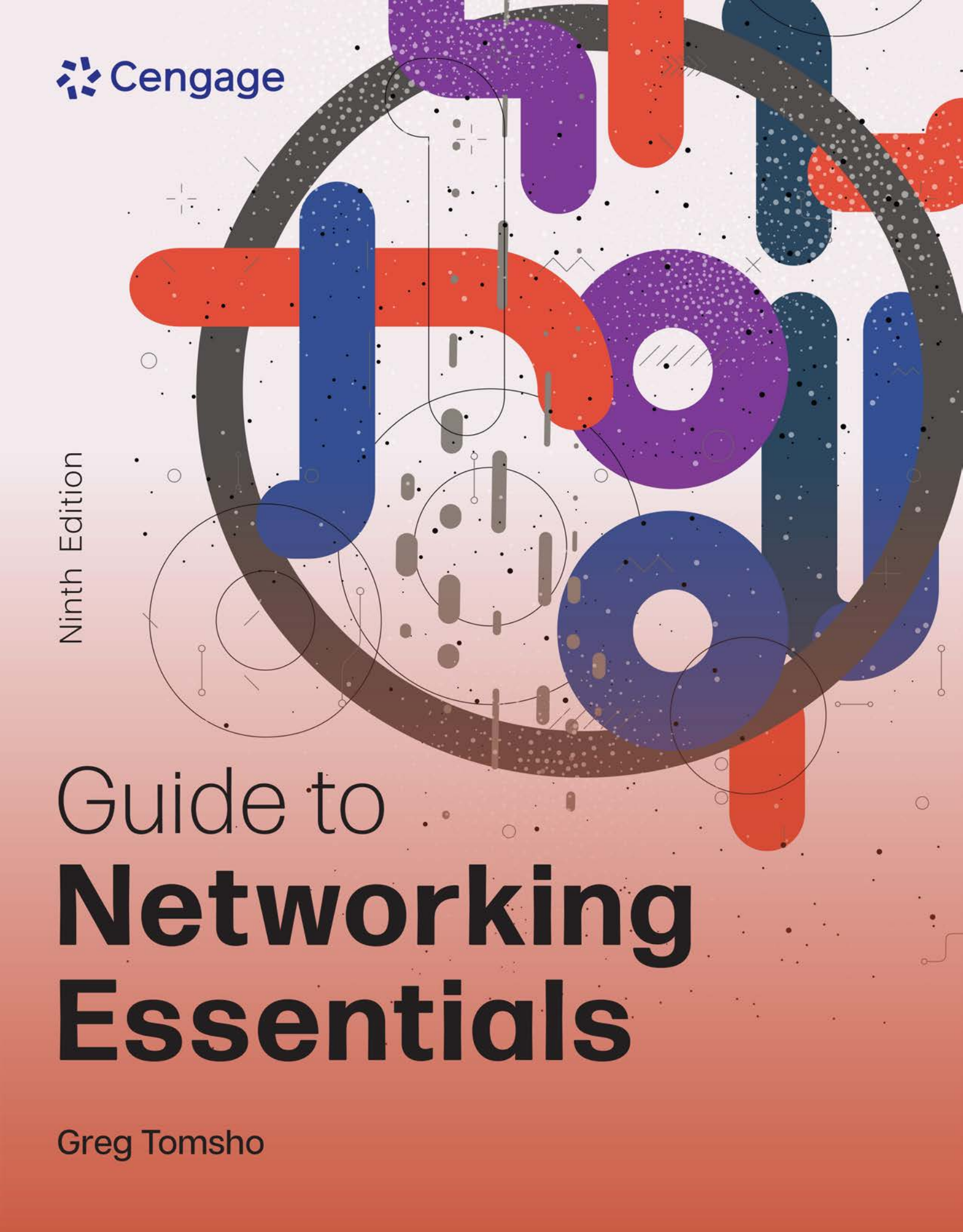
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