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Digital Systems

Principles and Applications

Eighth Edition

Ronald J. Tocci Neal S. Widmer

Digital Systems

Principles and Applications, Eighth Edition

by Ronald J. Tocci and Neal S. Widmer

Authors Tocci and Widmer have again created a digital electronics text with a wide variety of tools and topics that provides the necessary foundation in digital electronics that students need for future studies.

NEW! The eighth edition features **more coverage of programmable logic devices (PLDs).** This technology is rapidly replacing the use of conventional small- and medium-scale ICs in modern digital systems. Interspersed throughout the text where appropriate, this PLD coverage offers students an alternative means of implementing digital logic circuits, from the simplest gates to complex systems.

NEW! Each text is packaged with two free CD-ROMs. The first CD-ROM contains the entire library of Texas Instruments Logic Data Sheets, including all TTL series, CMOS, and bus interface parts. The second CD-ROM contains:

- **Circuits from the text rendered in both Electronics Workbench™ and CircuitMaker® software programs.** Students with access to Electronics Workbench software can open and work interactively with the Electronics Workbench circuit files to increase their understanding of concepts and to prepare for laboratory activities. Free CircuitMaker Student Version software is included on the CD-ROM, enabling students to access the CircuitMaker files.
- **A limited-compile demonstration version of the PAL Expert CUPL language compiler** from Logical Devices, Inc.

UPDATED! **Topics that apply to digital signal processing (DSP),** a very rapidly advancing technology in electronics, have been expanded and improved.

UPDATED! **Digital logic technology coverage and terms** often encountered in personal computer literature have been updated and improved.

UPDATED! Students have *free* access to the text's **Companion Website at http://www.prenhall.com/tocci.** This site contains review questions for each chapter, which help students test their understanding of the material.

To view the website that accompanies this text, please go to http://www.prenhall.com/tocci

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Eighth Edition

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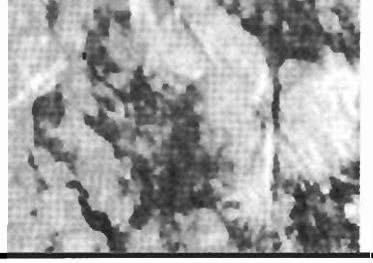


PREFACE

This book is a comprehensive study of the principles and techniques of modern digital systems. It is intended for use in two- and four-year programs in technology, engineering, and computer science. Although a background in basic electronics is helpful, the majority of the material requires no electronics training. Those portions of the text that utilize electronic concepts can be skipped without adversely affecting the comprehension of the logic principles.

General Improvements

This eighth edition contains several general improvements to the seventh edition. All of the material has been checked for currency and updated wherever necessary. Some of the material has been rewritten for greater clarity and completeness. Several new examples, section review questions, and end-of-chapter problems have been added, both to reinforce the new text material and to support the retained material better.

PLD COVERAGE The most striking change in this eighth edition of *Digital Systems: Principles and Applications* is the new approach to teaching programmable logic devices (PLDs). This book has been rewritten to teach the PLD as one of the ways, along with traditional integrated circuits, to implement circuits from the simplest gates to the most complicated digital systems. Whenever a major change in technology occurs, there is a period during which educational institutions must decide when and how to change the way they teach related topics. Some of us remember the transition from vacuum tubes to transistors, and most of us remember the shift from transistor circuits to op-amps. Over the past 15 years, the technology of digital systems has moved toward programmable logic. Very few new digital systems today use small-scale and medium-scale integrated circuits in anything other than a minor role. Most modern digital circuitry is contained in a programmable device, gate array, or full custom integrated circuit. Still, in order to learn how to create those "systems in a chip," students must first understand the building blocks, such as decoders, multiplexers, adders, buffers, latches, registers, counters, and so on. In introductory lab-based courses, the wiring and testing of these building blocks is still a vital part of the pedagogy. It solidifies concepts such as binary inputs and outputs, physical device operation, and practical limitations. It also provides a realistic forum for developing troubleshooting skills.

