海外优秀数学类教材系列丛书

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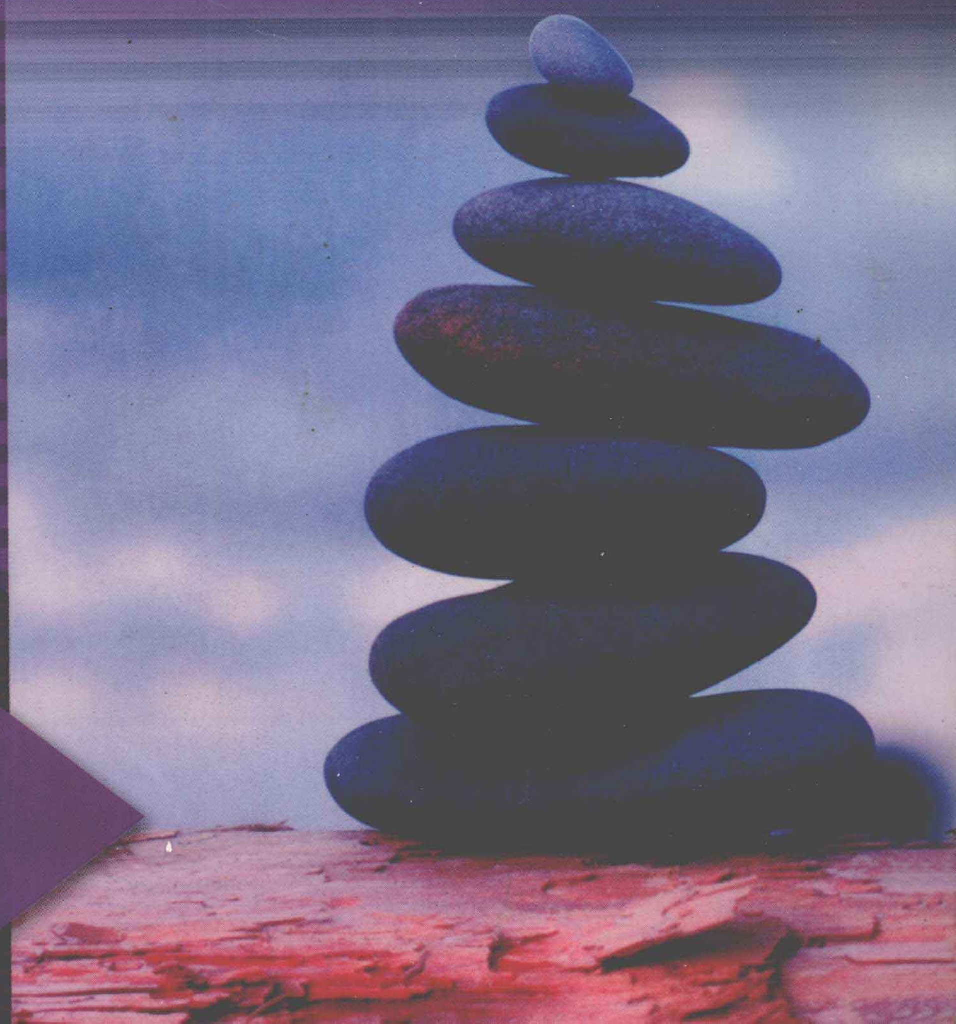
影印版

Discrete Mathematics with Applications (Third Edition)

离散数学及其应用

(第3版)

SUSANNA S. EPP



高等教育出版社
Higher Education Press

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出版者的话

在我国已经加入 WTO、经济全球化的今天，为适应当前我国高校各类创新人才培养的需要，大力推进教育部倡导的双语教学，配合教育部实施的“高等学校教学质量与教学改革工程”和“精品课程”建设的需要，高等教育出版社有计划、大规模地开展了海外优秀数学类系列教材的引进工作。

高等教育出版社和 Pearson Education，John Wiley & Sons，McGraw-Hill，Thomson Learning 等国外出版公司进行了广泛接触，经国外出版公司的推荐并在国内专家的协助下，提交引进版权总数 100 余种。收到样书后，我们聘请了国内高校一线教师、专家、学者参与这些原版教材的评介工作，并参考国内相关专业的课程设置和教学实际情况，从中遴选出了这套优秀教材组织出版。