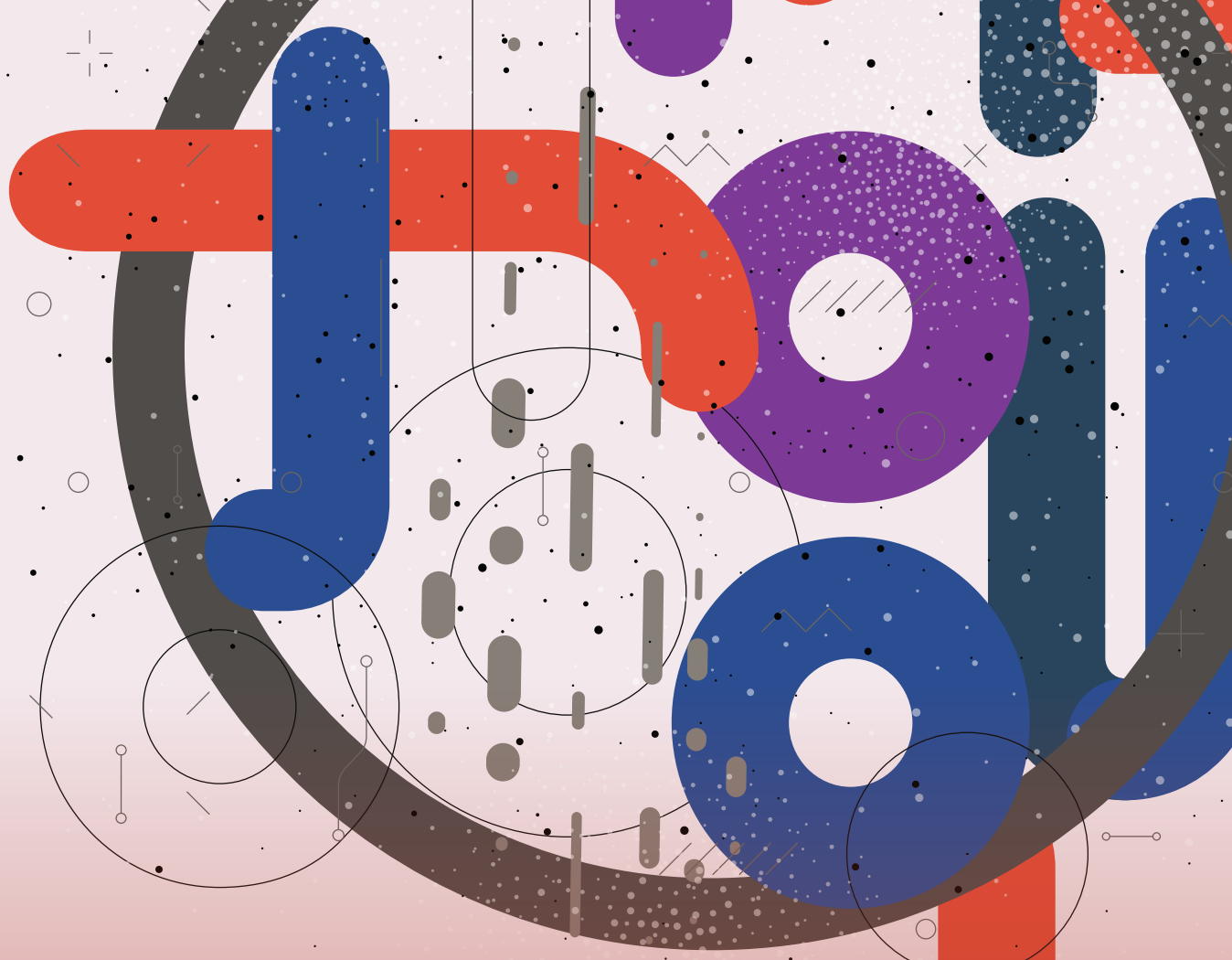

