain adds the first two numbers while the second brain is adding the third and fourth numbers; then the second brain gives its results to the first brain, and the first brain sums the results of the first two summing operations. So multicore CPUs enable computers to carry out multiple instructions simultaneously, which results in better overall performance when running demanding applications.

Output Components Output components include monitors and printers, but they also include storage devices, network cards, and speakers, to name a few. The external interfaces mentioned previously as input components can be used as output components, too. For example, a disk drive connected to a USB port allows reading files from the disk (input) and writing files to the disk (output).

Storage Components

Storage components are a major part of a computer's configuration. Generally speaking, the more storage a computer has, the better the performance is. As you saw in the previous section, most storage components are both input and output devices, allowing data to be saved (output) and then accessed again later (input). When most people think of storage, they think of disk drives, CD/DVD drives, and USB or flash drives. However, there are two main categories of storage: short-term storage and long-term storage.

RAM: Short-Term Storage Short-term storage is the random access memory (RAM) on a computer. RAM is short-term storage because when power to the computer is turned

off, RAM's contents are gone, just as though you erased a whiteboard. When power is restored, RAM has no data stored until the CPU begins to write data to it.

The amount of RAM, or memory, in a computer is crucial to the computer's capability to operate efficiently. RAM is also referred to as "working storage." Everything the CPU is currently processing must be available in RAM, including program instructions and the data the current application requires. So to run a spreadsheet program, there must be enough RAM to load both the spreadsheet program and the data in the spreadsheet. If there's not enough available memory, the spreadsheet program won't run, or the computer uses the disk drive to supplement RAM temporarily.

Neither option is desirable. The reason temporary use of the disk drive isn't optimal is because RAM is thousands of times faster than the fastest disk drives. The time required to access data in RAM is measured in nanoseconds (billionths of a second), but access to data on a disk drive is measured in milliseconds (thousandths of a second). So if the disk drive must be used to supplement RAM while running an application, that application, and indeed the entire computer, slows down precipitously.

On current computers, the amount of RAM installed is usually 1 GB or more. More is generally better, but the amount of RAM that a system can use effectively depends on the OS installed. The 32-bit version of an OS can usually access a maximum of 4 GB of RAM, whereas the 64-bit version can access many thousands of gigabytes. The amount of RAM you actually need depends on how you use your computer. If you usually have only one or two typical business applications open at once, 1 GB or even less is probably enough. However, if you run complex graphics applications or games or have several applications open simultaneously, you'll likely benefit from having more RAM.

Long-Term Storage Long-term storage maintains its data even when there's no power. Examples include hard disks, CDs/DVDs, and USB flash drives as well as other types of removable media. Long-term storage is used to store document and multimedia files as well as the files that make up applications and the OS. The amount of storage a computer needs depends on the type and quantity of files to be stored. In general, office documents, such as word-processing files, spreadsheets, and presentations, require comparatively little space. Multimedia files—pictures, music files, and videos—require much more space. Long-term storage is plentiful and extremely inexpensive. Hard drive specifications are in hundreds of gigabytes, with terabyte (1000 GB) drives quite commonplace. More details about hard disks are discussed later in "Personal Computer Hardware."

Data Is Stored in Bits Whether storage is long term or short term, data on a computer is stored and processed as binary digits ("bits," for short). A bit holds a 1 or 0 value, which makes representing bits with electrical pulses easy. For example, a pulse of 5 volts of electricity can represent a 1 bit, and a pulse of 0 volts (or the absence of a pulse) can represent a 0 bit. Bits can also be stored as pulses of light, as with fiber-optic cable: A 1 bit is represented by the presence of light and a 0 bit as the absence of light.

Data in a computer, such as the letters in a word-processing document or the music played from an MP3 music file, is represented by collections of 8 bits, called a byte. You can look at each byte as a printable character in a document. For example, a single byte from an MP3 file plays about 1/17 thousandth of a second of music. To put it another way, one second of MP3 music takes more than 17,000 bytes.

