

# DATA AND COMPUTER COMMUNICATIONS



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*Ninth Edition*

**William Stallings**

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*For my brave, extraordinary  
and fascinating wife ATS*



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## PREFACE

*Begin at the beginning and go on till you come to the end; then stop*

—*Alice in Wonderland*, Lewis Carroll

### OBJECTIVES

This book attempts to provide a unified overview of the broad field of data and computer communications. The organization of the book reflects an attempt to break this massive subject into comprehensible parts and to build, piece by piece, a survey of the state of the art. The book emphasizes basic principles and topics of fundamental importance concerning the technology and architecture of this field and provides a detailed discussion of leading-edge topics.

The following basic themes serve to unify the discussion:

- **Principles:** Although the scope of this book is broad, there are a number of basic principles that appear repeatedly as themes and that unify this field. Examples are multiplexing, flow control, and error control. The book highlights these principles and contrasts their application in specific areas of technology.
- **Design approaches:** The book examines alternative approaches to meeting specific communication requirements.
- **Standards:** Standards have come to assume an increasingly important, indeed dominant, role in this field. An understanding of the current status and future direction of technology requires a comprehensive discussion of the related standards.

### INTENDED AUDIENCE

The book is intended for both an academic and a professional audience. For the professional interested in this field, the book serves as a basic reference volume and is suitable for self-study. As a textbook, it can be used for a one-semester or two-semester course. It covers the material in Networking (NET), a core area in the Information Technology body of knowledge, which is part of the Draft ACM/IEEE/AIS Computing Curricula 2005. The book also covers the material in Computer Networks (CE-NWK), a core area in Computer Engineering 2004 Curriculum Guidelines from the ACM/IEEE Joint Task Force on Computing Curricula.

### PLAN OF THE TEXT

The book is divided into seven parts, which are described in Chapter 0:

- Overview
- Data Communications
- Wide Area Networks

## xvi PREFACE

- Local Area Networks
- Internet and Transport Protocols
- Network Security
- Internet Applications

The book includes a number of pedagogic features, including the use of animations and numerous figures and tables to clarify the discussions. Each chapter includes a list of key words, review questions, homework problems, suggestions for further reading, and recommended Web sites. The book also includes an extensive online glossary, a list of frequently used acronyms, and a reference list. In addition, a test bank is available to instructors.

The chapters and parts of the book are sufficiently modular to provide a great deal of flexibility in the design of courses. See Chapter 0 for a number of detailed suggestions for both top-down and bottom-up course strategies.

## WHAT'S NEW IN THIS EDITION

This ninth edition is seeing the light of day less than four years after the publication of the eighth edition. During that time, the pace of change in this field continues unabated. In this new edition, I try to capture these changes while maintaining a broad and comprehensive coverage of the entire field. To begin the process of revision, the eighth edition of this book was extensively reviewed by a number of professors who teach the subject. The result is that, in many places, the narrative has been clarified and tightened, and illustrations have been improved.

Beyond these refinements to improve pedagogy and user-friendliness, there have been major substantive changes throughout the book. Highlights include:

- **Animations:** Animation provides a powerful tool for understanding the complex mechanisms of network protocols. The ninth edition incorporates a number of separate animations covering such protocols as Hypertext Transfer Protocol (HTTP), Simple Mail Transfer Protocol (SMTP), and Transmission Control Protocol (TCP). A directory of the animations is provided after the Preface.
- **Examples:** The number of examples incorporated in the book has been significantly expanded.
- **Twisted-pair transmission standards:** This new edition covers the 2009 ANSI/TIA 568-C standards and the recent ISO/IEC 11801 twisted-pair transmissions, which are important for gigabit-range Ethernet and other high-speed twisted-pair applications.
- **Expanded coverage of broadband Internet access:** The sections on cable modem and DSL broadband access have been expanded.
- **New coverage of fourth-generation (4G) mobile wireless networks:** Includes the key 4G technology of orthogonal frequency division multiple access (OFDMA).