The wiring of these circuits on a conventional breadboard still provides a means of learning that is not attainable through graphics, simulation, or text descriptions.

However, programmable devices can be used to demonstrate these concepts just as effectively as medium-scale integrated circuits. Because the means to implement these circuits in current technology is with the PLD, the skills necessary to use PLDs must be developed concurrently with the knowledge of basic building blocks. We believe that PLDs can be used to implement logic circuits long before the student has acquired enough knowledge to fully understand all of the inner workings of a PLD. In so doing, students are given a chance to learn the development and programming steps using relatively simple circuits. Later they can expand their knowledge of advanced features of programming languages as they become aware of more advanced circuits. Eventually, after learning all the building blocks, students can understand the circuitry of a PLD in order to take full advantage of its capabilities and realize its limitations.

SEQUENCING Our approach to PLDs in this edition gives instructors *three* options: (1) The PLD material can be skipped in its entirety without affecting the continuity of the text; (2) PLDs can be taught as a separate topic by skipping PLD material initially and then going back to the last sections of Chapters 4, 5, 6, 7, and 9 before reading Chapter 12; or (3) PLDs can be introduced as the course unfolds—chapter by chapter—and woven into the fabric of the lecture/lab experience. We believe our approach will provide maximum flexibility for a variety of courses and objectives.

It is a rare instructor who uses the chapters of a textbook in the sequence in which they are presented. This book was written so that, for the most part, each chapter builds on previous material, but it is possible to alter the chapter sequence somewhat. The first part of Chapter 6 (arithmetic operations) can be covered right after Chapter 2 (number systems), although this would produce a long interval before the arithmetic circuits of Chapter 6 are encountered. Much of the material in Chapter 8 (IC characteristics) can be covered earlier (e.g., after Chapter 4 or 5) without causing any serious problems.

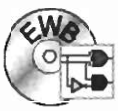
This book can be used either in a one-term course or in a two-term sequence. When used in one term, it may be necessary, depending on available class hours, to omit some topics. Here is a list of sections and chapters that can be deleted with minimal disruption. Obviously, the choice of deletions will depend on factors such as program or course objectives and student background:

Chapter 1:	All	Chapter 8:	Sections 11, 14–21
Chapter 2:	Section 6	Chapter 9:	Sections 5, 9, 15
Chapter 4:	Sections 7, 10–14	Chapter 10:	Sections 7, 14–18
Chapter 5:	Sections 3, 24–26	Chapter 11:	Sections 17–21
Chapter 6:	Sections 5–7, 11, 13, 16–20	Chapter 12:	All
Chapter 7:	Sections 10, 14, 23–25		

PROBLEM SETS The seventh edition contained four categories of problems: challenging **(C)**, troubleshooting **(T)**, new **(N)**, and design **(D)**. The eighth edition adds the category of *basic* **(B)** to designate problems that are very fundamental applications of the concepts in that particular chapter. Also, we have added more problems that exercise a basic understanding. Undesignated problems are considered to be of intermediate difficulty, between basic and challenging.

DATA SHEETS Although a few data sheets are retained in Appendix B, the accompanying CD-ROM is now the primary source of manufacturers' data sheets. The information on this single CD is equivalent to an entire shelf full of data books covering all TTL, CMOS, and high-speed bus interface logic ICs. We feel this will provide students with a much more complete reference resource while retaining enough printed data sheets to teach them how to read and interpret data sheet content in the absence of a computer with CD-ROM capability.

