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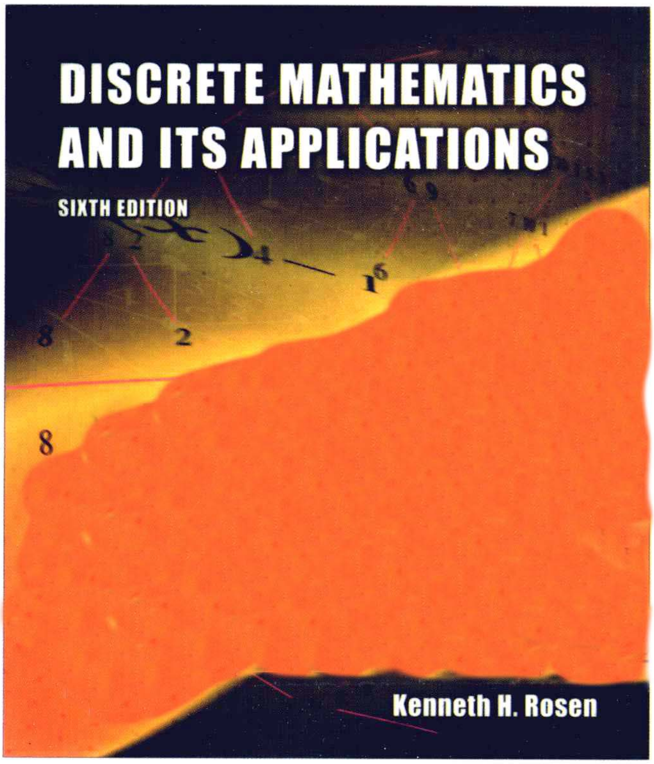

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（美）Kenneth H. Rosen 著

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China Machine Press

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离散数学及其应用

（英文精编版·第6版）

Discrete Mathematics and Its Applications

(Sixth Edition)

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Adapter's Forword

Purpose

The original of *Discrete Mathematics and its Applications* is intended for one-term or two-term introductory courses of Discrete Mathematics taken by students from wide variety of majors, including computer science, mathematics, engineering and etc. It's an excellent textbook written by Prof. Kenneth H. Rosen and has been widely used in over 600 institutions around the world.

The sixth edition gives a focused introduction to the primary themes of the Discrete Mathematics course and demonstrates the relevance and practicality of Discrete Mathematics to a wide variety of real-world applications. All the topics, examples, references and exercises are quite helpful to the students.

In recent years, bilingual teaching has been encouraged in universities and colleges in China. More and more Chinese instructors and students are getting interested in this book. However, as a textbook, over 800 original pages make Chinese students find it difficult to read. In order to introduce this book to more Chinese college students, we tried to maintain the author's writing style and omitted some contents to adapt for the Chinese students' English reading ability. The compressed version fits into the syllabus of undergraduate course, and reduce students' reading burden as well.

What is Compressed

Since some contents in the original are taught in some other courses, such as Number theory, Discrete Probability, Induction and Recursion, Boolean Algebra and Finite-state Machine, we removed them which were in the original book as Chapter 3, Chapter 4, Chapter 6, Chapter 11 and Chapter 12. As a result, Logic and Proofs, Sets, Functions, Relations, Graphs, Trees, Counting and Advanced Counting Techniques are reserved in the compressed version.

There are over 3800 exercises in the original textbook, posing various types of questions. Some of them are designed for basic skill development, some are in intermediate level and some are more difficult and challenging. In order to keep the original feature of the book, we removed the even-number questions of the remained Chapters, so that the questions with different difficulties are reserved. The historical information for the background of many topics is also removed, so as to reduce the reading burden of students.

Some concepts are given in the exercises. It is difficult for students to comprehend because of the simplicity of the descriptions, such as the concepts about the Normal and Canonical forms for a proposition. So we have added the detail description about them in Chapter 1.

