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Computer Networks and Internets

with Internet Applications

Third Edition

计算机网络与因特网（第3版）

Douglas E. Comer

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Computer Networks And Internets

With Internet Applications

THIRD EDITION

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国际知名大学原版教材

——信息技术学科与电气工程学科系列

出 版 说 明

郑大钟

清华大学信息科学与技术学院

当前，在我国的高等学校中，教学内容和课程体系的改革已经成为教学改革中的一个非常突出的问题，而为数不少的课程教材中普遍存在“课程体系老化，内容落伍时代，本研层次不清”的现象又是其中的急需改变的一个重要方面。同时，随着科教兴国方针的贯彻落实，要求我们进一步转变观念扩大视野，使教学过程适应以信息技术为先导的技术革命和我国社会主义市场经济的需要，加快教学过程的国际化进程。在这方面，系统地研究和借鉴国外知名大学的相关教材，将会对推进我们的课程改革和推进我国大学教学的国际化进程，乃至对我们一些重点大学建设国际一流大学的努力，都将具有重要的借鉴推动作用。正是基于这种背景，我们决定在国内推出信息技术学科和电气工程学科国外知名大学原版系列教材。

本系列教材的组编将遵循如下的几点基本原则。(1) 书目的范围限于信息技术学科和电气工程学科所属专业的技术基础课和主要的专业课。(2) 教材的范围选自于具有较大影响且为国外知名大学所采用的教材。(3) 教材属于在近 5 年内所出版的新书或新版书。(4) 教材适合于作为我国大学相应课程的教材或主要教学参考书。(5) 每本列选的教材都须经过国内相应领域的资深专家审看和推荐。(6) 教材的形式直接以英文原版形式印刷出版。

本系列教材将按分期分批的方式组织出版。为了便于使用本系列教材的相关教师和学生从学科和教学的角度对其在体系和内容上的特点和特色有所了解，在每本教材中都附有我们所约请的相关领域资深教授撰写的影印版序言。此外，出于多样化的考虑，对于某些基本类型的课程，我们还同时列选了多于一本的不同体系、不同风格和不同层次的教材，以供不同要求和不同学时的同类课程的选用。

本系列教材的读者对象为信息技术学科和电气工程学科所属各专业的本科生，同时兼顾其他工程学科专业的本科生或研究生。本系列教材，既可采用作为相应课程的教材或教学参考书，也可提供作为工作于各个技术领域的工程师和技术人员的自学读物。

组编这套国外知名大学原版系列教材是一个尝试。不管是书目确定的合理性，教材选择的恰当性，还是评论看法的确切性，都有待于通过使用和实践来检验。感谢使用本系列教材的广大教师和学生的支持。期望广大读者提出意见和建议。

Computer Networks and Internets with Internet Applications

Third Edition

影印版序

互联网是目前信息社会最重要的基础设施之一。为什么第一代互联网在美国诞生，为什么美国目前又在领导下一代互联网研究的潮流？我认为人才是最重要的原因。这些人才应该具有能够领导下一代互联网研究潮流的素质，他们对于信息网络科学技术发展有正确见解，对于创新技术有高度的敏感性，同时又不被某些似是而非的技术解决方案所迷惑；他们具有跨学科的知识，能够从宏观上理解互联网成功的原因，又能够了解技术细节，会编写程序。这样的人才真是太难得了。在此，我特地推荐这本由 Douglas E. Comer 教授所写的英文教科书，这本书能够帮助读者成为上述的人才。

Douglas E. Comer 博士是互联网的先驱者之一。他从 20 世纪 70 年代开始从事互联网的研究和开发工作，曾是互联网体系结构委员会的成员。该委员会是确定互联网发展标准的权威机构。他也曾任美国计算机网 CSTNET 技术委员会的主席，该网络是美国早期互联网建设中最重要的网络之一。他是美国普渡大学计算机科学系的教授，从事计算机网络和操作系统方面的教学和科研工作。我列举以上 Douglas E. Comer 博士的简历，说明要想成为网络大师在实践和理论上所必需的一些经历。

