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国外优秀信息科学与技术系列教学用书

# 计算机网络

——自顶向下方法与 Internet 特色

(第三版 影印版)

## COMPUTER NETWORKING

A Top-Down Approach Featuring the Internet

(Third Edition)

■ James F. Kurose  
Keith W. Ross



高等教育出版社  
Higher Education Press

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TP393  
Y26

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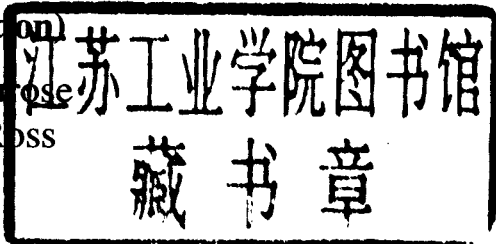
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图字: 01-2004- 6299 号

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原版 ISBN: 0-321-22735-2

For sale and distribution in the People's Republic of China exclusively (except Taiwan, Hong Kong SAR and Macao SAR).

仅限于中华人民共和国境内 (不包括中国香港、澳门特别行政区和中国台湾地区) 销售发行。

#### 图书在版编目 (CIP) 数据

计算机网络: 自顶向下方法与 Internet 特色 = Computer Networking: A Top-Down Approach Featuring the Internet: 第 3 版 / (美) 库罗斯 (Kurose, J. F.), (美) 罗斯 (Ross, K. W.). — 影印本. — 北京: 高等教育出版社, 2005. 1  
ISBN 7-04-012231-6

I. 计… II. ①库…②罗… III. 计算机网络—高等学校—教材—英文 IV. TP393

中国版本图书馆CIP数据核字(2005)第003359号

出版发行	高等教育出版社	购书热线	010-58581118
社 址	北京市西城区德外大街4号	免费咨询	800-810-0598
邮政编码	100011	网 址	<a href="http://www.hep.edu.cn">http://www.hep.edu.cn</a>
总 机	010-58581000		<a href="http://www.hep.com.cn">http://www.hep.com.cn</a>
经 销	北京蓝色畅想图书发行有限公司	网上订购	<a href="http://www.landaco.com">http://www.landaco.com</a>
印 刷	北京新丰印刷厂		<a href="http://www.landaco.com.cn">http://www.landaco.com.cn</a>
开 本	787×1092 1/16	版 次	2005年1月第1版
印 张	53.25	印 次	2005年1月第1次印刷
字 数	1 020 000	定 价	58.00元

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物料号: 12231-00

# 前 言

20 世纪末，以计算机和通信技术为代表的信息科学和技术对世界经济、科技、军事、教育和文化等产生了深刻影响。信息科学技术的迅速普及和应用，带动了世界范围信息产业的蓬勃发展，为许多国家带来了丰厚的回报。

进入 21 世纪，尤其随着我国加入 WTO，信息产业的国际竞争将更加激烈。我国信息产业虽然在 20 世纪末取得了迅猛发展，但与发达国家相比，甚至与印度、爱尔兰等国家相比，还有很大差距。国家信息化的发展速度和信息产业的国际竞争能力，最终都将取决于信息科学技术人才的质量和数量。引进国外信息科学和技术优秀教材，在有条件的学校推动开展英语授课或双语教学，是教育部为加快培养大批高质量的信息技术人才采取的一项重要举措。

为此，教育部要求由高等教育出版社首先开展信息科学和技术教材的引进试点工作。同时提出了两点要求，一是要高水平，二是要低价格。在高等教育出版社和信息科学技术引进教材专家组的努力下，经过比较短的时间，第一批引进的 20 多种教材已经陆续出版。这套教材出版后受到了广泛的好评，其中有不少是世界信息科学技术领域著名专家、教授的经典之作和反映信息科学技术最新进展的优秀作品，代表了目前世界信息科学技术教育的一流水平，而且价格也是最优惠的，与国内同类自编教材相当。

这项教材引进工作是在教育部高等教育司和高教社的共同组织下，由国内信息科学技术领域的专家、教授广泛参与，在对大量国外教材进行多次遴选的基础上，参考了国内和国外著名大学相关专业的课程设置进行系统引进的。其中，John Wiley 公司出版的贝尔实验室信息科学研究中心副总裁 Silberschatz 教授的经典著作《操作系统概念》，是我们经过反复谈判，做了很多努力才得以引进的。William Stallings 先生曾编写了在美国深受欢迎的信息科学技术系列教材，其中有多种教材获得过美国教材和学术作者协会颁发的计算机科学与工程教材奖，这批引进教材中就有他的两本著作。留美中国学者 Jiawei Han 先生的《数据挖掘》是该领域中具有里程碑意义的著作。由达特茅斯学院 Thomas Cormen 和麻省理工学院、哥伦比亚大学的几