Ninth Edition

Guide to Networking Essentials

Greg Tomsho

Cengage

Australia • Brazil • Canada • Mexico • Singapore • United Kingdom • United States

Cengage

***Guide To Networking Essentials,* Ninth Edition**
Greg Tomsho

SVP, Product Management: Cheryl Costantini

VP, Product Management: Mark Santee

Portfolio Product Director: Rita Lombard

Portfolio Product Manager: Natalie Onderdonk

Product Assistant: Anh Nguyen

Learning Designer: Andrew Southwell

Senior Content Manager: Michelle Ruelos Cannistraci

Content Project Manager: Geetha Dhandapani

Technical Editor: Danielle Shaw

Developmental Editor: Ann Shaffer

Senior Manager, Product Marketing: Neela Bali

Senior Product Marketing Manager: Cybele Beckham

Content Acquisition Analyst: Nichole Nalenz

Production Service: Straive

Designer: Erin Griffin

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Cengage
5191 Natorp Boulevard
Mason, OH 45040
USA

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Brief Contents

Contents

Chapter 4

Chapter 5

Chapter 6

Chapter 7

Chapter 8

Introduction

Guide to Networking Essentials, Ninth Edition, serves the needs of students, instructors, aspiring information technology professionals, and others who are interested in learning more about networking technologies but 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 the Cisco Certified Support Technician (CCST) Networking: Exam 100-150, CompTIA Network+, Cisco Certified Network Associate (CCNA), and CompTIA Security+. In particular, the ninth edition has been updated to fully cover the CCST Networking exam.

Throughout the book, Certification icons map chapter sections to the CCST Networking certification objectives. Many instructors also use the book for Network+ test preparation and as an introductory course for the CCNA certification. With the extensive use of tables that compare important properties of networking technologies, this book also makes an excellent networking reference.

The ninth edition builds on the strengths of the eighth 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 and Wi-Fi standards, cloud computing and edge computing, Windows 11, Windows Server 2022, and recent Linux distributions. In keeping with the latest trends in networking, this edition includes an updated chapter on the Internet of Things (IoT), including use cases, network technologies, common IoT devices, and hands-on projects. In addition, mention is given to generative AI, particularly as it pertains to network troubleshooting.

All-new Packet Tracer labs in this book use network simulation software, so many of the labs that use physical equipment such as switches and routers can be completed in a virtual environment. 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 animations in previous editions of *Guide to Networking Essentials* are available on the author's YouTube channel. These animations 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. You can access the animations from the YouTube playlist at *https://www.youtube.com/playlist?list=PLXyThKOLtSMb_T3pnTDYAeRJfyAjtxl8U* or from the author's channel at *http://www.youtube.com/@gtsho*.

Intended Audience

Guide to Networking Essentials, Ninth 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 professionals 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 experience using 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, entering a URL shown in this book might lead to an updated URL; in other cases, it will 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 probably use its search engine to help you find what you need. In addition, try using general web search tools 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. The latest Ethernet and Wi-Fi standards are compared and contrasted.
- **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. Expanded coverage on IPv6 addressing and operation has been added to reflect the growing importance of this protocol in practice and on certification exams.
- **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. A new section on Cisco device IOS commands is included to support the CCST Networking certification exam objectives.
- 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, "The Internet of Things,"** introduces this rapidly growing field of information technology, often associated with the term "edge computing." You'll learn about IoT use cases, IoT networking, industrial and commercial IoT devices, and how to get started in IoT yourself.
- **Chapter 14, "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. Tables for PowerShell, command prompt, Linux shell, and Cisco IOS network testing and troubleshooting commands have been added.
- **Appendix B, "CCST Networking: Exam 100-150 Objectives,"** provides a detailed list of where objectives are covered throughout the book.

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.
- **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 essential 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.
- **Packet Tracer labs**—Using Packet Tracer, readers can perform labs using virtual network hardware. These labs are written to mirror the hands-on projects whenever possible so labs can still be done even when the physical hardware is not available. All Packet Tracer labs are self-grading and instructors can download the completed version of each lab from the Cengage web site. A short readme.txt file provides more information for instructors about the Packet Tracer labs.
- **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 introduced with bold text are gathered in a Key Terms list at the end of each 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.
- **Challenge Labs**—The end-of-chapter Challenge Labs gives you more opportunities for hands-on practice, 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.
- **Case Projects**—The end-of-chapter Case Projects ask you to evaluate a scenario and decide on a course of action to for solving a problem. These valuable tools help you sharpen decision-making, critical thinking, and troubleshooting skills—all important aspects of network administration.
- **Making the Connection**—NEW!
  The 9th edition of *Guide to Networking Essentials* includes a "Making the Connection" scenario at the beginning of each chapter. This new feature engages students with a story taken from the author's experiences in information technology that highlights some of the topics and technologies discussed in the chapter. These stories illustrate how technologies interact, emphasizing the value of learning even the smallest details of how networks work as students journey toward a career in networking and information technology.