SIMULATION FILES This edition also includes simulation files that can be loaded into Electronics Workbench and CircuitMaker. The circuit schematics of many of the figures throughout the text have been captured as input files for these two popular simulation tools. Each file has some way of demonstrating the operation of the circuit or reinforcing a concept. In many cases, instruments are attached to the circuit and input sequences are applied to demonstrate the concept presented in one of the figures of the text. These circuits can then be modified as desired to expand on topics or create assignments and tutorials for students. All figures in the text that have a corresponding simulation file on the CD-ROM are identified by this icon:



IC TECHNOLOGY This new edition continues the practice begun with the last two editions of giving more prominence to CMOS as the principal IC technology in the small- and medium-scale integration applications. This has been accomplished while still retaining the substantial coverage of TTL logic.

REAL-WORLD APPLICATIONS The examples of real-world applications that were distributed throughout previous editions have been retained to motivate those students who ask, "Why do we need to know this?" Some examples are copy machine control circuits, liquid process control sequencer circuits, space shuttle battery-voltage monitor, digital thermostat, and a look-up table function generator. PLD examples are chosen to offer an alternate way to implement equivalent SSI and MSI circuitry that is explained earlier in the text. However, new PLD examples are included that consolidate several types of circuits and several design methods in a single PLD system. For example, the universal stepper motor driver depicted in Figure P-1 uses a single GAL 16V8 to implement the sequencer, decoder, and tristate buffered outputs for an interface circuit that is very useful when working with stepper motors in the lab. Figure P-2 shows a scanned keypad encoder that is very useful as an input device to microprocessors and other digital systems. It includes sequential ring counter circuits as well as encoders and tristate output control. These are circuits that can easily be built and used in future experiments involving digital systems.

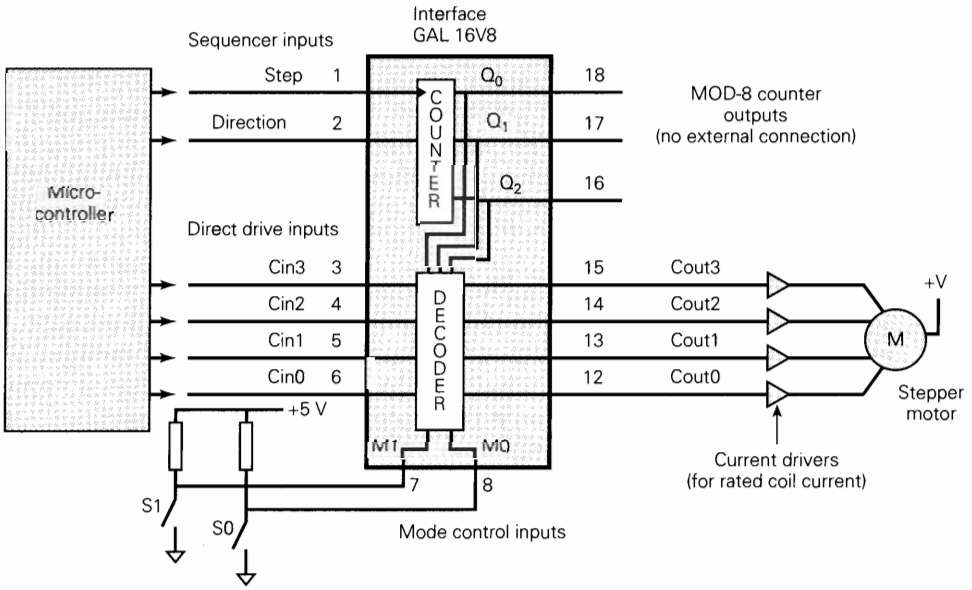
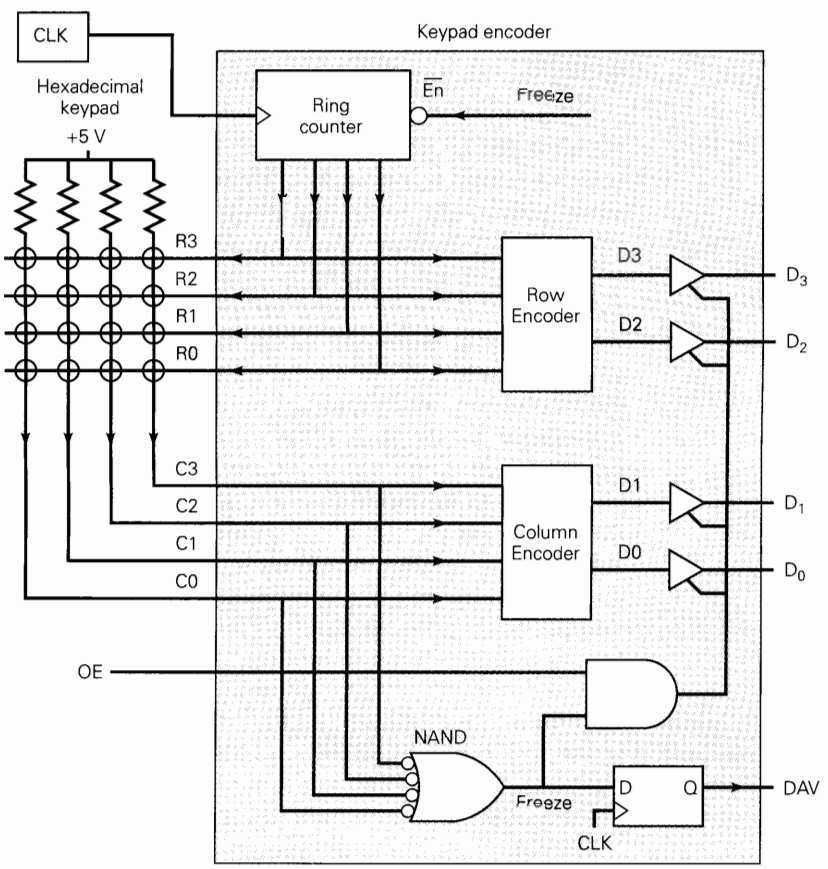