Personal Computer Hardware

Most people are familiar with personal computer (PC) hardware. Other types of computers, such as minicomputers and mainframes, are usually locked away in a heavily air-conditioned room and privy only to the eyes of IT staff. Besides, the basic hardware used to build a PC or a mainframe differs only in the details. This section describes four major PC components housed in a computer case:

- Motherboard
- Hard drive
- RAM
- BIOS/CMOS

The Motherboard and Its Components The motherboard is the nerve center of a computer, much like the spinal cord is the nerve center of the human body. It's a network of wires and controlling circuits that connects all computer components, including the CPU, RAM, disk drives, and I/O devices, such as network interface cards. Some key components of a motherboard are labeled in Figure 1-1 and explained in Table 1-2.

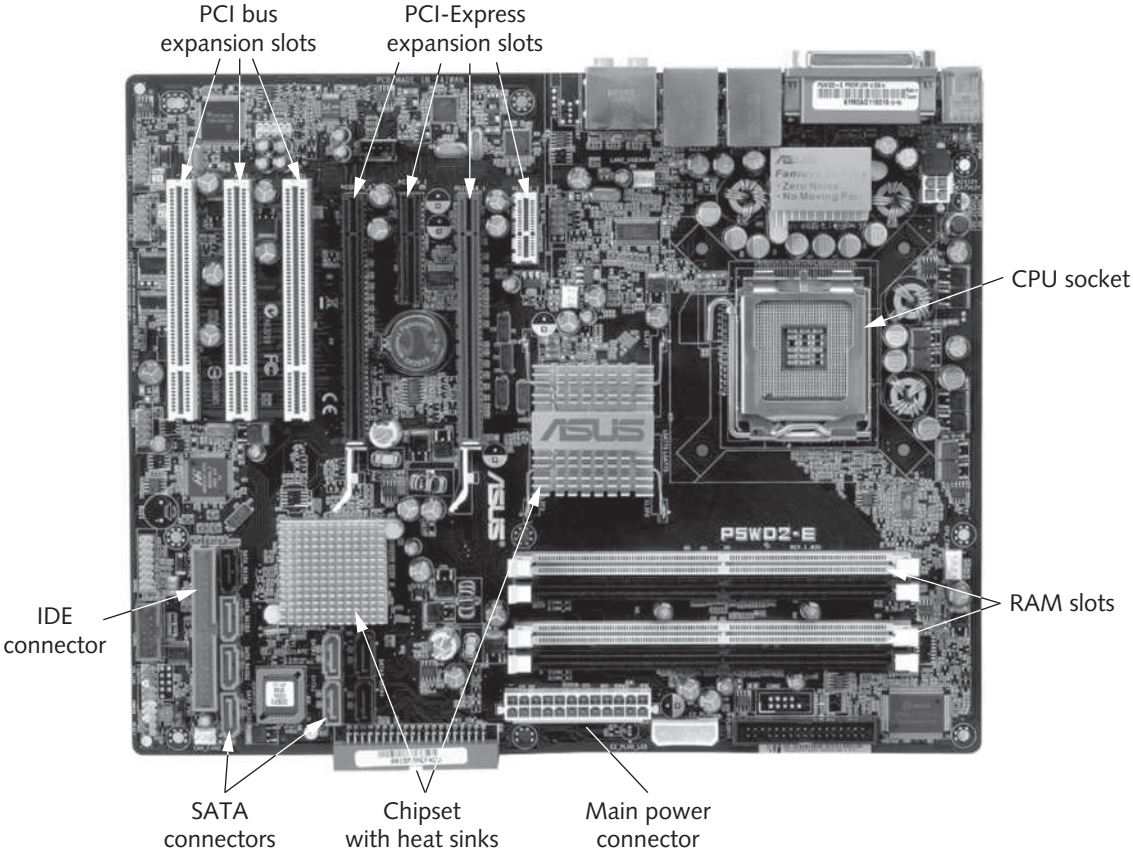

Figure 1-1 A PC motherboard

Table 1-2 Key components of a motherboard

Component	Description
CPU socket	The CPU is installed in this socket.
PCI bus expansion slots	Used to add functionality to a PC by adding expansion cards that have a Peripheral Component Interconnect (PCI) connector.
PCI-Express expansion slots	PCI-Express supersedes PCI and supports faster data transfer speeds. The larger slots are suitable for high-performance expansion cards, such as graphics cards and disk controllers. The smaller slots are best suited to sound cards and network interface cards.
RAM slots	Slots for installing RAM on the motherboard.
Chipset with heat sinks	The chipset consists of two chips referred to as the Northbridge and the Southbridge. These chips control data transfers between memory, expansion slots, I/O devices, and the CPU. The heat sink sits on top of the chipset to prevent it from overheating.
SATA connectors	Used for connecting hard drives and CD/DVD drives that use the Serial AT Attachment (SATA) specification.
IDE connector	Used for connecting Integrated Drive Electronics (IDE) hard drives and CD/DVD-ROM drives. Most systems now use SATA for hard drives and IDE for CD/DVD-ROM drives.
Main power connector	This connector is where the motherboard receives power from the system power supply.

All data that goes into or comes out of a computer goes through the motherboard because all storage and I/O devices are connected to the motherboard, as is the CPU, which processes data going in and coming out of a computer.