这批教材普遍具有以下特点：(1) 基本上是近 3 年出版的，在国际上被广泛使用，在同类教材中具有相当的权威性；(2) 高版次，历经多年教学实践检验，内容翔实准确、反映时代要求；(3) 各种教学资源配套整齐，为师生提供了极大的便利；(4) 插图精美、丰富，图文并茂，与正文相辅相成；(5) 语言简练、流畅、可读性强，比较适合非英语国家的学生阅读。

本系列丛书中，有 Finney、Weir 等编的《托马斯微积分》(第 10 版，Pearson)，其特色可用“呈传统特色、富革新精神”概括，本书自 20 世纪 50 年代第 1 版以来，平均每四五年就有一个新版面世，长达 50 余年始终盛行于西方教坛，作者既有相当高的学术水平，又热爱教学，长期工作在教学第一线，其中，年近 90 的 G.B.Thomas 教授长年在 MIT 工作，具有丰富的教学经验；Finney 教授也在 MIT 工作达 10 年；Weir 是美国数学建模竞赛委员会主任。Stewart 编的立体化教材《微积分》(第 5 版，Thomson Learning) 配备了丰富的教学资源，是国际上最畅销的微积分原版教材，2003 年全球销量约 40 余万册，在美国，占据了约 50%～60% 的微积分教材市场，其用户包括耶鲁等名牌院校及众多一般院校。本系列丛书还包括 Anton 编的经典教材《线性代数及其应用》(第 8 版，Wiley)；Jay L. Devore 编的优秀教材《概率论与数理统计》(第 5 版，Thomson Learning) 等。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一定的权威性、系统性、先进性和经济性等特点。

通过影印、翻译、编译这批优秀教材，我们一方面要不断地分析、学习、消化吸收国外优秀教材的长处，吸取国外出版公司的制作经验，提升我们自编教材的立体化配套标准，使我国高校教材建设水平上一个新的台阶；与此同时，我们还将尝试组织海外作者和国内作者合编外文版基础课数学教材，并约请国内专家改编部分国外优秀教材，以适应我国实际教学环境。

这套教材出版后，我们将结合各高校的双语教学计划，开展大规模的宣传、培训工作，及时地将本套丛书推荐给高校使用。在使用过程中，我们衷心希望广大高校教师和同学提出宝贵的意见和建议。

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PREFACE

My purpose in writing this book was to provide a clear, accessible treatment of discrete mathematics for students majoring or minoring in computer science, mathematics, mathematics education, and engineering. The goal of the book is to lay the mathematical foundation for computer science courses such as data structures, algorithms, relational database theory, automata theory and formal languages, compiler design, and cryptography, and for mathematics courses such as linear and abstract algebra, combinatorics, probability, logic and set theory, and number theory. By combining discussion of theory and practice, I have tried to show that mathematics has engaging and important applications as well as being interesting and beautiful in its own right.

A good background in algebra is the only prerequisite; the course may be taken by students either before or after a course in calculus. Previous editions of the book have been used successfully by students at hundreds of institutions in North and South America, Europe, the Middle East, Asia, and Australia.

Recent curricular recommendations from the Institute for Electrical and Electronic Engineers Computer Society (IEEE-CS) and the Association for Computing Machinery (ACM) include discrete mathematics as the largest portion of "core knowledge" for computer science students and state that students should take at least a one-semester course in the subject as part of their first-year studies, with a two-semester course preferred when possible. This book includes all the topics recommended by those organizations and can be used effectively for either a one-semester or a two-semester course.

At one time, most of the topics in discrete mathematics were taught only to upper-level undergraduates. Discovering how to present these topics in ways that can be understood by first- and second-year students was the major and most interesting challenge of writing this book. The presentation was developed over a long period of experimentation during which my students were in many ways my teachers. Their questions, comments, and written work showed me what concepts and techniques caused them difficulty, and their reaction to my exposition showed me what worked to build their understanding and to encourage their interest. Many of the changes in this edition have resulted from continuing interaction with students.