FIGURE P-1 Stepper motor driver from Figure 12-20.

FIGURE P-2 Scanned keypad encoder from Figure 12-25.



Specific Changes

The major changes in the topical coverage are:

- **Chapter 1.** A look at the "digital future" has been updated.
- **Chapter 2.** This chapter now covers new and improved methods for using calculators to perform conversions between number systems.
- **Chapter 3.** IEEE standard symbol coverage has been reduced.
- **Chapter 4.** (1) Material on K-mapping, including a complete example using "don't cares," has been added. (2) PLDs are introduced as another way of implementing logic circuits. The general concepts of PLD hardware are introduced in the simplest possible way, showing basic sum-of-products circuits programmed using fuse technology. This chapter describes the required computer hardware and programming fixture along with the role each plays in the development process. A specific high-level hardware description language is introduced and a simple combinational logic circuit is implemented as an example of the entire process.
- **Chapter 5.** Logic circuits with feedback, including SR and D latches, are implemented using PLDs. The state transition method of hardware description is used to implement a simple counter circuit on a PLD.
- **Chapter 6.** A section is added that demonstrates a 4-bit full adder implemented on a PLD. The use of set notation in the hardware description language is introduced along with indexed variables to combine 4-bit data sets logically.
- **Chapter 7.** (1) Material on the 74178 (obsolete) has been deleted, and coverage of the 74165 and 74174 ICs has been expanded. (2) The registered outputs of PLDs are introduced along with two more methods of specifying the state sequence of a counter circuit (state machine).
- **Chapter 8.** Several incremental revisions and changes in technology have motivated a substantial rearrangement of topics in Chapter 8. Ball grid array packages are introduced. All TTL examples and data sheets now feature the ALS series, while the fundamental circuit characteristics are described using the more easily understood standard TTL. In addition, the topical coverage of MOS and CMOS has been consolidated and the coverage of PMOS and NMOS reduced to reflect current industrial use and emphasis on CMOS as the most popular technology today. ECL material is updated. The continued expansion of low-voltage technologies is updated. Open-collector and open-drain circuit descriptions are consolidated to eliminate redundancy and tristate logic coverage is improved. The high-speed bus interface series are also introduced, along with a brief introduction to the nature of transmission lines and the need for bus terminations.
- **Chapter 9.** This chapter describes color LCD displays and technology used in laptop computer screens. Gas discharge (vacuum fluorescent) displays and two IEEE notation sections have been deleted. A section on PLDs covers the use of the truth table method of hardware description. Conventional MSIC functions are implemented using PLDs.
- **Chapter 10.** The section on sampling has been expanded to address the issue of minimum sample rate (Nyquist) and signal aliasing. The application of A/D and D/A converters to the rapidly growing field of digital signal processing is expanded with a basic and easy-to-understand introduction to DSP.