  Because the Making the Connection section relates to material covered in the chapter, to get the most out of it, please consider re-reading this section after you have read the chapter.

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 and banners throughout the book alert you to these additional materials:

Exam Tip | Exam Tips offer insights into topics they must pay particular attention to as they are covered in the CCST Networking exam.

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

Caution | Cautions identify information about potential mistakes or hazards.

Hands-On Projects

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

Self-Check Questions

To complete the learning cycle, these self-check questions help students practice recalling the information they have read. With answers and extensive explanations provided at the end of each chapter, this low-stakes practice testing helps students assess how well they're learning and what material they might need to review before completing graded work.

MindTap

MindTap for *Guide to Networking Essentials,* Ninth Edition, is an online learning solution designed to help you master the skills you need in today's workforce. Research shows that employers need critical thinkers, troubleshooters, and creative problem-solvers to stay relevant in our fast-paced, technology-driven world. MindTap helps you with assignments and activities that provide hands-on practice and real-life relevance. MindTap guides you through assignments that help you progress from basic knowledge and understanding to more challenging problems.

MindTap activities and assignments are tied to defined learning objectives. MindTap features include the following:

- **Live Virtual Machine Labs** allow you to practice, explore, and try different solutions in a safe sandbox environment. Each chapter provides you with an opportunity to complete an in-depth project hosted in a live virtual machine environment. You implement the skills and knowledge gained in the chapter through real design and configuration scenarios.
- **Pre- and Post-Assessments** emulate the text and assess your understanding of key concepts at the beginning and end of the course.
- **Networking for Life** assignments encourage you to stay current with what's happening in the field of Windows Server.
- **Reflection** activities encourage classroom and online discussion of key issues covered in the chapters.

Instructors, MindTap is designed around learning objectives and provides analytics and reporting so you can easily see where the class stands in terms of progress, engagement, and completion rates. Use the content and learning path as is, or pick and choose how your materials

will integrate with the learning path. You control what the students see and when they see it. Learn more at cengage.com/mindtap/.

Instructor and Student Resources

Additional instructor and student resources for this product are available online. Instructor assets include an Instructor's Manual, Educator's Guide, PowerPoint® slides, and a test bank powered by Cognero®. Student assets include data files. Sign up or sign in at www.cengage.com to search for and access this product and its online resources..

- **Instructor's Manual**—The Instructor's Manual that accompanies this course provides additional instructional material to assist in class preparation, including suggestions for classroom activities, discussion topics, and additional projects.
- **Cengage Testing Powered by Cognero**—This flexible online system allows you to do the following:
  - Author, edit, and manage test bank content from multiple Cengage solutions.
  - Create multiple test versions in an instant.
  - Deliver tests from your learning management system, your classroom, or wherever you want.
- **PowerPoint presentations**—This course comes with Microsoft PowerPoint slides for each chapter. These are 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.
- **Solution and Answer Guide**—The instructor's resources include solutions to all end-of-chapter material, including review questions and case projects.
- **Data Files**—Students need to download the Student Data Files to complete the Packet Tracer labs throughout the book. Solution Files are provided for Challenge Labs and Packet Tracer Labs.
- **Narrated Network Animations**—These animations show students how various network devices and processes work using animations with voice over narration. You can find the network animations on the author's YouTube channel: *www.youtube.com/@gtsho*

To go to directly to the playlist of network animations, go to: *https://www.youtube.com/playlist?list=PLXyThKOLtSMb_T3pnTDYAeRJfyAjtxl8U* 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.

Contact the Author

I would like to hear from you. Please e-mail me at *books@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 a tenth 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 *https://www.youtube.com/playlist?list=PLXyThKOLtSMb_T3pnTDYAeRJfyAjtxl8U*, 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

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Hardware and Software Requirements

The importance of a solid lab environment can't be overstated. This book contains hands-on projects that require a variety of network equipment and software. Most of the hands-on projects use a PC with Windows 11 installed.