这本书篇幅巨大，但我建议读者能够通读，这样才能对于互联网这一跨学科领域有一个全面的认识。对于计算机网络分层模型有一定了解的读者可以看到，本书是对普通网络用户开始传授知识，开篇包括互联网的简史、网络测试和网络编程。然后从物理层和数据链路层讲起，涵盖了主要局域网和广域网的技术。在网络层讲述互联体系结构，包括目前的 IP 版本 4 和未来的 IP 版本 6，以及传输层协议 TCP。本书有大量的篇幅讲授网络应用的设计思路和大量的实例分析，包括服务器客户机模型、域名系统、电子邮件、文件传输、万维网、中间件、网络管理和网络安全等等。

本书极其鲜明地表现了美国大学工程教育的一个重要特点，即涵盖面广，知识体系结构之间的关系清晰，习题灵活，启发性强。这样，学生和读者可以有一个正确的宏观概念，对于毕业后需要解决的问题能够正确地找到当时最新的参考材料。我建议，读者在阅读的过程中，应该发掘并总结归纳 Douglas E. Comer 教授在书中讲授的互联网最本质的精神，争取把这本厚书读薄。

当然，网络是一门试验科学，如果希望真正深刻理解本书中的观点，就要从事网络的实践。由于这本书的结构和所涵盖内容的广泛，十年后重温这本书，读者一定会深有感触，感到信息网络技术发展的震撼。

李　星
清华大学电子工程系教授
2001 年 11 月 10 日

To Packets Everywhere

Preface

I am extremely pleased that *Computer Networks And Internets* is generating such excitement. In addition to the hundreds of U.S. schools using it in their networking courses, many professionals have written to say that it is being used in industry, and enthusiastic comments have arrived about the foreign translations. The success is especially satisfying in a market glutted with networking books. This book stands out because of its breadth of coverage, logical organization, explanation of concepts, focus on the Internet, and wealth of supplemental materials for both students and instructors on the CD-ROM and on the web site:

http://www.netbook.cs.purdue.edu

The new edition has been completely revised and updated, with three new chapters (3, 14, and 25), many new sections, and over 80 additional glossary entries. The CD-ROM and Web site have also been reorganized and expanded.

Each new chapter responds to requests from instructors and readers. Chapter 3 responds to those who requested an early introduction to network applications and programming. The chapter explains how to build applications that operate across the Internet before one acquires knowledge of the underlying technologies or protocol facilities. The chapter presents a simplified API (code is available), and shows examples of Internet applications that use the API to communicate. Even readers who are not interested in programming will be able to appreciate how much functionality can be achieved with a handful of procedures.

Chapter 14 was written in response to those who requested expanded coverage of connection-oriented networking. The chapter explores the connection-oriented paradigm, and uses ATM as an example. In addition to explaining concepts and details such as label switching, the chapter provides an assessment of the technology, and discusses why ATM has failed to live up to its ambitious design goals.

Chapter 25 was written in response to those who requested a chapter on Internet routing and Internet routing protocols. The chapter discusses both static and automatic routing. It covers the autonomous system concept and specific protocols such as RIP, OSPF, and BGP. Finally, the chapter examines the difficult problem of multicast route propagation.

The text answers the basic question "how do computer networks and internets operate?" in the broadest sense. It provides a comprehensive, self-contained tour through all of networking from the lowest levels of data transmission and wiring to the

highest levels of application software. At each level, it shows how the facilities and services provided by lower levels are used and extended in the next level. Thus, after describing how a modem uses a carrier to encode data, the text shows how packet-switching systems like the Internet use modems to send frames. After describing how technologies like Ethernet transfer frames, the text shows how a protocol like TCP uses such transmission facilities to transfer data reliably. Ultimately, the text explains how Internet applications like the World Wide Web operate over the resulting infrastructure.

The text is intended for upper-division undergraduates, or beginning graduate students, who have little or no background in networking. It does not use sophisticated mathematics, nor does it assume a knowledge of operating systems. Instead, the text defines concepts clearly, uses examples and drawings to illustrate how the technology operates, and states results of analysis without providing mathematical proofs.