- **Chapter 11.** All PLD material has been edited or moved to other areas of the text, mostly Chapter 12. Coverage of terms and concepts often referred to in PC literature is expanded, including a snapshot of the transient state of DRAM technology, definition of latency and its effect on execution speed, as well as a description of L1 and L2 cache systems in modern PCs. Circular buffers are introduced as a memory structure due to their prevalent use in DSP systems.
- **Chapter 12.** This chapter has been rewritten to begin with an overview of the internal hardware of simple PLDs. The material from Chapter 11 of the seventh edition has been revised and combined with material from Chapter 12. The popular GAL 22V10 is also introduced with an example that requires its added capability. Two complete and very practical digital systems—a universal stepper motor driver and a scanned keypad encoder—are implemented using a single PLD. Material has been added to offer a glimpse into the real world of advanced digital system design by describing other hardware definition languages (HDL) and the general architecture of the more advanced field programmable gate arrays.
- **Appendix A.** The material on microprocessors (Chapter 13 in past editions) has admittedly been a superficial introduction to a very important and complex subject. We believe most programs cover this material in another course and use a text dedicated to the subject. Consequently, we have relegated the material to Appendix A with intentions of eventually phasing this material out of the book. We invite feedback on these plans by way of the Prentice Hall Companion Website for this book, http://www.prenhall.com/tocci.

Retained Features

This edition retains all of the features that made the previous editions so widely accepted. It utilizes a block diagram approach to teach the basic logic operations without confusing the reader with the details of internal operation. All but the most basic electrical characteristics of the logic ICs are withheld until the reader has a firm understanding of logic principles. In Chapter 8 the reader is introduced to the internal IC circuitry. At that point, the reader can interpret a logic block's input and output characteristics and "fit" it properly into a complete system.

The treatment of each new topic or device typically follows these steps: the principle of operation is introduced; thoroughly explained examples and applications are presented, often using actual ICs; short review questions are posed at the end of the section; and finally, in-depth problems are available at the end of the chapter. Ranging from simple to complex, these problems provide instructors with a wide choice of student assignments. These problems are often intended to reinforce the material without simple repetition of the principles. They require the student to demonstrate comprehension of the principles by applying them to different situations. This also helps the student develop confidence and expand his or her knowledge of the material.

The IEEE/ANSI standard for logic symbols is introduced and discussed with minimum disruption of the topic flow, and, if desired, can be omitted completely or in part. The extensive troubleshooting coverage is spread over Chapters 4 through 11 and includes presentation of troubleshooting principles and techniques, case studies, 25 troubleshooting examples, and 60 *real* troubleshooting problems. When supplemented with hands-on lab exercises, this material can help foster the development of good troubleshooting skills.

The eighth edition offers over 200 worked-out examples, more than 400 review questions, and over 450 chapter problems/exercises. Some of these problems are applications that show how the logic devices presented in the chapter are used in a typical microcomputer system.

An IC index is provided to help the reader easily locate material on any IC cited or used in the text. The back endsheets contain tables of the most often used Boolean algebra theorems, logic gate summaries, and flip-flop truth tables for quick reference when doing problems or working in the lab.