Themes of a Discrete Mathematics Course

Discrete mathematics describes processes that consist of a sequence of individual steps. This contrasts with calculus, which describes processes that change in a continuous fashion. Whereas the ideas of calculus were fundamental to the science and technology of the industrial revolution, the ideas of discrete mathematics underlie the science and technology of the computer age. The main themes of a first course in discrete mathematics are logic and proof, induction and recursion, combinatorics and discrete probability, algorithms and their analysis, discrete structures, and applications and modeling.

Logic and Proof Probably the most important goal of a first course in discrete mathematics is to help students develop the ability to think abstractly. This means learning to use logically valid forms of argument and avoid common logical errors, appreciating what it means to reason from definitions, knowing how to use both direct and indirect argument to derive new results from those already known to be true, and being able to work with symbolic representations as if they were concrete objects.

Induction and Recursion An exciting development of recent years has been the increased appreciation for the power and beauty of "recursive thinking." To think recursively means to address a problem by assuming that similar problems of a smaller nature have already been solved and figuring out how to put those solutions together to solve the larger problem. Such thinking is widely used in the analysis of algorithms, where recurrence relations that result from recursive thinking often give rise to formulas that are verified by mathematical induction.

Combinatorics and Discrete Probability Combinatorics is the mathematics of counting and arranging objects, and probability is the study of laws concerning the measurement of random or chance events. Discrete probability focuses on situations involving discrete sets of objects, such as finding the likelihood of obtaining a certain number of heads when an unbiased coin is tossed a certain number of times. Skill in using combinatorics and probability is needed in almost every discipline where mathematics is applied, from economics to biology, to computer science, to chemistry and physics, to business management.

Algorithms and Their Analysis The word *algorithm* was largely unknown in the middle of the twentieth century, yet now it is one of the first words encountered in the study of computer science. To solve a problem on a computer, it is necessary to find an algorithm or step-by-step sequence of instructions for the computer to follow. Designing an algorithm requires an understanding of the mathematics underlying the problem to be solved. Determining whether or not an algorithm is correct requires a sophisticated use of mathematical induction. Calculating the amount of time or memory space the algorithm will need in order to compare it to other algorithms that produce the same output requires knowledge of combinatorics, recurrence relations, functions, and O-, Ω-, and Θ-notations.

Discrete Structures Discrete mathematical structures are the abstract structures that describe, categorize, and reveal the underlying relationships among discrete mathematical objects. Those studied in this book are the sets of integers and rational numbers, general sets, Boolean algebras, functions, relations, graphs and trees, formal languages and regular expressions, and finite-state automata.

Applications and Modeling Mathematical topics are best understood when they are seen in a variety of contexts and used to solve problems in a broad range of applied situations. One of the profound lessons of mathematics is that the same mathematical model can be used to solve problems in situations that appear superficially to be totally dissimilar. A goal of this book is to show students the extraordinary practical utility of some very abstract mathematical ideas.

Special Features of This Book

Mathematical Reasoning The feature that most distinguishes this book from other discrete mathematics texts is that it teaches—explicitly but in a way that is accessible to first- and second-year college and university students—the unspoken logic and reasoning that underlie mathematical thought. For many years I taught an intensively interactive transition-to-abstract-mathematics course to mathematics and computer science majors. This experience showed me that while it is possible to teach the majority of students to understand and construct straightforward mathematical arguments, the obstacles to doing so cannot be passed over lightly. To be successful, a text for such a course must address students' difficulties with logic and language directly and at some length. It must also include enough concrete examples and exercises to enable students to develop the mental models needed to conceptualize more abstract problems. The treatment of logic and proof in this book blends common sense and rigor in a way that explains the essentials, yet avoids overloading students with formal detail.

Spiral Approach to Concept Development A number of concepts in this book appear in increasingly more sophisticated forms in successive chapters to help students develop the ability to deal effectively with increasing levels of abstraction. For example, by the time students encounter the relatively advanced mathematics of Fermat's little theorem and the Chinese remainder theorem in the Section 10.4, they have been introduced to the logic of mathematical discourse in Chapters 1 and 2, learned the basic methods of proof and the concepts of *mod* and *div* in Chapter 3, studied partitions of the integers in Chapter 5, considered *mod* and *div* as functions in Chapter 7, and become familiar with equivalence relations in Sections 10.2 and 10.3. This approach builds in useful review and develops mathematical maturity in natural stages.