Using virtualization can simplify the lab environment. For example, you can use VMware Workstation, VirtualBox, Hyper-V, 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 require two or three computers, referred to as "Lab Computers" in the setup instructions, which you connect to hubs, switches and routers to create small test networks. Lab Computers use Windows 11 (but earlier versions can be substituted) and should be physical computers that have easy access to power, a NIC, and other ports. While it is highly recommended that students perform the labs with physical equipment (switches, routers, cables, etc.), the Packet Tracer labs at the end of each chapter were designed to mimic the physical hands-on labs as closely as possible so students can still perform most labs using Packet Tracer if physical devices are not available.

"Student Computers," as described in the setup instructions, 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. The "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 11 Enterprise or Education Edition recommended
- Computer name: Net-*XX* (replacing *XX* with a student number, such as 01 or 02)
- Administrator account: NetAdmin with the password Password01 set to never expire
- Workgroup name: NetEss
- Memory: Minimum 2 GB
- Hard disk 1: 60 GB or more (Windows installed on this drive)
- Hard disk 2: 20 GB or more; unallocated
- IP address via DHCP server or static if required on your network
- Wireshark installed (This is a free protocol analyzer from *www.wireshark.org*.)
- Internet access

In addition, students will install Packet Tracer, a network simulator, on their computers. Packet Tracer Lab 1-1 provides instructions for installing Packet Tracer. Packet Tracer may be preinstalled on the student computers, but students will need a Cisco Netacad account to get full functionality from Packet Tracer.

The author has provided Packet Tracer files to help students perform the Packet Tracer labs. These files are available for download from *cengage.com*.

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. Students access this share by using \\net-instr\netdocs in Chapter 1.

Lab Computers (Three Computers Minimum)

- Windows 11 Enterprise or Education Edition
- Computer names: Computer1, Computer2, Computer3
- Administrator account: NetAdmin with the password Password01 set to never expire
- Workgroup name: NetEss
- Memory: Minimum 2 GB
- 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 (This is 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 (If you don't have hubs, you can try to procure them on eBay.)
- Two 10/100 or faster managed switches
- One router with two Ethernet ports pre-configured according to Hands-on Project 2-5
- One wireless router 802.11 b/g/n minimum SSID NetEss; open security
- 802.11 b/g/n minimum 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)
- An Ubuntu Linux Live DVD or ISO file
- Windows Server 2022 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)
- VirtualBox (downloaded and installed by students or the instructor)

Chapter 1

Introduction to Computer Networks

Chapter Objectives

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

1. Describe basic computer concepts, components, and operations
2. Explain the fundamentals of network communication
3. Define common networking terms
4. Compare different network models

Making the Connection Sigrid was in her last year of high school and needed to take an elective. She wasn't interested in the art or music classes that most of her friends took. But she knew she liked problem solving and she had heard about a new program that taught computer networking. "People always need help with computers and I like to solve problems," she thought. So she enrolled.

It wasn't exactly like she thought it would be. The class focused more on networking than computers. But, as the weeks rolled by, she found herself fascinated by the details of how networks work. She particularly liked the idea that she could capture network packets and peer inside them to see exactly what was going on when she requested a web page. And problem solving was definitely a part of it!

She and her classmates did labs where they had to make the right cable connections and enter the correct addresses for all the computers in the network. When someone's lab wasn't working, she found that she enjoyed helping out her fellow students to find out what was wrong. And she was good at it.

She was skeptical at first about the instructor's insistence that they learn about something called "layers" and the difference between packets and frames. Now, fast-forward

five years and Sigrid is the Senior Cybersecurity Analyst for a large University in California. Every single day she is reminded why all those terms are so important. When she hires junior analysts, she insists that they know networking, the layered model, and have a firm grasp of the terms that describe networking and cybersecurity processes.

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 mobile device or 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 will 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.

About the Hands-On Activities

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. A table of hands-on requirements for each chapter can be found in the preface of this book.