After an introduction (Chapters 1—3), the body of the text is organized into four sections. The first section (Chapters 4—6) provides a brief explanation of how the underlying hardware works. The section explains the concept of a carrier signal, discusses modulating a carrier, and shows how a modem encodes data on a carrier wave for transfer. The section also discusses asynchronous, character-oriented data transmission and defines terms such as *bandwidth* and *baud* that arise in later chapters.

The second section (Chapters 7—16) focuses on packet switching. The section introduces the motivation for using packets, and then describes characteristics used to categorize networks as LANs, WANs, local loops, public or private, connection-oriented or connectionless, as well as basic network topologies and wiring schemes. The section also introduces the concepts of next-hop routing, switching, and protocol layering, with the terminology used for each. Finally, the section uses several common network technologies as examples, including Ethernet, FDDI, Token Ring, ATM, and ADSL.

The third section (Chapters 17—25) focuses on the Internet protocols. After discussing the motivation for internetworking, the section describes internet architecture and routers, internet addressing, address binding, and the TCP/IP protocols. Protocols such as IP, TCP, ICMP, and ARP are reviewed in more detail, allowing students to understand how the concepts relate to practice. Chapter 24 on TCP covers the important and deep topic of reliability in transport protocols. Appendix 5 shows how to put theory into practice by building a home network that connects multiple computers to the Internet through a single IP address.

The final section (Chapters 26—38) examines network applications. As with other sections of the text, coverage is quite broad — the section includes a discussion of both general principles and specific applications. The section begins by describing the client-server model that network applications use to communicate. The section then describes the socket API, and shows code from an example client and server that use sockets for communication. The section describes name resolution with the domain name system and applications such as e-mail, file transfer, and Web browsing, including an explanation of dynamic and active documents along with examples using CGI, Java, and JavaScript. In each case, the text describes the structure of the software, and explains how a client and server interact to provide the service. Chapter 35 discusses

middleware, including both procedural and object oriented middleware technologies. Later chapters in the section discuss network security and explain how application software can be used for network management. Finally, Chapter 38 considers the interesting problem of initialization. The chapter shows how application-level software can achieve what seems to be impossible — use of protocol software to obtain the information needed to initialize the protocol software being used.

The text is ideally suited for a one-semester introductory course on networking taught at the senior level. Designed for a comprehensive course, it covers the entire subject from wiring to applications. In the course at Purdue, for example, students have weekly lab assignments to reinforce the concepts and provide hands-on experience. By the time they finish our course, each student is expected to: know how an IP router uses a routing table to forward IP datagrams; describe how a datagram crosses the Internet; explain the difference between a hub and a layer 2 switch; know how TCP identifies a connection and why a concurrent web server can handle multiple connections to port 80; describe the conceptual differences between a bridge and an IP router; compute the length of a single bit as it travels across a 100BaseT network; explain why TCP is classified as end-to-end; distinguish between the CSMA/CD media access mechanism used by Ethernet and a token passing scheme; and know how DSL uses multiplexing to send data at high speed.

The goal of a single course is breadth, not depth — to cover the subject, one cannot focus on a few technologies or a few concepts. Thus, the key to a successful course lies in maintaining a quick pace. To cover the fundamental topics in a semester, the lower-layer material in Section *1* can be condensed into a week, and the sections on networks and internetworking can be allocated five weeks each, leaving a few weeks for the section on applications and topics such as network management and security.

Instructors should impress on students the importance of concepts and principles: specific technologies may become obsolete in a few years, but the principles will remain. In addition, instructors should give students a feeling for the excitement that pervades networking.

Although no single topic is challenging, students may find the quantity of material daunting. In particular, students are faced with a plethora of new terms. Networking acronyms and jargon can be especially confusing; students spend much of the time becoming accustomed to using proper terms. To help students master terminology, Appendix 1 contains a glossary of terms and acronyms. To provide additional clarification, definitions in the glossary have been written independently rather than being taken verbatim from the text.

Because programming and experimentation are crucial to helping students learn about networks, laboratory experience is an essential part of any networking course. Appendix 6 describes the architecture of the undergrad networking lab at Purdue, and shows how inexpensive hardware can be used to create a useful lab environment. Our lab curriculum at Purdue emphasizes two main aspects of networking: socket programming and packet analysis. We begin the semester by having students construct client software to access the web and extract data (e.g., write a program to print the current

temperature). Chapter 3 explains the simple API that we give students; with our API, students can write working code before they learn about protocols, addresses, or sockets. Later in the semester, of course, students learn to use the socket API. Eventually, they write a concurrent web server (CGI support is optional). In addition to application programming, students also use the lab facilities to capture packets from a live network. They write programs that decode packet headers (Ethernet/IP/TCP).