- **New coverage of virtual LANs:** VLAN technology is covered, as well is the IEEE 802.1Q standard.
- **Updated coverage of high-speed Ethernet:** The new 100-Gbps standard is covered, including the multilane distribution (MLD) transmission technique, plus expanded coverage of 64B/66B encoding.
- **Updated coverage of Wi-Fi/IEEE 802.11 wireless LANs:** IEEE 802.11 and the related Wi-Fi specifications have continued to evolve. New coverage includes 802.11n.
- **Mobile IP:** New to this edition is coverage of Mobile IP, which standardizes techniques for IP addressing and routing for mobile end systems.
- **MPLS:** New to this edition is full chapter devoted to Multiprotocol Label Switching, which is becoming increasingly important on the Internet and other IP-based networks, as well as in telecommunications networks.
- **Expanded coverage of security:** The coverage of security, in Part Six, has been completely rewritten and expanded to two chapters. It is more detailed, covering a number of new topics.

In addition, throughout the book, virtually every topic has been updated to reflect the developments in standards and technology that have occurred since the publication of the eighth edition.

## ONLINE DOCUMENTS FOR STUDENTS

For this new edition, a tremendous amount of original supporting material has been made available online, in the following categories:

- **Online chapters:** To limit the size and cost of the book, two chapters of the book are provided in PDF format. The chapters are listed in this book's table of contents.
- **Online appendices:** There are numerous interesting topics that support material found in the text but whose inclusion is not warranted in the printed text. A total of 23 appendices cover these topics for the interested student. The appendices are listed in this book's table of contents.
- **Homework problems and solutions:** To aid the student in understanding the material, a separate set of homework problems with solutions are available. These enable the students to test their understanding of the text.
- **Key papers:** Several dozen papers from the professional literature, many hard to find, are provided for further reading.
- **Supporting documents:** A variety of other useful documents are referenced in the text and provided online.

Purchasing this textbook new grants the reader six months of access to this online material. See the access card in the front of this book for details.

## INSTRUCTIONAL SUPPORT MATERIALS

To support instructors, the following materials are provided:

- **Solutions Manual:** Solutions to all end-of-chapter Review Questions and Problems.
- **Projects Manual:** Suggested project assignments for all of the project categories listed below.
- **PowerPoint Slides:** A set of slides covering all chapters, suitable for use in lecturing.
- **PDF files:** Reproductions of all figures and tables from the book.
- **Test Bank:** A chapter-by-chapter set of questions.

All of these support materials are available at the Instructor Resource Center (IRC) for this textbook, which can be reached through the Publisher's Web site [www.pearsonhighered.com/stallings](http://www.pearsonhighered.com/stallings) or by clicking on the button labeled "Book Info and More Instructor Resources" at this book's Web site [WilliamStallings.com/DCC/DCC9e.html](http://WilliamStallings.com/DCC/DCC9e.html). To gain access to the IRC, please contact your local Prentice Hall sales representative via [pearsonhighered.com/educator/replicator/requestSalesRep.page](http://pearsonhighered.com/educator/replicator/requestSalesRep.page) or call Prentice Hall Faculty Services at 1-800-526-0485.

In addition, the book's Web site supports instructors with:

- Links to Web sites for other courses being taught using this book
- Sign-up information for an Internet mailing list for instructors

## INTERNET SERVICES FOR INSTRUCTORS AND STUDENTS

There is a Web site for this book that provides support for students and instructors. The site includes links to other relevant sites, transparency masters of figures in the book, and sign-up information for the book's Internet mailing list. The Web page is at [WilliamStallings.com/DCC/DCC9e.html](http://WilliamStallings.com/DCC/DCC9e.html). For more information, see Chapter 0. The Publisher's Web site [www.pearsonhighered.com/stallings](http://www.pearsonhighered.com/stallings) provides instructors and students with direct links to the Companion Web site, Instructor Resources, Premium Content, and Web chapters.

New to this edition is a set of homework problems with solutions. Students can enhance their understanding of the material by working out the solutions to these problems and then checking their answers.

An Internet mailing list has been set up so that instructors using this book can exchange information, suggestions, and questions with each other and with the author. As soon as typos or other errors are discovered, an errata list for this book will be available at [WilliamStallings.com](http://WilliamStallings.com). In addition, the Computer Science Student Resource site at [WilliamStallings.com/StudentSupport.html](http://WilliamStallings.com/StudentSupport.html) provides documents, information, and useful links for computer science students and professionals.