An Overview of Computer Concepts

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. Other types of nontraditional computers include smartphones, smart watches, home assistants like Amazon Echo and Google Home, and smart "things" such as appliances, thermostats, and even lamps, which are collectively referred to as **Internet of Things (IoT)** devices. 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 broken down into the three basic tasks all computers perform: input, processing, and output. Information is input to a computer from a user device such as a keyboard or mouse, or from a storage device such as a disk 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.xlsx` containing the numbers and formulas the spreadsheet program should use. Both the program (Microsoft Excel) and the data file (`MyBudget.xlsx`) 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. Or, a notification might pop up on your screen reminding you of a calendar event. 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 **central processing unit (CPU)**. The CPU is a computer component that interprets and executes instructions in a computer program or application such as a word processor or Web browser. 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 math 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. GPUs are also used in other applications that require intensive math calculations such as machine learning. Other devices, such as network interface cards and disk controller cards, might also include specialized 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 sound cards, 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 it performs. 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 so-called because the data in the storage is not maintained when power is turned off to the device. **Random access memory (RAM)** is short-term storage on a computer. RAM is a very high-speed storage component that is used to store the operating system, computer programs, and associated data that are currently running on the computer. RAM does not retain any data when the power is off. When the power on a computer is turned on, the operating system and other programs are loaded into RAM.

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) or microseconds (millionths 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 noticeably.

On current desktop computers, the amount of RAM installed is usually 8 GB or more. More is generally better, but 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, 2 GB might be enough. However, if you run complex graphics applications or games or if you have several applications open simultaneously, you'll 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, solid-state drives (SSDs), 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 on modern computers is plentiful and inexpensive compared to RAM. Disk drive specifications are in hundreds of gigabytes, with multi-terabyte (a terabyte is 1000 GB) drives quite commonplace. More details about disk drives 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 represented 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.

Bits, Bytes, Megabytes, and Beyond

Some types of computer information are expressed in bits and others are expressed in bytes. For example, when we talk about how fast a network connection is, the speed is usually expressed in bits, as in 100 million bits per second or 100 Mbps. When we talk about how much data a disk drive can store, the capacity is expressed in bytes, as in 100 billion bytes or 100 GB. Notice that when expressing bits, a lowercase b is used, but when expressing bytes, an uppercase B is used. If you want to convert bits to bytes, simply divide by 8; for example, 100 Mbps would be about 12.5 MBps. Conversely, to convert bytes to bits, multiply by 8. All of the prefixes used to express large numbers of bits or bytes can be confusing, so Table 1-1 is given as a reference. Notice that each prefix increases the previous prefix by a factor of 1000; for example, 1 megabyte is equal to 1000 kilobytes.

Table 1-1 Prefixes used for expressing bits and bytes

Prefix	Value
Kilo (K)	Thousand (10^3)
Mega (M)	Million (10^6)
Giga (G)	Billion (10^9)
Tera (T)	Trillion (10^{12})
Peta (P)	Quadrillion (10^{15})
Exa (E)	Quintillion (10^{18})
Zeta (Z)	Sextillion (10^{21})
Yotta (Y)	Septillion (10^{24})

Note 1 | Table 1-1 isn't exactly right because computers do everything in binary, including how they count. So, a kilobyte is actually 1024 or 2^{10} bytes. A megabyte is 1000 kilobytes, which is actually 1,048,576 bytes, but it's much easier for us humans to work with round numbers like million and billion. So, when estimating storage capacity, we round 100 GB to 100 billion bytes instead of the more difficult 107,374,182,400 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. 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
- Storage device
- RAM
- Firmware

