
Applications of Discrete Mathematics

UPDATED EDITION

Edited by

John G. Michaels
*State University of New York
College at Brockport*

Kenneth H. Rosen
AT&T Laboratories



Boston Burr Ridge, IL Dubuque, IA Madison, WI New York
San Francisco St. Louis Bangkok Bogotá Caracas Kuala Lumpur
Lisbon London Madrid Mexico City Milan Montreal New Delhi
Santiago Seoul Singapore Sydney Taipei Toronto

The McGraw-Hill Companies

APPLICATIONS OF DISCRETE MATHEMATICS, UPDATED EDITION
JOHN G. MICHAELS AND KENNETH H. ROSEN

Published by McGraw-Hill Higher Education, an imprint of The McGraw-Hill Companies, Inc., 1221 Avenue of the Americas, New York, NY 10020.
Copyright © 2007 by The McGraw-Hill Companies, Inc. All rights reserved.

The contents, or parts thereof, may be reproduced in print form solely for classroom use with DISCRETE MATHEMATICS AND ITS APPLICATIONS, SIXTH EDITION by Kenneth H. Rosen provided such reproductions bear copyright notice, but may not be reproduced in any other form or for any other purpose without the prior written consent of The McGraw-Hill Companies, Inc., including, but not limited to, in any network or other electronic storage or transmission, or broadcast for distance learning.

www.mhhe.com

Contents

PREFACE v

PART I – Discrete Structures and Computing

- 1 THE APPORTIONMENT PROBLEM 2
Russell B. Campbell, *University of Northern Iowa*
- 2 FINITE MARKOV CHAINS 19
Eric Rieders, *DePaul University*
- 3 RATIONAL ELECTION PROCEDURES 40
Russell B. Campbell, *University of Northern Iowa*
- 4 GÖDEL'S UNDECIDABILITY THEOREM 57
Stephen F. Andrilli, *La Salle University*
- 5 CODING THEORY 73
Kenneth H. Rosen, *AT&T Laboratories*

PART II – Combinatorics

- 6 STIRLING NUMBERS 95
Thomas A. Dowling, *Ohio State University*
- 7 CATALAN NUMBERS 112
Thomas A. Dowling, *Ohio State University*
- 8 RAMSEY NUMBERS 138
John G. Michaels, *SUNY College at Brockport*

9	ARRANGEMENTS WITH FORBIDDEN POSITIONS	158
	John G. Michaels, <i>SUNY College at Brockport</i>	
10	BLOCK DESIGNS AND LATIN SQUARES	174
	William C. Arlinghaus, <i>Lawrence Technological University</i>	
11	SCHEDULING PROBLEMS AND BIN PACKING	187
	Robert A. McGuigan, <i>Westfield State College</i>	
12	BURNSIDE-PÓLYA COUNTING METHODS	203
	Jonathan L. Gross, <i>Columbia University</i>	

PART III — Graph Theory

13	FOOD WEBS	225
	Robert A. McGuigan, <i>Westfield State College</i>	
14	APPLICATIONS OF SUBGRAPH ENUMERATION	241
	Fred J. Rispoli, <i>Dowling College</i>	
15	TRAVELING SALESMAN PROBLEM	263
	Arthur M. Hobbs, <i>Texas A&M University</i>	
16	THE TANTALIZING FOUR CUBES	288
	William C. Arlinghaus, <i>Lawrence Technological University</i>	
17	THE ASSIGNMENT PROBLEM	299
	Fred J. Rispoli, <i>Dowling College</i>	
18	SHORTEST PATH PROBLEMS	322
	William C. Arlinghaus, <i>Lawrence Technological University</i>	
19	NETWORK SURVIVABILITY	332
	Arthur M. Hobbs, <i>Texas A&M University</i>	
20	THE CHINESE POSTMAN PROBLEM	354
	John G. Michaels, <i>SUNY College at Brockport</i>	
21	GRAPH LAYOUTS	365
	Zevi Miller, <i>Miami University</i>	
22	GRAPH MULTICOLORINGS	394
	Kenneth H. Rosen, <i>AT&T Laboratories</i>	
23	NETWORK FLOWS	408
	Arthur M. Hobbs, <i>Texas A&M University</i>	
24	PETRI NETS	431
	Robert A. McGuigan, <i>Westfield State College</i>	
	SOLUTIONS TO EXERCISES	S-1
	INDEX	I-1