Computer Bus Fundamentals Table 1-2 mentions PCI bus expansion slots as a component of a motherboard. A **bus** is a collection of wires carrying data from one place to another on the computer. There are many bus designs and formats, each for a particular purpose. Although bus types come and go, it's safe to say that replacements for an older bus design will almost certainly be faster than their predecessor.

In a computer, there are buses between the CPU and RAM, between the CPU and disk drives, and between the CPU and expansion slots, among others. For the purposes of this book, you're most interested in the bus connecting expansion slots to the motherboard because you usually connect a network interface card (NIC) into one of these slots. NIC installation and expansion slot bus types are discussed in Chapter 2. What you need to know now is that not all motherboards come with all types of expansion slots, and the faster and busier your computer is, the faster its bus type needs to be.

Hard Drive Fundamentals The hard drive is the primary long-term storage component on your computer. Hard drives consist of magnetic disks, called "platters," that store data in the form of magnetic pulses. These magnetic pulses are maintained even when power is turned off. Each pulse represents a single bit of data.

The platters spin at extremely fast speeds, with some faster disks having rotational speeds of 15,000 revolutions per minute (rpm). A read/write head is attached to an actuator arm that moves across the spinning platters in response to commands from the computer to read or write a file (see Figure 1-2). Generally, the faster the rotational speed, the better the hard drive performance is. When a file is requested to be written or read, its location is determined, and then the read/write heads are moved over the corresponding spot on the platter. After the platter spins to the file's starting location, the read/write heads are activated to read or write the data. The average amount of time platters take to spin into position is called the "rotational delay" or "latency." The amount of time required to move read/write heads to the correct place is the seek time, and the time it takes to read or write data is the transfer time. The average amount of time between the request to read or write data and the time the action is performed is the access time.