位学者共同编著的经典著作《算法导论》，在经历了 11 年的锤炼之后于 2001 年出版了第二版。目前任教于美国 Massachusetts 大学的 James Kurose 教授，曾在美国三所高校先后 10 次获得杰出教师或杰出教学奖，由他主编的《计算机网络》出版后，以其体系新颖、内容先进而倍受欢迎。在努力降低引进教材售价方面，高等教育出版社做了大量和细致的工作。这套引进的教材体现了权威性、系统性、先进性和经济性等特点。

教育部也希望国内和国外的出版商积极参与此项工作，共同促进中国信息技术教育和信息产业的发展。我们在与外商的谈判工作中，不仅要坚定不移地引进国外最优秀的教材，而且还要千方百计地将版权转让费降下来，要让引进教材的价格与国内自编教材相当，让广大教师和学生负担得起。中国的教育市场巨大，外国出版公司和国内出版社要通过扩大发行数量取得效益。

在引进教材的同时，我们还应做好消化吸收，注意学习国外先进的教学思想和教学方法，提高自编教材的水平，使我们的教学和教材在内容体系上，在理论与实践的结合上，在培养学生的动手能力上能有较大的突破和创新。

目前，教育部正在全国 35 所高校推动示范性软件学院的建设和实施，这也是加快培养信息科学技术人才的重要举措之一。示范性软件学院要立足于培养具有国际竞争力的实用性软件人才，与国外知名高校或著名企业合作办学，以国内外著名 IT 企业为实践教学基地，聘请国内外知名教授和软件专家授课，还要率先使用引进教材开展教学。

我们希望通过这些举措，能在较短的时间，为我国培养一大批高质量的信息技术人才，提高我国软件人才的国际竞争力，促进我国信息产业的快速发展，加快推动国家信息化进程，进而带动整个国民经济的跨越式发展。

教育部高等教育司

二〇〇二年三月

# About the Authors

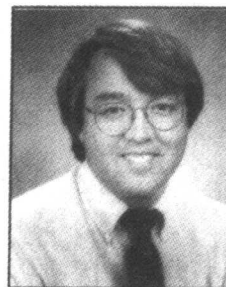
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## **Jim Kurose**

Jim Kurose is a professor of Computer Science at the University of Massachusetts, Amherst.

Dr. Kurose has received a number of recognitions for his educational activities including Outstanding Teacher Awards from the National Technological University (eight times), the University of Massachusetts, and the Northeast Association of Graduate Schools. He received the IEEE Taylor Booth Education Medal and was recognized for his leadership of Massachusetts' Commonwealth Information Technology Initiative. He has been the recipient of a GE Fellowship, an IBM Faculty Development Award, and a Lilly Teaching Fellowship.

Dr. Kurose is a former Editor-in-Chief of the IEEE Transactions on Communications and of the IEEE/ACM Transactions on Networking. He has been active in the program committees for IEEE Infocom, ACM SIGCOMM, and ACM SIGMETRICS for a number of years and has served as Technical Program Co-Chair for those conferences. He is a Fellow of the IEEE and the ACM. His research interests include network protocols and architecture, network measurement, sensor networks, multimedia communication, and modeling and performance evaluation. He holds a Ph.D. in Computer Science from Columbia University.



## **Keith Ross**

Keith Ross is the Leonard J. Shustek Professor in Computer Science at Polytechnic University in Brooklyn. From 1985 to 1998 he was a professor in the Department of Systems Engineering at the University of Pennsylvania. From 1998 to 2003 he was a professor in the Multimedia Communications Department at Institute Eurecom in France. Keith Ross is also the principal founder and original CEO of Wimba, which develops voice-over-IP technologies for e-learning markets.

Dr. Ross has published numerous research papers and has written two books. He has served on editorial boards on many major journals, including IEEE/ACM Transactions on Networking, and on numerous programming committees, including ACM SIGCOMM and IEEE Infocom. He has supervised 15 Ph.D. theses. His research and teaching interests include P2P systems, multimedia networking, network protocols, and stochastic networks. He received his Ph.D. from the University of Michigan.