A comprehensive glossary provides concise definitions of all terms in the text that have been highlighted in boldface type.

Supplements

An extensive complement of teaching and learning tools has been developed to accompany this textbook. Each component of this package provides a unique function, and each can be used independently or in conjunction with the others.

Each text is packaged with two free CD-ROMs. The first CD-ROM contains:

- **The *entire library* of Texas Instruments Logic Data Sheets,** including all TTL series, CMOS, and bus interface parts.

The second CD-ROM contains:

- **Circuits from the text rendered in both Electronics Workbench™ and CircuitMaker® software programs.** Students with access to Electronics Workbench software can open and work interactively with the Electronics Workbench circuit files to increase their understanding of concepts and to prepare for laboratory activities. This software can be obtained by contacting Electronics Workbench at www.electronicsworkbench.com. Free CircuitMaker Student Version software is included on the CD-ROM, enabling students to access the CircuitMaker files.
- **A limited-compile demonstration version of the PAL EXPERT CUPL** language compiler from Logical Devices, Inc. A fully licensed copy of this powerful software is being offered at an educational discounted price to users of this text by mentioning promotional offer #PreH5P1-2000 when ordering.

STUDENT RESOURCES

- **StudyWizard Tutorial Software.** Students can enhance their understanding of each chapter by answering the review questions and testing their knowledge of the terminology with this program. This program is available separately from the text. Contact your local bookstore for more information.
- **Lab Manual: A Design Approach,** by Gregory Moss, contains topical units with lab projects that emphasize simulation and design. It utilizes the CUPL software in its programmable logic exercises. The new edition contains new projects and examples, revised PLD coverage to match textbook revisions, and some new screen captures. (ISBN 0-13-086588-5)
- **Lab Manual: A Troubleshooting Approach,** by Jim DeLoach and Frank Ambrosio, offers over 40 experiments with an analysis and troubleshooting approach. (ISBN 0-13-089703-5)

- **Student Study Guide,** by Frank Ambrosio, provides reinforcement of all of the topics presented in the text. The new edition includes updated coverage to match the new edition of the textbook and features entirely updated diagrams. (ISBN 0-13-085639-8)
- **Companion Website (www.prenhall.com/tocci).** This website offers students a free, online study guide that they can check for conceptual understanding of key topics.
- **Electronics Supersite (www.prenhall.com/electronics).** Students will find additional troubleshooting exercises, links to industry sites, an interview with an electronics professional, and more.

INSTRUCTOR RESOURCES

- **Companion Website (www.prenhall.com/tocci).** For the professor, this website offers the ability to post your syllabus online with our Syllabus Builder. This is a great solution for classes taught online, self-paced, or in any computer-assisted manner.
- **Electronics Supersite (www.prenhall.com/electronics).** Instructors will find the *Prentice Hall Electronics Technology Journal,* extra classroom resources, and all of the supplements for this text available online for easy access. Contact your local Prentice Hall sales representative for your "User Name" and "Passcode."
- **Online Course Support.** If your program is offering your digital electronics course in a distance learning format, please contact your local Prentice Hall sales representative for a list of product solutions.
- **Instructor's Resource Manual** presents worked-out, step-by-step solutions to all text problems. (ISBN 0-13-085635-5)
- **Lab Results Manual** includes worked-out lab results for both Lab Manuals. (ISBN 0-13-085637-1)
- **PowerPoint CD-ROM** contains slides featuring all figures from the text; 150 selected slides contain explanatory text to elaborate on the presented graphic. (ISBN 0-13-089704-3)
- **Test Item File** is a hard-copy set of hundreds of questions that can be used for tests and quizzes. (ISBN 0-13-085636-3)
- **PH Test Manager** (Windows) is a computerized version of the Test Item File. In CD-ROM format, this enables on-screen manipulation and editing of all test items and includes graphics capabilities and a sophisticated function plotter. (ISBN 0-13-085641-X)