Acknowledgments

I would like to thank Kenneth H. Rosen, the author of the original book, and McGraw-Hill, the original publisher, who authorized us to compress the original book. It is their understanding and generosity that make it possible for more Chinese students to enjoy this distinguished book.

Thanks to everyone at China Machine Press who has put into great effort to make this cooperation possible.

Thanks to my colleague Jie Yang who has given precious comments for the work.

The compression is made based on my teaching experiences, and the syllabus of Discrete Mathematics course for undergraduate students. It is certainly wild open for discussions on further improvements. Your comments and suggestions are extremely important, and we would be highly appreciated.

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Preface

In writing this book, I was guided by my long-standing experience and interest in teaching discrete mathematics. For the student, my purpose was to present material in a precise, readable manner, with the concepts and techniques of discrete mathematics clearly presented and demonstrated. My goal was to show the relevance and practicality of discrete mathematics to students, who are often skeptical. I wanted to give students studying computer science all of the mathematical foundations they need for their future studies. I wanted to give mathematics students an understanding of important mathematical concepts together with a sense of why these concepts are important for applications. And most importantly, I wanted to accomplish these goals without watering down the material.

For the instructor, my purpose was to design a flexible, comprehensive teaching tool using proven pedagogical techniques in mathematics. I wanted to provide instructors with a package of materials that they could use to teach discrete mathematics effectively and efficiently in the most appropriate manner for their particular set of students. I hope that I have achieved these goals.

I have been extremely gratified by the tremendous success of this text. The many improvements in the sixth edition have been made possible by the feedback and suggestions of a large number of instructors and students at many of the more than 600 schools where this book has been successfully used. There are many enhancements in this edition. The companion website has been substantially enhanced and more closely integrated with the text, providing helpful material to make it easier for students and instructors to achieve their goals.

This text is designed for a one- or two-term introductory discrete mathematics course taken by students in a wide variety of majors, including mathematics, computer science, and engineering. College algebra is the only explicit prerequisite, although a certain degree of mathematical maturity is needed to study discrete mathematics in a meaningful way.

Goals of a Discrete Mathematics Course

A discrete mathematics course has more than one purpose. Students should learn a particular set of mathematical facts and how to apply them; more importantly, such a course should teach students how to think logically and mathematically. To achieve these goals, this text stresses mathematical reasoning and the different ways problems are solved. Five important themes are interwoven in this text: mathematical reasoning, combinatorial analysis, discrete structures, algorithmic thinking, and applications and modeling. A successful discrete mathematics course should carefully blend and balance all five themes.

1. *Mathematical Reasoning:* Students must understand mathematical reasoning in order to read, comprehend, and construct mathematical arguments. This text starts with a discussion of mathematical logic, which serves as the foundation for the subsequent discussions of methods of proof. Both the science and the art of constructing proofs are addressed. The technique of mathematical induction is stressed through many different types of examples of such proofs and a careful explanation of why mathematical induction is a valid proof technique.

2. *Combinatorial Analysis:* An important problem-solving skill is the ability to count or enumerate objects. The discussion of enumeration in this book begins with the basic techniques of counting. The stress is on performing combinatorial analysis to solve counting problems and analyze algorithms, not on applying formulae.

3. *Discrete Structures:* A course in discrete mathematics should teach students how to work with discrete structures, which are the abstract mathematical structures used to represent discrete objects and relationships between these objects. These discrete structures include sets, permutations, relations, graphs, trees, and finite-state machines.

4. *Algorithmic Thinking:* Certain classes of problems are solved by the specification of an algorithm. After an algorithm has been described, a computer program can be constructed implementing it. The mathematical portions of this activity, which include the specification of the algorithm, the verification that it works properly, and the analysis of the computer memory and time required to perform it, are all covered in this text. Algorithms are described using both English and an easily understood form of pseudocode.

5. *Applications and Modeling:* Discrete mathematics has applications to almost every conceivable area of study. There are many applications to computer science and data networking in this text, as well as applications to such diverse areas as chemistry, botany, zoology, linguistics, geography, business, and the Internet. These applications are natural and important uses of discrete mathematics and are not contrived. Modeling with discrete mathematics is an extremely important problem-solving skill, which students have the opportunity to develop by constructing their own models in some of the exercises.