Support for the Student Students at colleges and universities inevitably have to learn a great deal on their own. Though it is often frustrating, learning to learn through self-study is a crucial step toward eventual success in a professional career. This book has a number of features to facilitate students' transition to independent learning.

Worked Examples

The book contains over 500 worked examples, which are written using a problem-solution format and are keyed in type and in difficulty to the exercises. Many solutions for the proof problems are developed in two stages: first a discussion of how one might come to think of the proof or disproof and then a summary of the solution, which is enclosed in a box. This format allows students to read the problem and skip immediately to the summary, if they wish, only going back to the discussion if they have trouble understanding the summary. The format also saves time for students who are rereading the text in preparation for an examination.

Exercises

The book contains almost 2,500 exercises. The sets at the end of each section have been designed so that students with widely varying backgrounds and ability levels will find some exercises they can be sure to do successfully and also some exercises that will challenge them.

Solutions for Exercises

To provide adequate feedback for students between class sessions, Appendix B contains a large number of complete solutions to exercises. Students are strongly urged not to consult solutions until they have tried their best to answer the questions on their own. Once they have done so, however, comparing their answers with those given can lead to significantly improved understanding. In addition, many problems, including some of the most challenging, have partial solutions or hints so that students can determine whether they are on the right track and make adjustments if necessary. There are also plenty of exercises without solutions to help students learn to grapple with mathematical problems in a realistic environment.

Figures and Tables

Figures and tables are included in every case where it seemed that doing so would help readers to a better understanding. In most, a second color is used to add meaning.

Reference Features

Many students have written me to say that the book helped them succeed in their advanced courses. One even wrote that he had used the first edition so extensively that it had fallen apart and he actually went out and bought a copy of the second edition, which he was continuing to use in a master's program. My rationale for screening statements of definitions and theorems, for putting titles on exercises, and for giving the meaning of symbols and a list of reference formulas in the endpapers is to make it easier for students to use this book for review in a current course and as a reference in later ones.

Support for the Instructor I have received a great deal of valuable feedback from instructors who have used previous editions of this book. Many aspects of the book have been improved through their suggestions.

Exercises
The large variety of exercises at all levels of difficulty allows instructors great freedom to tailor a course to the abilities of their students. Exercises with solutions in the back of the book have numbers in blue and those whose solutions are given in a separate Student Solutions Manual/Study Guide have numbers that are a multiple of three. There are exercises of every type that are represented in this book which have no answer in either location to enable instructors to assign whatever mixture they prefer of exercises with and without answers. The ample number of exercises of all kinds gives instructors a significant choice of problems to use for review assignments and exams. Instructors are invited to use the many exercises stated as questions rather than in "prove that" form to stimulate class discussion on the role of proof and counterexample in problem solving.

Flexible Sections
Most sections are divided into subsections so that an instructor who is pressed for time can choose to cover certain subsections only and either omit the rest or leave them for the students to study on their own. The division into subsections also makes it easier for instructors to break up sections if they wish to spend more then one day on them.

Presentation of Proof Methods
It is inevitable that the proofs and disproofs in this book will seem easy to instructors. Many students, however, find them difficult. In showing students how to discover and construct proof and disproofs, I have tried to describe the kinds of approaches that mathematicians use when confronting challenging problems in their own research.

Instructor's Manual
An instructor's manual is available to anyone teaching a course from this book. It contains suggestions about how to approach the material of each chapter, solutions for all exercises not fully solved in Appendix B, transparency masters, review sheets, ideas for projects and writing assignments, and additional exercises.

Highlights of the Third Edition

The changes that have been made for this edition are based on suggestions from colleagues and other long-time users of the first and second editions, on continuing interactions with my students, and on developments within the evolving fields of computer science and mathematics.