To Julie and our three precious  
ones—Chris, Charlie, and Nina  
JFK

To my wonderful wife, Véronique,  
(she's such a great cook among other things!),  
and our three daughters, Cécile, Claire, and Katie  
KWR

# Preface

Welcome to the third edition of *Computer Networking: A Top-Down Approach Featuring the Internet*. Since the publication of the first edition four years ago, our book has been adopted for use at hundreds of colleges and universities, translated into more than 10 languages, and used by over one-hundred thousand students and practitioners worldwide. We've heard from many of these readers and have been overwhelmed by the positive response.

We think one important reason for this success has been that the book offers a fresh approach to computer networking instruction. Why is a fresh approach needed? In recent years we have witnessed two revolutionary changes in the field of networking – changes not reflected in books based on a 1980's or early-to-mid 1990's approach towards networking. First, the Internet has taken over computer networking. Any serious discussion about computer networking today has to be done with the Internet in mind. Second, the biggest “growth area” in the field of networking has arguably been in networking services and applications, as evidenced by the emergence of the Web, ubiquitous e-mail use, audio and video streaming, Internet phone, instant messaging, peer-to-peer applications, and online commerce.

## What's new in the third edition?

We've made changes in this third edition, but we've also kept unchanged what we believe (and the instructors and students who have used our book have confirmed) to be the most important aspects of this book: its top-down approach, its focus on the Internet, its attention to both principles and practice, and its accessible style and approach toward learning about computer networking.

Nevertheless, we have made many significant changes in the third edition, including a **new chapter on wireless and mobile networks**. We are currently witnessing a major shift in how users access the Internet and its services. Untethered users now access the Internet wirelessly from offices, homes, and public places. They do so while on the road and on the move, via an array of devices including laptops, phones, PDAs and more. Our new chapter on wireless and mobility includes in-depth coverage of 802.11, an overview of cellular Internet access, and a comprehensive discussion of mobility in the Internet and in cellular networks. With the addition of this new chapter, the textbook now contains four advanced, specialty chapters: wireless and mobile networks; multimedia networks; network security; and network management.

A second major addition is a set of **hands-on Ethereal labs**. Ethereal is free, public-domain packet sniffing and analysis tool that can be run on all popular



operating systems, including the most common Windows operating systems. It has rich functionality that includes an intuitive user interface and the ability to analyze nearly 400 protocols. In addition to the existing and new programming assignments, our book now has six Ethereal labs that are coordinated with the material in the text and that can be done on a student's own personal computer. (We'll also be creating additional Ethereal labs over the upcoming years.) In these labs, students can observe network protocols in action, seeing how protocol entities running in their computers interact and exchange messages with protocol entities executing elsewhere in the Internet. Students learn by doing. We have also added **two new socket programming assignments**: a UDP assignment and a proxy Web server assignment.

And that is not all. The third edition has been updated to reflect rapid changes in the field of networking over the last few years. It includes new and expanded material on peer-to-peer networking, BGP, MPLS, network security, broadcast routing, and Internet addressing and forwarding. We have also restructured Chapter 4, exposing more clearly the roles of forwarding and routing, and their interplay within the network layer.

## Audience

This textbook is for a first course on computer networking. It can be used in both computer science and electrical engineering departments. In terms of programming languages, the book assumes only that the student has experience with C, C++, or Java (and even then only in a few places). Although this book is more precise and analytical than many other introductory computer networking texts, it rarely uses any mathematical concepts that are not taught in high school. We have made a deliberate effort to avoid using any advanced calculus, probability, or stochastic process concepts. The book is therefore appropriate for undergraduate courses and for first-year graduate courses. It should also be useful to practitioners in the telecommunications industry.

## What Is Unique about This Textbook?

The subject of computer networking is enormously complex, involving many concepts, protocols, and technologies that are woven together in an intricate manner. To cope with this scope and complexity, many computer networking texts are often organized around the "layers" of a network architecture. With a layered organization, students can see through the complexity of computer networking—they learn about the distinct concepts and protocols in one part of the architecture while seeing the big picture of how all parts fit together. From a pedagogical perspective, our personal experience has been that such a layered approach is indeed highly desirable. Nevertheless, we have found the traditional approach of teaching—bottom up, that

is, from the physical layer towards the application layer—is not the best approach for a modern course on computer networking.