Special Features

Accessibility This text has proved to be easily read and understood by beginning students. There are no mathematical prerequisites beyond college algebra for almost all of this text. Students needing extra help will find tools on the MathZone companion website for bringing their mathematical maturity up to the level of the text. The few places in the book where calculus is referred to are explicitly noted. Most students should easily understand the pseudocode used in the text to express algorithms, regardless of whether they have formally studied programming languages. There is no formal computer science prerequisite.

Each chapter begins at an easily understood and accessible level. Once basic mathematical concepts have been carefully developed, more difficult material and applications to other areas of study are presented.

Flexibility This text has been carefully designed for flexible use. The dependence of chapters on previous material has been minimized. Each chapter is divided into sections of approximately the same length, and each section is divided into subsections that form natural blocks of material for teaching. Instructors can easily pace their lectures using these blocks.

Writing Style The writing style in this book is direct and pragmatic. Precise mathematical language is used without excessive formalism and abstraction. Care has been taken to balance the mix of notation and words in mathematical statements.

Mathematical Rigor and Precision All definitions and theorems in this text are stated extremely carefully so that students will appreciate the precision of language and rigor needed in mathematics. Proofs are motivated and developed slowly; their steps are all carefully justified. The axioms used in proofs and the basic properties that follow from them are explicitly described in an appendix, giving students a clear idea of what they can assume in a proof. Recursive definitions are explained and used extensively.

Worked Examples Examples are used to illustrate concepts, relate different topics, and introduce applications. In most examples, a question is first posed, then its solution is presented with the appropriate amount of detail.

Applications The applications included in this text demonstrate the utility of discrete mathematics in the solution of real-world problems. This text includes applications to a wide variety of areas, including computer science, data networking, psychology, chemistry, engineering, linguistics, biology, business, and the Internet.

Algorithms Results in discrete mathematics are often expressed in terms of algorithms; hence, key algorithms are introduced in each chapter of the book. The computational complexity of the algorithms in the text is also analyzed at an elementary level.
Key Terms and Results A list of key terms and results follows each chapter. The key terms include only the most important that students should learn, not every term defined in the chapter.
Exercises There are exercises in the text, with many different types of questions posed. There is an ample supply of straightforward exercises that develop basic skills, a large number of intermediate exercises, and many challenging exercises. Exercises are stated clearly and unambiguously, and all are carefully graded for level of difficulty. Exercise sets contain special discussions that develop new concepts not covered in the text, enabling students to discover new ideas through their own work.

Exercises that are somewhat more difficult than average are marked with a single star *; those that are much more challenging are marked with two stars **. Exercises whose solutions require calculus are explicitly noted. Exercises that develop results used in the text are clearly identified with the symbol ☞. Answers or outlined solutions to exercises are provided at the back of the text. The solutions include proofs in which most of the steps are clearly spelled out.
Review Questions A set of review questions is provided at the end of each chapter. These questions are designed to help students focus their study on the most important concepts and techniques of that chapter. To answer these questions students need to write long answers, rather than just perform calculations or give short replies.
Computer Projects Each chapter is followed by a set of computer projects. The computer projects tie together what students may have learned in computing and in discrete mathematics. Computer projects that are more difficult than average, from both a mathematical and a programming point of view, are marked with a star, and those that are extremely challenging are marked with two stars.
Computations and Explorations A set of computations and explorations is included at the conclusion of each chapter. These exercises are designed to be completed using existing software tools, such as programs that students or instructors have written or mathematical computation packages such as Maple or Mathematica. Many of these exercises give students the opportunity to uncover new facts and ideas through computation. (Some of these exercises are discussed in the *Exploring Discrete Mathematics with Maple* companion workbook available online.)
Writing Projects Each chapter is followed by a set of writing projects. To do these projects students need to consult the mathematical literature. Some of these projects are historical in nature and may involve looking up original sources. Others are designed to serve as gateways to new topics and ideas. All are designed to expose students to ideas not covered in depth in the text. These projects tie mathematical concepts together with the writing process and help expose students to possible areas for future study. (Suggested references for these projects can be found online or in the printed *Student's Solutions Guide*.)
Suggested Readings A list of suggested readings for each chapter is provided in a section at the end of the text. These suggested readings include books at or below the level of this text, more difficult books, expository articles, and articles in which discoveries in discrete mathematics were originally published. Some of these publications are classics, published many years ago, while others have been published within the last few years.