## PROJECTS AND OTHER STUDENT EXERCISES

For many instructors, an important component of a data communications or networking course is a project or set of projects by which the student gets hands-on experience to reinforce concepts from the text. This book provides an unparalleled degree of support for including a projects

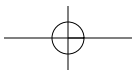
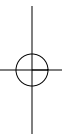
component in the course. The IRC not only includes guidance on how to assign and structure the projects but also includes a set of User's Manuals for various project types plus specific assignments, all written especially for this book. Instructors can assign work in the following areas:

- **Animation assignments:** Described in the following section.
- **Practical exercises:** Using network commands, the student gains experience in network connectivity.
- **Sockets programming projects:** The book is supported by a detailed description of Sockets (Appendix T). The IRC includes a set of programming projects. Sockets programming is an “easy” topic and one that can result in very satisfying hands-on projects for students.
- **Wireshark projects:** Wireshark is a protocol analyzer that enables students to study the behavior of protocols. A video tutorial is provided to get students started.
- **Simulation projects:** The student can use the simulation package *cnet* to analyze network behavior.
- **Performance modeling projects:** Two performance modeling techniques are provided: a *tools* package and OPNET.
- **Research projects:** The IRC includes a list of suggested research projects that would involve Web and literature searches.
- **Reading/report assignments:** The IRC includes a list of papers that can be assigned for reading and writing a report, plus suggested assignment wording.
- **Writing assignments:** The IRC includes a list of writing assignments to facilitate learning the material.
- **Discussion topics:** These topics can be used in a classroom, chat room, or message board environment to explore certain areas in greater depth and to foster student collaboration.

This diverse set of projects and other student exercises enables the instructor to use the book as one component in a rich and varied learning experience and to tailor a course plan to meet the specific needs of the instructor and students. See Appendix B for details.

## ANIMATIONS

New to this edition is the incorporation of animations. Animations provide a powerful tool for understanding the complex mechanisms of network protocols. A number of Web-based animations are used to illustrate protocol behavior. Each animation allows the user to step through the operation of the protocol by selecting the next step at each point in the protocol exchange. The entire protocol exchange is illustrated by an animated diagram as the exchange proceeds. The animations can be used in two ways. In a **passive mode**, the student can click more or less randomly on the next step at each point in the animation and watch as the given concept or principle is illustrated. In an **active mode**, the user can be given a specific set of steps to invoke and watch the animation, or be given a specific end point and devise a sequence of steps that achieve the desired result. Thus, the animations can serve as the basis for student assignments. The IRC includes a set of assignments for each of the animations, plus suggested solutions so that instructors can assess the student's work.





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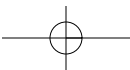
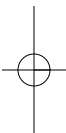
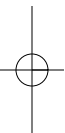
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With all this assistance, little remains for which I can take full credit. However, I am proud to say that, with no help whatsoever, I selected all of the quotations.





## ABOUT THE AUTHOR

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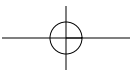
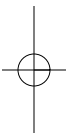
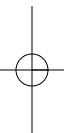
William Stallings has made a unique contribution to understanding the broad sweep of technical developments in computer security, computer networking, and computer architecture. He has authored 17 titles, and counting revised editions, a total of 42 books on various aspects of these subjects. His writings have appeared in numerous ACM and IEEE publications, including the *Proceedings of the IEEE* and *ACM Computing Review*.

He has 11 times received the award for best Computer Science textbook of the year from the Text and Academic Authors Association.

In over 30 years in the field, he has been a technical contributor, technical manager, and an executive with several high-technology firms. He has designed and implemented both TCP/IP-based and OSI-based protocol suites on a variety of computers and operating systems, ranging from microcomputers to mainframes. As a consultant, he has advised government agencies, computer and software vendors, and major users on the design, selection, and use of networking software and products.

He created and maintains the **Computer Science Student Resource Site** at [WilliamStallings.com/StudentSupport.html](http://WilliamStallings.com/StudentSupport.html). The site provides documents and links on a variety of subjects of general interest to computer science students and professionals. He is a member of the editorial board of *Cryptologia*, a scholarly journal devoted to all aspects of cryptology.

Dr. Stallings holds a Ph.D. from Massachusetts Institute of Technology in Computer Science and a B.S. from Notre Dame in Electrical Engineering.







## ANIMATIONS DIRECTORY

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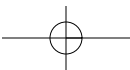
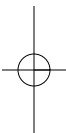
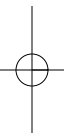
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# DATA AND COMPUTER COMMUNICATIONS