Improved Pedagogy

- The number of exercises has been increased to almost 2,500. Approximately 980 new exercises have been added.
- Exercises have been added for topics where students seemed to need additional practice, and they have been modified, as needed, to address student difficulties.
- Additional full answers have been incorporated into Appendix B to give students more help for difficult topics.

- The exposition has been reexamined throughout and revised where needed.
- Careful work has been done to improve format and presentation.
- Discussion of historical background and recent results has been expanded and the number of photographs of mathematicians and computer scientists whose contributions are discussed in the book has been increased.

Logic

- The treatment of quantification has been significantly expanded, with a new section entirely devoted to multiple quantifiers.
- Exercises have been added using Tarski's World, an excellent pedagogical tool developed by Jon Barwise and John Etchemendy at Stanford University.
- Applications related to Internet searching are now included.
- Terms for various forms of argument have been simplified.

Introduction to Proof

- The directions for writing proofs have been expanded.
- The descriptions of methods of proof have been made clearer.
- Exercises have been revised and/or relocated to promote the development of student understanding.

Induction and Recursion

- The format for outlining proofs by mathematical induction has been improved.
- The subsections in the section on sequences have been reorganized.
- The sets of exercises for the sections on strong mathematical induction and the well-ordering principle and on recursive definitions have been significantly expanded.

Number Theory

- A subsection on open problems in number theory has been incorporated, and the discussion of recent mathematical discoveries in number theory has been expanded.
- A new section on modular arithmetic and cryptography has been added. It includes a discussion of RSA cryptography, Fermat's little theorem, and the Chinese remainder theorem.
- The discussion of testing for primality has been moved to later in Chapter 3 to make clear its dependence on indirect argument.

Set Theory

- The properties of the empty set are now introduced in the first section of Chapter 5.
- The second section of Chapter 5 is now entirely devoted to element proofs.
- Algebraic proofs of set properties and the use of counterexamples to disprove set properties have been moved to the third section of Chapter 5.
- The treatment of Boolean algebras has been expanded, and the relationship among logical equivalences, set properties, and Boolean algebras has been highlighted.

Combinatorics and Discrete Probability

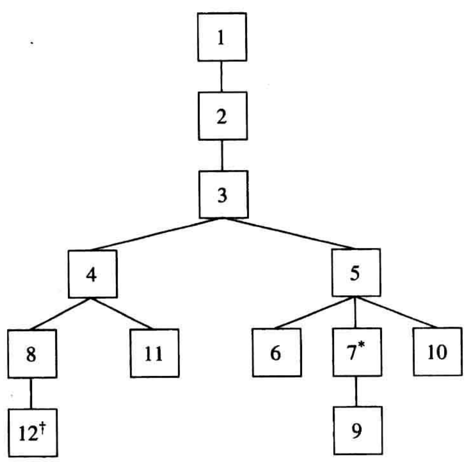
- Exercises for the section on the binomial theorem has been significantly expanded.
- Two new sections have been added on probability, including expected value, conditional probability and independence, and Bayes' theorem.
- Combinatorial aspects of Internet protocol (IP) addresses are explained.

Organization

This book may be used effectively for a one- or two-semester course. Each chapter contains core sections, sections covering optional mathematical material, and sections covering optional applications. Instructors have the flexibility to choose whatever mixture will best serve the needs of their students. The following table shows a division of the sections into categories.

Chapter	Core Sections	Sections Containing Optional Mathematical Material	Sections Containing Optional Computer Science Applications
1	1.1–1.3		1.4, 1.5
2	2.1–2.4	2.2, 2.3	2.3
3	3.1–3.4, 3.6	3.5, 3.7	3.8
4	4.1–4.2	4.3–4.4	4.5
5	5.1	5.2–5.4	5.4
6	6.1–6.4	6.5–6.9	6.3
7	7.1–7.2	7.3–7.5	7.1, 7.2, 7.5
8	8.1, 8.2	8.3, 8.4	8.4
9	9.1, 9.2	9.4	9.3, 9.5
10	10.1–10.3	10.4, 10.5	10.4, 10.5
11	11.1, 11.5	11.2, 11.3, 11.4	11.1, 11.2, 11.5, 11.6
12	12.1, 12.2	12.3	12.1–12.3

The following tree diagram shows, approximately, how the chapters of this book depend on each other. Chapters on different branches of the tree are sufficiently independent that instructors need to make at most minor adjustments if they skip chapters but follow paths along branches of the tree.