Giving students access to a network builds enthusiasm and encourages experimentation — our experience shows that students who have access to a live network understand and appreciate the subject better. Thus, if a dedicated packet analyzer is not available, an inexpensive analyzer can be configured by installing appropriate software on a standard PC. For students without access to networking facilities, the CD-ROM contains examples of packet traces; students can write programs that read a trace and process packets as if they have been captured from the network.

The CD-ROM included with the text and the Web site both contain materials that will make teaching easier and help readers understand the material. For instructors, the CD-ROM contains course materials, figures from the text that can be used in presentations, and animated figures that help clarify the concepts. The CD-ROM also contains materials not in the text, including photographs of network wiring and equipment as well as files of data that can be used as input to student projects.

To help both professors and students locate information, the CD-ROM includes a keyword search mechanism. When given a term, the search mechanism locates a definition from the online glossary as well as other items related to the term. Finally, the CD-ROM contains links to the Web site, which is updated continuously. Two electronic mailing lists have been established for the text: general information can be obtained from *netbook@cs.purdue.edu*; discussions about teaching the material occur on *netbook-inst@cs.purdue.edu*. To join either list, send an e-mail message to the list name *-request* with a body that consists of the word *subscribe*. To avoid having the mail server send multiple copies of each message over the Internet, instructors are requested to establish a single local alias for all students at their site.

I thank all the people who have contributed to this edition of the book. Dennis Brylow, and John Lin, proofread chapters throughout the text. Jennifer Seitzer, Abdullah Abonamah, and George Varghese reviewed an earlier edition and made valuable comments. Mike Evangelista wrote the client and server application code in Chapter 3 as well as the API; he ported the API to Linux, Solaris, and Windows platforms. Ralph Droms prepared the CD-ROM, and manages the Web materials. Jim Griffioen reviewed drafts of the three new chapters and offered global perspective as well as technical details. Special thanks go to my wife and partner, Chris, whose careful editing and helpful suggestions made many improvements throughout.

Douglas E. Comer

January, 2001

About The Author

Dr. Douglas Comer is an internationally recognized expert on TCP/IP protocols, computer networking, and the Internet. One of the researchers who contributed to the Internet as it was being formed in the late 1970s and 1980s, he was a member of the Internet Architecture Board, the group responsible for guiding the Internet's development. He was also chairman of the CSNET technical committee and a member of the CSNET executive committee.

Comer consults for industry on the design of computer networks. In addition to talks in universities, each year Comer teaches many onsite courses to networking professionals around the world. His operating system, Xinu, and implementation of TCP/IP protocols (both documented in his textbooks), have been used in commercial products.

Comer is a professor of computer science at Purdue University, where he teaches courses and does research on computer networking, internetworking, and operating systems. In addition to writing a series of best-selling technical books, he serves as the North American editor of the journal *Software — Practice and Experience.* Comer is a Fellow of the ACM.

Additional information can be found at:

www.cs.purdue.edu/people/comer

What Others Have Said About Computer Networks And Internets

"The book is one of the best that I have ever read. Thank you."

Gokhan Mutlu
Ege University, Turkey

"An excellent book for beginners and professionals alike — comprehensive coverage, and easy to follow."

John Lin
Bell Labs

"The breadth is astonishing."

George Varghese
University of California at

"I just could not put it down before I finished it. It was simply superb."

Lalit Y. Raju
Regional Engineering College

"The miniature webserver in Chapter 3 is brilliant — readers \ thrill out of it."

Dennis Brylow
Purdue University

"Despite the plethora of acronyms that infest the discipline of ne book is not intimidating. Comer is an excellent writer, who ex] plains the terminology. The text covers the entire scope of net wires to the web. I find it outstanding."

Jennifer Seitzer
University of Dayton

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Chapter Contents

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PART I Data Transmission