Ancillaries

Student's Solutions Guide This student manual, available separately, contains full solutions to all odd-numbered problems in the exercise sets. These solutions explain why a particular method is used and why it works. For some exercises, one or two other possible approaches are described to show that a problem can be solved in several different ways. Suggested references for the writing projects found at the end of each chapter are also included in this volume. Also included are a guide to writing proofs and an extensive description of common mistakes students make in discrete mathematics, plus sample tests and a sample crib sheet for each chapter designed to help students prepare for exams.

(ISBN-10: 0-07-310779-4) *(ISBN-13: 978-0-07-310779-0)*

Instructor's Resource Guide This manual, available by request for instructors, contains full solutions to even-numbered exercises in the text. Suggestions on how to teach the material in each chapter of the book are provided, including the points to stress in each section and how to put the material into perspective. It also offers sample tests for each chapter and a test bank containing over 1300 exam questions to choose from. Answers to all sample tests and test bank questions are included. Finally, several sample syllabi are presented for courses with differing emphasis and student ability levels, and a complete section and exercise migration guide is included to help users of the fifth edition update their course materials to match the sixth edition.

(ISBN-10: 0-07-310781-6) *(ISBN-13: 978-0-07-310781-3)*

Instructor's Testing and Resource CD An extensive test bank of more than 1300 questions using Brownstone Diploma testing software is available by request for use on Windows or Macintosh systems. Instructors can use this software to create their own tests by selecting questions of their choice or by random selection. They can also sort questions by section, difficulty level, and type; edit existing questions or add their own; add their own headings and instructions; print scrambled versions of the same test; export tests to word processors or the Web; and create and manage course grade books. A printed version of this test bank, including the questions and their answers, is included in the *Instructor's Resource Guide*.

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Acknowledgments

I would like to thank the many instructors and students at a variety of schools who have used this book and provided me with their valuable feedback and helpful suggestions. Their input has made this a much better book than it would have been otherwise. I especially want to thank Jerrold Grossman, John Michaels, and George Bergman for their technical reviews of the sixth edition and their "eagle eyes," which have helped ensure the accuracy of this book. I also appreciate the help provided by all those who have submitted comments via the website.

I thank the reviewers of this sixth and the five previous editions. These reviewers have provided much helpful criticism and encouragement to me. I hope this edition lives up to their high expectations.

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Kenneth H. Rosen

To the Student

What is discrete mathematics? Discrete mathematics is the part of mathematics devoted to the study of discrete objects. (Here *discrete* means consisting of distinct or unconnected elements.) The kinds of problems solved using discrete mathematics include:

- How many ways are there to choose a valid password on a computer system?
- What is the probability of winning a lottery?
- Is there a link between two computers in a network?
- How can I identify spam e-mail messages?
- How can I encrypt a message so that no unintended recipient can read it?
- What is the shortest path between two cities using a transportation system?
- How can a list of integers be sorted so that the integers are in increasing order?
- How many steps are required to do such a sorting?
- How can it be proved that a sorting algorithm correctly sorts a list?
- How can a circuit that adds two integers be designed?
- How many valid Internet addresses are there?

You will learn the discrete structures and techniques needed to solve problems such as these.

More generally, discrete mathematics is used whenever objects are counted, when relationships between finite (or countable) sets are studied, and when processes involving a finite number of steps are analyzed. A key reason for the growth in the importance of discrete mathematics is that information is stored and manipulated by computing machines in a discrete fashion.