*Instructors who wish to define a function as a binary relation can cover Section 10.1 before Section 7.1.

†Section 10.3 is needed for Section 12.3 but not for Sections 12.1 and 12.2.

Acknowlegments

I owe a debt of gratitude to many people at DePaul University for their support and encouragement throughout the years I worked on editions of this book. A number of my colleagues used early versions and previous editions and provided many excellent suggestions for improvement. For this, I am thankful to Louis Aquila, J. Marshall Ash, Allan Berele, Jeffrey Bergen, William Chin, Barbara Cortzen, Constantine Georgakis, Sigrun Goes, Jerry Goldman, Lawrence Gluck, Leonid Krop, Carolyn Narasimhan, Walter Pranger, Eric Rieders, Ayse Sahin, Yuen-Fat Wong, and, most especially, Jeanne LaDuke. The thousands of students to whom I have taught discrete mathematics have had a profound influence on the book's form. By sharing their thoughts and thought processes with me, they taught me how to teach them better. I am very grateful for their help. I owe the DePaul University administration, especially my dean, Michael Mezey, and my former dean, Richard Meister, a special word of thanks for considering the writing of this book a worthwhile scholarly endeavor.

My thanks to the reviewers for their valuable suggestions for this edition of the book: Pablo Echeverria, Camden County College; William Gasarch, University of Maryland; Joseph Kolibal, University of Southern Mississippi; Benny Lo, International Technological University; George Luger, University of New Mexico; Norman Richert, University of Houston—Clear Lake; Peter Williams, California State University at San Bernardino; and Jay Zimmerman, Towson University. For their help with the first and second editions of the book, I am grateful to Itshak Borosh, Texas A & M University; Douglas M. Campbell, Brigham Young University; David G. Cantor, University of California at Los Angeles; C. Patrick Collier, University of Wisconsin-Oshkosh; Kevan H. Croteau, Francis Marion University; Irinel Drogan, University of Texas at Arlington; Henry A. Etlinger, Rochester Institute of Technology; Melvin J. Friske, Wisconsin Lutheran College; Ladnor Geissinger, University of North Carolina; Jerrold R. Griggs, University of South Carolina; Nancy Baxter Hastings, Dickinson College; Lillian Hupert, Loyola University Chicago; Leonard T. Malinowski, Finger Lakes Community College; John F. Morrison, Towson State Unviersity; Paul Pederson, University of Denver; George Peck, Arizona State University; Roxy Peck, California Polytechnic State University, San Luis Obispo; Dix Pettey, University of Missouri; Anthony Ralston, State University of New York at Buffalo; John Roberts, University of Louisville; and George Schultz, St. Petersburg Junior College, Clearwater. Special thanks are due John Carroll, San Diego State University; Dr. Joseph S. Fulda; and Porter G. Webster, University of Southern Mississippi for their unusual thoroughness and their encouragement.

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The older I get the more I realize the profound debt I owe my own mathematics teachers for shaping the way I perceive the subject. My first thanks must go to my husband, Helmut Epp, who, on a high school date (!), introduced me to the power and beauty of the field axioms and the view that mathematics is a subject with ideas as well as formulas and techniques. In my formal education, I am most grateful to Daniel Zelinsky and Ky Fan at Northwestern University and Izaak Wirszup, I. N. Herstein, and Irving Kaplansky at the University of Chicago, all of whom, in their own ways, helped lead me to appreciate the elegance, rigor, and excitement of mathematics.

To my family, I owe thanks beyond measure. I am grateful to my mother, whose keen interest in the workings of the human intellect started me many years ago on the track that led ultimately to this book, and to my late father, whose devotion to the written word has been a constant source of inspiration. I thank my children and grandchildren for their affection and cheerful acceptance of the demands this book has placed on my life. And, most of all, I am grateful to my husband, who for many years has encouraged me with his faith in the value of this project and supported me with his love and his wise advice.

Susanna Epp

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