## A Top-Down Approach

Our book broke new ground 4 years ago by treating networking in a top-down manner—that is, by beginning at the application layer and working its way down toward the physical layer. The top-down approach has several important benefits. First, it places emphasis on the application layer (a “high growth area” in networking). Indeed, many of the recent revolutions in computer networking—including the Web, peer-to-peer file sharing, and media streaming—have taken place at the application layer. An early emphasis on application-layer issues differs from the approaches taken in most other texts, which have only a small (or nonexistent) amount of material on network applications, their requirements, application-layer paradigms (e.g., client/server), and application programming interfaces.

Second, our experience as instructors (and that of many instructors have used this text) has been that teaching networking applications near the beginning of the course is a powerful motivational tool. Students are thrilled to learn about how networking applications work—applications such as email and the Web, which most students use on a daily basis. Once a student understands the applications, the student can then understand the network services needed to support these applications. The student can then, in turn, examine the various ways in which such services might be provided and implemented in the lower layers. Covering applications early thus provides motivation for the remainder of the text.

Third, a top-down approach enables instructors to introduce network application development at an early stage. Students not only see how popular applications and protocols work, but also learn how easy it is to create their own network applications and application-level protocols. With the top-down approach, students get early exposure to the notions of application programming interfaces (APIs), service models, and protocols—important concepts that resurface in all subsequent layers. By providing socket programming examples in Java, we highlight the central ideas without confusing students with complex code. Undergraduates in electrical engineering and computer science should not have difficulty following the Java code.

## An Internet Focus

As indicated by the title, this textbook features the Internet, and uses the Internet’s architecture and protocols as primary vehicles for studying fundamental computer networking concepts. Of course, we also include concepts and protocols from other network architectures. But the spotlight is clearly on the Internet, a fact reflected in our organizing the book around the Internet’s five-layer architecture: the application, transport, network, link, and physical layers.

Another benefit of spotlighting the Internet is that most computer science and electrical engineering students are eager to learn about the Internet and its protocols. They've heard that the Internet is a revolutionary and disruptive technology and can see that it is profoundly changing our world. Given the enormous relevance of the Internet, students are naturally curious about what is "under the hood." Thus, it is easy for an instructor to get students excited about basic principles when using the Internet as the guiding focus.

## Addressing Principles

Two of the unique features of the book—its top-down approach and its focus on the Internet—appear in the subtitle of this book. If we could have squeezed a *third* phrase into the subtitle, it would have contained the word *principles*. The field of networking is now mature enough that a number of fundamentally important issues can be identified. For example, in the transport layer, the fundamental issues include reliable communication over an unreliable network layer, connection establishment/teardown and handshaking, congestion and flow control, and multiplexing. Two fundamentally important network-layer issues are determining "good" paths between two routers and interconnecting a large number of heterogeneous networks. In the data link layer, a fundamental problem is sharing a multiple access channel. In network security, techniques for providing confidentiality, authentication, and message integrity are all based on cryptographic fundamentals. This text identifies fundamental networking issues and studies approaches towards addressing these issues. The student learning these principles will gain knowledge with a long "shelf life;" long after today's network standards and protocols have been become obsolete, the principles they embody will remain important and relevant. We believe that the combination of using the Internet to get the student's foot in the door and then emphasizing fundamental issues and solution approaches will allow the student to quickly understand just about any networking technology.

## The Web Site

Purchasing this textbook grants each reader six months of access to a companion Web site for all book readers at <http://www.aw.com/kurose-ross>, which includes:

- ◆ *Interactive learning material.* The site contains interactive Java applets, illustrating key networking concepts. It also provides direct access to the programs such as the Traceroute program (through your browser) that shows the path that packets follow in the Internet. Professors can use these interactive features as mini labs. The Web site also provides direct access to search engines for Internet Drafts and to a newsgroup in which topics of this book are discussed. Finally, the site also makes available interactive quizzes that permit students to check their basic understanding of the subject matter.

- ◆ *Links to relevant on-line material.* We've made an effort to include Web URLs for as many of the book's references as possible. The bibliography is online and will be updated as links change, and as new material becomes available. We've also added links to some of our own favorite Web sites. The links point not only to RFCs and journal and conference articles, but also to sites that are more pedagogical in nature, including home-brewed pages on particular aspects of Internet technology and articles appearing in online trade magazines. Professors can assign the material behind the links as supplementary or even required reading.
- ◆ *Laboratory assignments.* The Web site also provides a number of detailed programming assignments and Ethereal lab assignments. The programming assignments include building a multithreaded Web server, building an e-mail client with a GUI interface, programming the sender and receiver sides of a reliable data transport protocol, programming a distributed routing algorithm, and more. The Web site also provides the details of the hands-on Ethereal Labs discussed above.