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

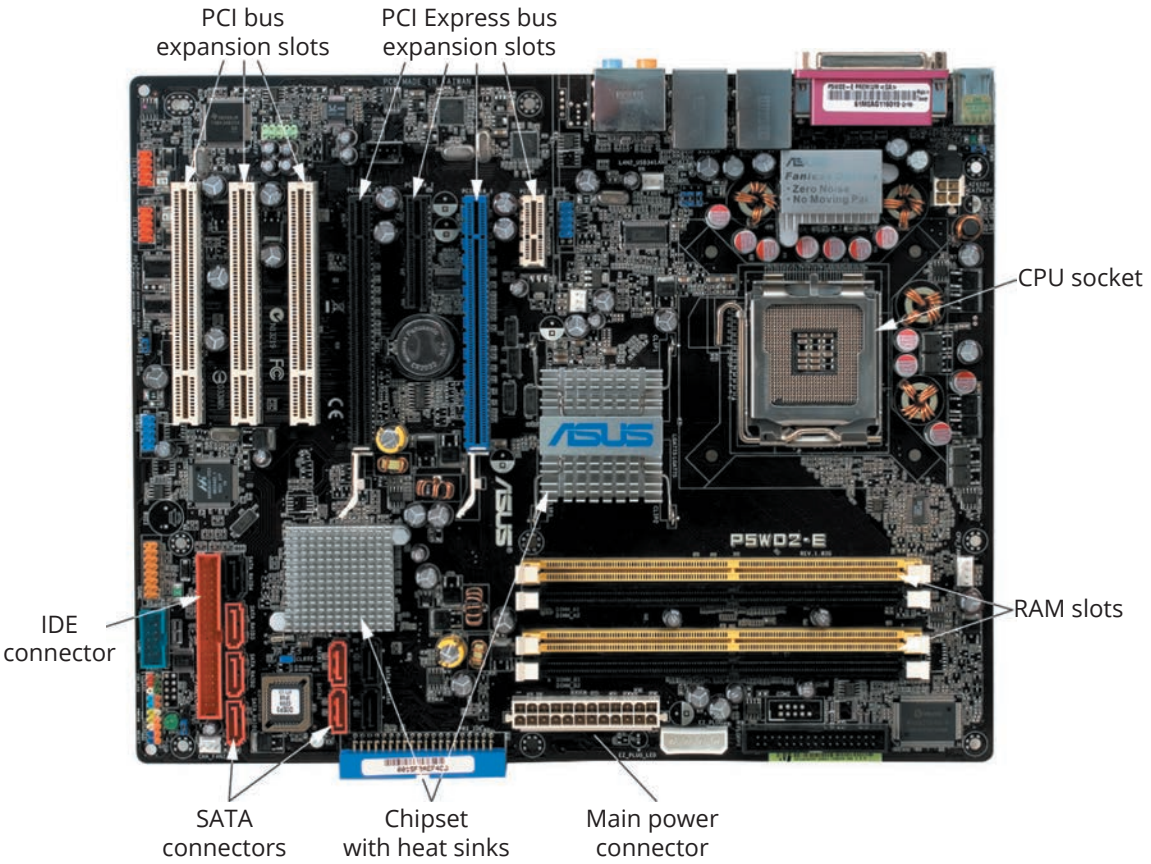


Table 1-2 Key components of a motherboard

Component	Description
CPU socket	The CPU is installed in this socket.
PCI Express bus expansion slots	Used to add functionality to a PC by adding expansion cards that have a Peripheral Component Interconnect Express (PCIe) connector. 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.
PCI bus expansion slots	This older expansion card standard is rarely found on new computers.
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. This older standard is rarely found on new computers.
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 1-3 mentions PCI Express 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.