Why Study Discrete Mathematics? There are several important reasons for studying discrete mathematics. First, through this course you can develop your mathematical maturity: that is, your ability to understand and create mathematical arguments. You will not get very far in your studies in the mathematical sciences without these skills.

Second, discrete mathematics is the gateway to more advanced courses in all parts of the mathematical sciences. Discrete mathematics provides the mathematical foundations for many computer science courses including data structures, algorithms, database theory, automata theory, formal languages, compiler theory, computer security, and operating systems. Students find these courses much more difficult when they have not had the appropriate mathematical foundations from discrete math. One student has sent me an e-mail message saying that she used the contents of this book in every computer science course she took!

Math courses based on the material studied in discrete mathematics include logic, set theory, number theory, linear algebra, abstract algebra, combinatorics, graph theory, and probability theory (the discrete part of the subject).

Also, discrete mathematics contains the necessary mathematical background for solving problems in operations research (including many discrete optimization techniques), chemistry, engineering, biology, and so on. In the text, we will study applications to some of these areas.

Many students find their introductory discrete mathematics course to be significantly more challenging than courses they have previously taken. One reason for this is that one of the primary goals of this course is to teach mathematical reasoning and problem solving, rather than a discrete set of skills. The exercises in this book are designed to reflect this goal. Although there are plenty of exercises in this text similar to those addressed in the examples, a large percentage of the exercises require original thought. This is intentional. The material discussed in the text provides the tools needed to solve these exercises, but your job is to successfully apply these tools using your own creativity. One of the primary goals of this course is to learn how to attack problems that may be somewhat different from any you may have previously seen. Unfortunately, learning how to solve only particular types of exercises is not sufficient for success in developing the problem-solving skills needed in subsequent courses and professional work. This text addresses many different topics, but discrete mathematics is an extremely diverse and large area of study. One of my goals as an author is to help you develop the skills needed to master the additional material you will need in your own future pursuits.

The Exercises I would like to offer some advice about how you can best learn discrete mathematics (and other subjects in the mathematical and computing sciences). You will learn the most by actively working exercises. I suggest that you solve as many as you possibly can. After working the exercises your instructor has assigned, I encourage you to solve additional exercises such as those in the exercise sets following each section of the text and in the supplementary exercises at the end of each chapter. (Note the key explaining the markings preceding exercises.)

Key to the Exercises

No marking	A routine exercise
*	A difficult exercise
**	An extremely challenging exercise
☞	An exercise containing a result used in the book (The Table below shows where each of these exercises are used.)
(*Requires calculus*)	An exercise whose solution requires the use of limits or concepts from differential or integral calculus

The best approach is to try exercises yourself before you consult the answer section at the end of this book. Note that the odd-numbered exercise answers provided in the text are answers only and not full solutions; in particular, the reasoning required to obtain answers is omitted in these answers. The *Student's Solutions Guide*, available separately, provides complete, worked solutions to all odd-numbered exercises in this text. When you hit an impasse trying to solve an odd-numbered exercise, I suggest you consult the *Student's Solutions Guide* and look for some guidance as to how to solve the problem. The more work you do yourself rather than passively reading or copying solutions, the more you will learn. The answers and solutions to the even-numbered exercises are intentionally not available from the publisher; ask your instructor if you have trouble with these.

Web Resources You are strongly encouraged to take advantage of additional resources available on the Web, especially those on the MathZone companion website for this book found at www.mhhe.com/rosen. You will find many Extra Examples designed to clarify key concepts; Self Assessments for gauging how well you understand core topics; Interactive Demonstration Applets exploring key algorithms and other concepts; a Web Resources Guide containing an extensive selection of links to external sites relevant to the world of discrete mathematics; extra explanations and practice to help you master core concepts; added instruction on writing proofs and on avoiding common mistakes in discrete mathematics; in-depth discussions of important applications; and guidance on utilizing Maple software to explore the computational aspects of discrete mathematics. Places in the text where these additional online resources are available are identified in the margins by special icons. You will also find NetTutor, an online tutorial service that you can use to receive help from tutors either via real-time chat or via messages. For more details on these online resources, see the description of the MathZone companion website immediately preceding this "To the Student" message.