## Pedagogical Features

We have each been teaching computer networking for nearly 20 years. We bring to this text more than combined 35 years of teaching experience to over 3,000 students. We have also been active researchers in computer networking during this time. (In fact, Jim and Keith first met each other as master's students in a computer networking course taught by Mischa Schwartz in 1979 at Columbia University.) We think all this gives us a good perspective on where networking has been and where it is likely to go in the future. Nevertheless, we have resisted temptations to bias the material in this book towards our own pet research projects. We figure you can visit our personal Web sites if you are interested in our research. Thus, this book is about modern computer networking—it is about contemporary protocols and technologies as well as the underlying principles behind these protocols and technologies. We also believe that learning (and teaching!) about networking can be fun. A sense of humor, use of analogies, and real-world examples in this book will hopefully make this material more fun.

## Historical Sidebars and Principles in Practice

The field of computer networking has a rich and fascinating history. We have made a special effort in the text to tell the history of computer networking. This is done with a special historical section in Chapter 1 and with about a dozen historical sidebars sprinkled throughout the chapters. In these historical pieces, we cover the invention of packet switching, the evolution of the Internet, the birth of major networking giants such as Cisco and 3Com, and many other important events. Students will be stimulated by these historical pieces. We include special sidebars that high-

light important principles in computer networking. These sidebars will help students appreciate some of the fundamental concepts being applied in modern networking.

## Interviews

We have included yet another original feature that should inspire and motivate students—interviews with renowned innovators in the field of networking. We provide interviews with Len Kleinrock, Tim Berners-Lee, Sally Floyd, Vint Cerf, Simon Lam, Charlie Perkins, Henning Schulzrinne, Steven Bellovin, and Jeff Case.

## Supplements for Instructors

We provide a complete supplements package to aid instructors in teaching this course. All of this material is available on the instructor's Web site, <http://www.aw.com/kurose-ross>. Access to this portion of the WWW site is available to instructors by contacting your Addison-Wesley sales representative or by sending an email message to [aw.cs@aw.com](mailto:aw.cs@aw.com).

- ◆ *Powerpoint slides.* The course Web site provides PowerPoint® slides for all nine chapters. The slides cover each chapter in detail. They use graphics and animations (rather than relying only on monotonous text bullets) to make the slides interesting and visually appealing. We provide the original PowerPoint slides so you can customize them to best suit your own teaching needs. Some of these slides have been contributed by other instructors who have taught from our book.
- ◆ *Homework Solutions.* The Web site provides a solutions manual for the homework problems in the text.
- ◆ *Discussion group and contributions from other instructors.* The Web site also includes a section where instructors can post comments, questions, and replies. We have also included instructional material contributed by other instructors using our book.

## Chapter Dependencies

The first chapter of this text presents a self-contained overview of computer networking. Introducing many key concepts and terminology, this chapter sets the stage for the rest of the book. All of the other chapters directly depend on this first chapter. We recommend that, after completing Chapter 1, instructors cover Chapters 2

through 5 in sequence, thereby teaching according to the top-down philosophy. Each of these five chapters leverages material from the preceding chapters.

After completing the first five chapters, the instructor has quite a bit of flexibility. There are no interdependencies among the last four chapters, so they can be taught in any order. However, each of the last four chapters depends on the material in the first five chapters. Many instructors teach the first five chapters and then teach one of the last four chapters for dessert.

## One Final Note: We'd Love to Hear from You

We encourage instructors and students to create new Java applets that illustrate the concepts and protocols in this book. If you have an applet that you think would be appropriate for this text, please submit it to the authors. If the applet (including notation and terminology) are appropriate, we will be happy to include it on the text's Web site, with an appropriate reference to the authors of the applet. As noted above, we also encourage instructors to send us new homework problems (and solutions) that would complement the current homework problems. We will post these on the instructor-only portion of the Web site.