Preface

Goals

The goal of this book is to present a wide variety of interesting applications of discrete mathematics in a flexible and accessible format. The intended audience includes students who are currently studying or have previously studied discrete mathematics from *Discrete Mathematics and Its Applications* by Kenneth H. Rosen, or any of the other texts now available.

The book can be used as a supplement since it provides material on many interesting and important applications not usually covered in an introductory course. This volume can also be used as a text for a second course in discrete mathematics — a short course, a semester-long course, or an independent study course. The range of applications covered makes it appealing for summer courses, including those for in-service secondary teachers who want to develop new skills.

Each chapter can be studied independently since there are no dependencies between chapters. Although the chapters have been written by different authors, a great deal of effort has been devoted to ensure consistency of format, writing styles, accessibility, completeness, and terminology. Devoting an entire chapter to each application permits a thorough treatment not usually possible in an introductory text.

We have covered a broad range of applications in different areas of discrete mathematics, arranged in three sections: discrete structures and computing, combinatorics, and graph theory. Although some applications could fit in two or even three of these sections, each application is placed into the section in which it most strongly fits. The applications come from a wide range of subjects including computer science, the social sciences, the natural sciences, the physical sciences, and mathematics.

Features

Some prominent features of this book are:

Accessibility Each chapter of the book has been written so that it is easily accessible. The basic ideas of each application are carefully and clearly explained, with more sophisticated ideas given in later parts of the chapters.

Prerequisites Prerequisite topics are listed at the beginning of each chapter, and a basic understanding of those topics will suffice for the study of that chapter. The appropriate sections of *Discrete Mathematics and Its Applications* by Kenneth H. Rosen are referenced.

Exercise Sets Each chapter includes a comprehensive exercise set containing routine, intermediate, and challenging exercises. Difficult exercises are marked with a star and very difficult exercises are marked with two stars. Solutions to all exercises are given in a separate section at the end of the book.

Suggested Readings A bibliography of suggested readings appears in each chapter and suggests publications that are useful for surveying related topics as well as proving particular results mentioned in the text.

Algorithms Many of the chapters include a description of algorithms, both in English and in an easily-understood form of Pascal-like pseudocode.

Biographical and Historical Information The historical background of each application is described, and biographical information about mathematicians and computer scientists is also given.

Computer Projects Each chapter concludes with a set of computer projects related to the topics covered in that chapter.

Updated Edition

This Updated Edition is a revision of the original 1991 printing of *Applications of Discrete Mathematics*, and offers several important improvements. Section and chapter references for *Discrete Mathematics and Its Applications* by Kenneth H. Rosen have been completely updated throughout to match the textbook's Sixth Edition, and new textbook references have been added where appropriate. The Suggested Readings sections at the end of each chapter have also been thoroughly revamped to include newer references, updated editions,

reissues of classic works, and online resources. In addition other outdated references and data sets have been replaced, errata in the original printing have been corrected, and discussion in certain sections has been streamlined.

Acknowledgements

We would like to thank Richard Wallis, our former editor at McGraw-Hill, for his support and enthusiasm for this project. The first editor appreciates the encouragement of his family, Lois and Margaret, during all phases of the development of this text. We also thank Fred Roberts of Rutgers University for his helpful advice and his many contributions to the area of discrete mathematics. We would also like to thank the contributors to this volume for their diligence, flexibility, patience, creativity, and, especially, their excellent work. Finally, we shall be very grateful to all instructors and students who send us their helpful suggestions.

John G. Michaels
Kenneth H. Rosen

For additional online resources to accompany *Discrete Mathematics and Its Applications*, please visit the textbook's MathZone Companion Website at:
<http://www.mhhe.com/rosen/>