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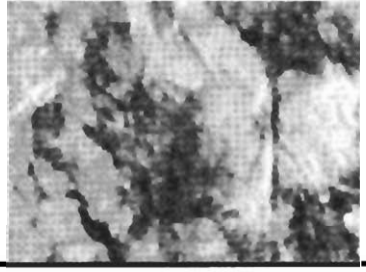
And finally, we want to let our wives and our children know how much we appreciate their support and their understanding. We hope that we can eventually make up for all the hours we spent away from them while we worked on this revision.

Ronald J. Tocci
Neal S. Widmer



COMPANION WEBSITE

DISCOVER THE COMPANION WEBSITE ACCOMPANYING THIS BOOK

The Prentice Hall Companion Website: A Virtual Learning Environment

Technology is a constantly growing and changing aspect of our field that is creating a need for content and resources. To address this emerging need, Prentice Hall has developed an online learning environment for students and professors alike—Companion Websites—to support our textbooks.

In creating a Companion Website, our goal is to build on and enhance what the textbook already offers. For this reason, the content for each user-friendly website is organized by chapter and provides the professor and student with a variety of meaningful resources. Common features of a Companion Website include:

FOR THE PROFESSOR—Every Companion Website integrates **Syllabus Manager™**, an online syllabus creation and management utility.

- **Syllabus Manager™** provides you, the instructor, with an easy, step-by-step process to create and revise syllabi, with direct links into Companion Website and other online content without having to learn HTML.
- Students may logon to your syllabus during any study session. All they need to know is the web address for the Companion Website and the password you've assigned to your syllabus.
- After you have created a syllabus using **Syllabus Manager™**, students may enter the syllabus for their course section from any point in the Companion Website.
- Clicking on a date, the student is shown the list of activities for the assignment. The activities for each assignment are linked directly to actual content, saving time for students.
- Adding assignments consists of clicking on the desired due date, then filling in the details of the assignment—name of the assignment, instructions, and whether or not it is a one-time or repeating assignment.
- In addition, links to other activities can be created easily. If the activity is online, a URL can be entered in the space provided, and it will be linked automatically in the final syllabus.
- Your completed syllabus is hosted on our servers, allowing convenient updates from any computer on the Internet. Changes you make to your syllabus are immediately available to your students at their next logon.

FOR THE STUDENT—

- **Chapter Objectives**—outline key concepts from the text
- **Interactive self-quizzes**—complete with hints and automatic grading that provide immediate feedback for students. Question formats include multiple choice, true or false, fill in the blanks, and matching.

After students submit their answers for the interactive self-quizzes, the Companion Website **Results Reporter** computes a percentage grade, provides a graphic representation of how many questions were answered correctly and incorrectly, and gives a question by question analysis of the quiz. Students are given the option to send their quiz to up to four email addresses (professor, teaching assistant, study partner, etc.).

- **Message Board**—serves as a virtual bulletin board to post—or respond to—questions or comments to/from a national audience
- **Chat**—real time chat with anyone who is using the text anywhere in the country—ideal for discussion and study groups, class projects, etc.

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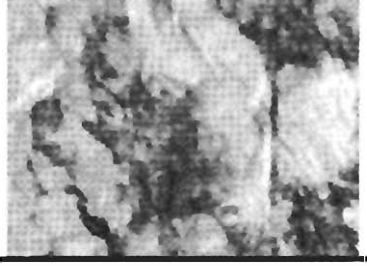

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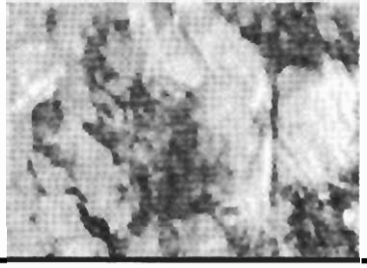

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