We also encourage students and instructors to e-mail us about any comments they might have about our book. It's been wonderful for us to hear from so many instructors and students from around the world about our first two editions. Feel free to send us interesting URLs, to point out typos, to disagree with any of our claims, and to tell us what works and what doesn't work. Tell us what you think should or shouldn't be included in the next edition. Send your e-mail to [kurose@cs.umass.edu](mailto:kurose@cs.umass.edu) and [ross@poly.edu](mailto:ross@poly.edu)

## Acknowledgements

Since we began writing this book in 1996, many people have given us invaluable help and have been influential in shaping our thoughts on how to best organize and teach a networking course. We want to say **A BIG THANKS** to everyone who has helped. We are also very thankful to the hundreds of readers from around the world—students, faculty, practitioners—who have sent us thoughts and comments on earlier editions of the book and suggestions for future editions of the book. Special thanks go out to:

Al Aho (Columbia University)  
Pratima Akkunoor (Arizona State University)  
Paul Amer (University of Delaware)

Shamiul Azom (Arizona State University)  
Paul Barford (University of Wisconsin)  
Bobby Bhattacharjee (University of Maryland)  
Steven Bellovin (AT&T Research)  
Pravin Bhagwat (Wibhu)  
Supratik Bhattacharyya (Sprint)  
Shahid Bokhari (University of Engineering & Technology, Lahore)  
Ernst Biersack (Eurécom Institute)  
Daniel Brushteyn (former University of Pennsylvania student)  
Ken Calvert (University of Kentucky)  
Evandro Cantu (Federal University of Santa Catarina)  
Jeff Case (SNMP Research International)  
Vinton Cerf (MCI WorldCom)  
Byung Kyu Choi (Michigan Technological University)  
John Daigle (University of Mississippi)  
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David Goodman (Polytechnic University)  
Tim Griffin (AT&T Research)  
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Sugih Jamin (University of Michigan)  
Shivkumar Kalyanaraman (Rensselaer Polytechnic Institute)  
Jussi Kangasharju (University of Darmstadt)  
Sneha Kasera (University of Utah)  
Hyojin Kim (former University of Pennsylvania student)  
Leonard Kleinrock (University of California at Los Angeles)  
David Kotz (Dartmouth College)

Beshan Kulapala (Arizona State University)  
Miguel A. Labrador (University of South Florida)  
Steve Lai (Ohio State University)  
Tim-Berners Lee (World Wide Web Consortium)  
Brian Levine (University of Massachusetts)  
William Liang (former University of Pennsylvania student)  
Willis Marti (Texas A&M University)  
Deep Medhi (University of Missouri, Kansas City)  
Bob Metcalfe (International Data Group)  
Sue Moon (KAIST)  
Erich Nahum (IBM Research)  
Christos Papadopoulos (University of Southern California)  
Craig Partridge (BBN Technologies)  
Radia Perlman (Sun Microsystems)  
Jitendra Padhye (Microsoft Research)  
Kevin Phillips (Sprint)  
George Polyzos (University of California at San Diego)  
Sriram Rajagopalan (Arizona State University)  
Ken Reek (Rochester Institute of Technology)  
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Jennifer Rexford (AT&T Research)  
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Avi Rubin (Johns Hopkins University)  
Dan Rubenstein (Columbia University)  
Despina Saporilla (Lucent Bell Labs)  
Henning Schulzrinne (Columbia University)  
Mischa Schwartz (Columbia University)  
Harish Sethu (Drexel University)  
K. Sam Shanmugan (University of Kansas)  
Prashant Shenoy (University of Massachusetts)  
Clay Shields (Georgetown University)  
Subin Shrestha (University of Pennsylvania)  
Peter Steenkiste (Carnegie Mellon University)  
Tatsuya Suda (University of California at Irvine)  
Kin Sun Tam (State University of New York at Albany)  
Don Towsley (University of Massachusetts)  
David Turner (California State University, San Bernardino)  
David Wetherall (University of Washington)  
Ira Winston (University of Pennsylvania)  
Raj Yavatkar (Intel)  
Yechiam Yemini (Columbia University)  
Ellen Zegura (Georgia Institute of Technology)  
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Shuchun Zhang (former University of Pennsylvania student)  
Phil Zimmermann (independent consultant)

We also want to thank the entire Addison-Wesley team, who have done an absolutely outstanding job (and who have put up with two very finicky authors!): Marilyn Lloyd, Susan Hartman Sullivan, Patty Mahtani and Beth Paquin. Thanks also to the artists, Janet Theurer and Patrice Rossi Calkin, for their work on the beautiful figures in the second and third editions of this book, and to Nancy Kotary and Daniel Rausch for their wonderful production work on this edition. Finally, a most special thanks go to Susan, our editor at Addison-Wesley. This book would not be what it is (and may well not have been at all) without her graceful management, constant encouragement, nearly infinite patience, good humor, and perseverance.