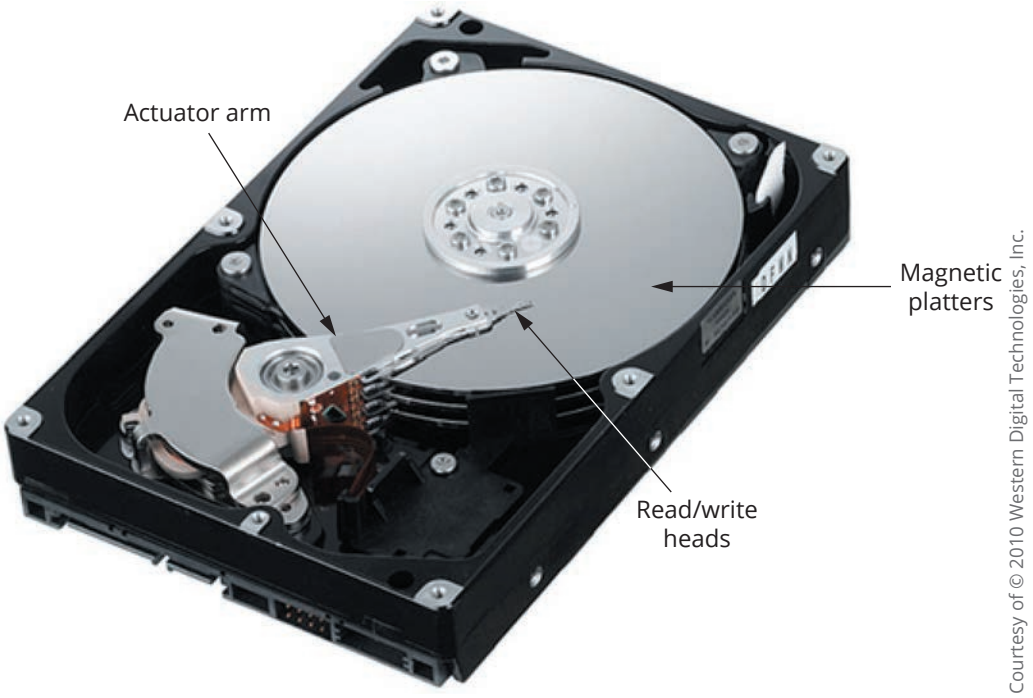
In a computer, there are buses between the CPU and RAM, between the CPU and disk drives, and between the CPU and expansion slots, among others. For the purposes of this book, you're most interested in the bus connecting expansion slots to the motherboard because you usually connect a network interface 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.

Storage Device Fundamentals

Most desktop computers and laptops are likely to come with a hard drive as their primary long-term storage component. 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

Figure 1-2 Inside a hard drive



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.

Note 2 | The terms used to measure hard drive performance aren't universal among manufacturers, but the terms used in the preceding paragraph represent most specifications.

Disk drives store the documents you use with your computer as well as the applications that open these documents. In addition, the drive stores the OS your computer loads when it boots. As mentioned, the disk drive 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 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. SSDs are most often used in mobile devices (such as laptops, smartphones, and tablets) but are also found on high-performance desktops and servers, either supplementing, or replacing, hard drive storage.

Note 3 | There are other types of flash storage that work like traditional SSDs that are even faster. That's because they connect directly to the PCI Express bus. By contrast, SSDs connect to the same bus as hard drives, typically a SATA or SAS bus. These faster SSDs are called NVMe or M.2 drives. As fast as NMVe and M.2 drives are, they are still much slower than RAM.

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**.

The electronic components that make up RAM provide much faster access times than either hard drives or flash-based storage devices. Because RAM is so much faster than long-term storage devices, any information the CPU processes is stored in RAM. If data the CPU requires is located on a disk 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.

Firmware Fundamentals

A key component of every computer is its firmware. **Firmware** is a computer program stored in **nonvolatile memory**, such as ROM or flash memory. Nonvolatile memory is a type of storage that maintains its data after power is removed. Firmware is located on the motherboard and is executed when the computer is first powered on. The firmware on most PCs is called the **basic input/output system (BIOS)** or **Unified Extensible Firmware Interface (UEFI)**. A main function of the BIOS or UEFI is to instruct 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 firmware 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 possible boot devices, the status of hardware devices, and perhaps a system password, if needed. CMOS is a type of low-power memory that requires only a small battery to maintain its data.

Note 4 | ROM is read-only memory that cannot be changed. The only way to update firmware stored in ROM is to replace the existing ROM chip with a new one, which is why ROM has largely been replaced by flash memory.

Computer Boot Procedure

To take a computer from a powered-off state to booting and 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.
3. The CPU carries out the firmware startup routines, including the POST.
4. Boot devices, as specified in the firmware configuration, are searched for an OS.
5. The OS is loaded into RAM.
6. OS services are started.

These steps apply to almost every type of computer, including very small computing devices, such as smartphones and tablets. Probably the biggest difference between types of computers is what occurs in the last step. OS services are programs that are part of the OS rather than applications a user starts. The services an OS starts can vary greatly, depending on which OS is loaded and how it's configured. The number and type of services started on a system are what, at least in part, account for the time it takes a system to boot completely. Examples of common OS services include the user interface, the file system, and, of course, networking services.