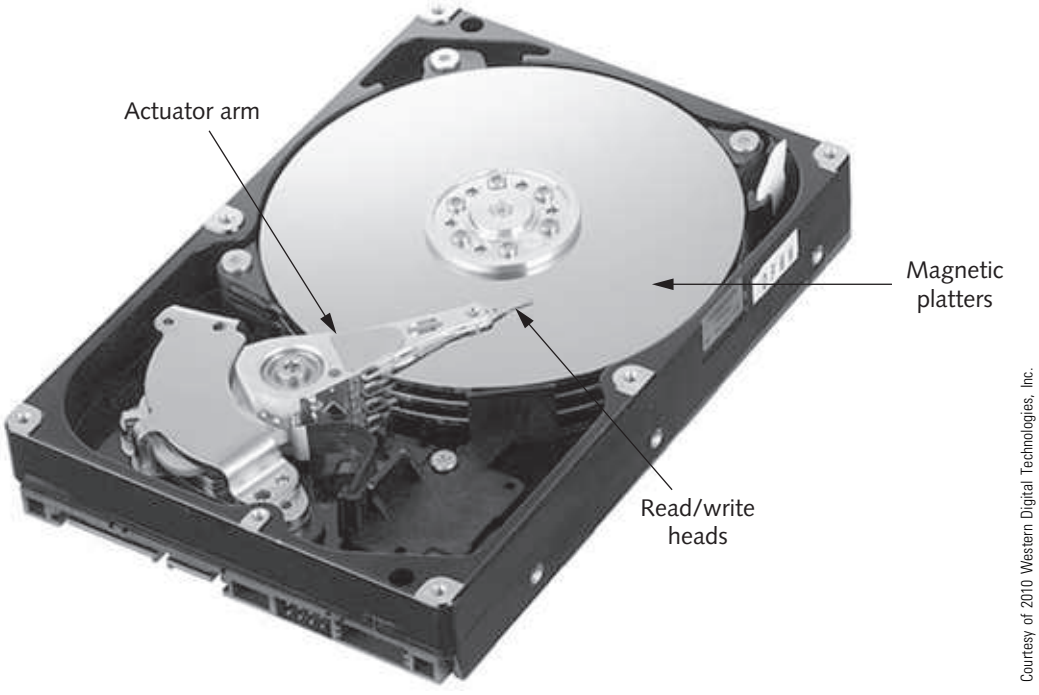

Figure 1-2 Inside a hard drive

The terms used to measure hard drive performance aren't universal among manufacturers, but the terms used in the preceding paragraph represent most specifications.

Hard disks store the documents you use with your computer as well as the applications that open these documents. In addition, the hard disk stores the OS your computer loads

when it boots. As mentioned, the hard disk acts as an input device when files are read. When the computer boots, the OS files are read from the disk, and instructions in these files are processed by the CPU. However, the files don't go directly from the hard disk to the CPU; first, they're transferred to short-term storage (RAM).

Solid State Drives Solid state drives (SSDs) are used in place of hard drives in many systems because of their speed and reliability. An SSD uses a type of storage called "flash memory" that contains no moving parts and has faster access times than a mechanical hard drive. SSDs are more expensive than hard drives when you compare the price per gigabyte of storage, but their price continues to fall. SSDs are most often used in mobile devices (such as laptops, smartphones, and tablets) but are also found on high-performance desktops and servers, often supplementing, rather than replacing, hard drive storage.

RAM Fundamentals RAM, the main short-term storage component on a computer, consists of capacitors to store data and transistors to control access to data. Capacitors require power to maintain the bits they store. Because RAM requires continuous power to store data, it's referred to as "volatile memory."

RAM has no moving parts, so as mentioned, accessing data in RAM is much faster than accessing data on a hard drive—there's no seek time or rotational delay. Because RAM is so much faster than a hard drive, any information the CPU processes should be in RAM. If data the CPU requires is located on the hard drive, it's loaded into RAM first, which takes considerable time. Therefore, the more RAM your system has, the more likely it is that all the data needed by running programs can be stored in RAM, making the system perform much faster.

BIOS/CMOS Fundamentals A key component of every computer is its basic input/output system (BIOS), which is a set of instructions located in a chip on the motherboard. A main function of the BIOS is to tell the CPU to perform certain tasks when power is first applied to the computer, including initializing motherboard hardware, performing a power-on self-test (POST), and beginning the boot procedure.

Because of the complexity of motherboards, configuring some hardware components and tuning performance parameters are often necessary. When a computer begins to boot, the BIOS program offers the user an opportunity to run the Setup utility to perform this configuration. The configuration data the user enters is stored in complementary metal oxide semiconductor (CMOS) memory. It holds information such as devices the CPU should check for an OS to boot, the status of hardware devices, and even a system password, if needed. CMOS is a type of low-power memory that requires only a small battery to maintain its data. It's also referred to as "nonvolatile memory" because it doesn't require power from the computer's main power supply.

Computer Boot Procedure

To take a computer from a powered-off state to running an OS, such as Windows or Linux, the following steps must take place:

1. Power is applied to the motherboard.
2. The CPU starts.