The Value of This Book My intention is to make your investment in this text an excellent value. The book, the associated ancillaries, and MathZone companion website have taken many years of effort to develop and refine. I am confident that most of you will find that the text and associated materials will help you master discrete mathematics. Even though it is likely that you will not cover some chapters in your current course, you should find it helpful—as many other students have—to read the relevant sections of the book as you take additional courses. Most of you will return to this book as a useful tool throughout your future studies, especially for those of you who continue in computer science, mathematics, and engineering. I have designed this book to be a gateway for future studies and explorations, and I wish you luck as you begin your journey.

Kenneth H. Rosen

LIST OF SYMBOLS

TOPIC	SYMBOL	MEANING
LOGIC	$\neg p$	negation of p
	$p \wedge q$	conjunction of p and q
	$p \vee q$	disjunction of p and q
	$p \oplus q$	exclusive or of p and q
	$p \rightarrow q$	the implication p implies q
	$p \leftrightarrow q$	biconditional of p and q
	$p \equiv q$	equivalence of p and q
	$\mathbf{T}$	tautology
	$\mathbf{F}$	contradiction
	$P(x_1, \ldots, x_n)$	propositional function
	$\forall x\, P(x)$	universal quantification of $P(x)$
	$\exists x\, P(x)$	existential quantification of $P(x)$
	$\exists! x\, P(x)$	uniqueness quantification of $P(x)$
	$\therefore$	therefore
	$p\{S\}q$	partial correctness of S
SETS	$x \in S$	x is a member of S
	$x \notin S$	x is not a member of S
	$\{a_1, \ldots, a_n\}$	list of elements of a set
	$\{x \mid P(x)\}$	set builder notation
	$\mathbf{N}$	set of natural numbers
	$\mathbf{Z}$	set of integers
	$\mathbf{Z}^+$	set of positive integers
	$\mathbf{Q}$	set of rational numbers
	$\mathbf{R}$	set of real numbers
	$S = T$	set equality
	$\emptyset$	the empty (or null) set
	$S \subseteq T$	S is a subset of T
	$S \subset T$	S is a proper subset of T
	$\|S\|$	cardinality of S
	$P(S)$	the power set of S
	$(a_1, \ldots, a_n)$	n-tuple
	(a, b)	ordered pair
	$A \times B$	Cartesian product of A and B
	$A \cup B$	union of A and B
	$A \cap B$	intersection of A and B
	$A - B$	the difference of A and B
	$\overline{A}$	complement of A
	$\bigcup_{i=1}^{n} A_i$	union of A_i, $i = 1, 2, \ldots, n$
	$\bigcap_{i=1}^{n} A_i$	intersection of A_i, $i = 1, 2, \ldots, n$
	$A \oplus B$	symmetric difference of A and B

TOPIC	*SYMBOL*	*MEANING*
FUNCTIONS	$f(a)$	value of the function f at a
	$f: A \to B$	function from A to B
	$f_1 + f_2$	sum of the functions f_1 and f_2
	$f_1 f_2$	product of the functions f_1 and f_2
	$f(S)$	image of the set S under f
	$\iota_A(s)$	identity function on A
	$f^{-1}(x)$	inverse of f
	$f \circ g$	composition of f and g
	$\lfloor x \rfloor$	floor function of x
	$\lceil x \rceil$	ceiling function of x
	a_n	term of $\{a_i\}$ with subscript n
	$\sum_{i=1}^{n} a_i$	sum of $a_1, a_2, \ldots, a_n$
	$\sum_{\alpha \in S} a_\alpha$	sum of a_α over $\alpha \in S$
	$\prod_{i=1}^{n} a_n$	product of $a_1, a_2, \ldots, a_n$
	$f(x)$ is $O(g(x))$	$f(x)$ is big-O of $g(x)$
	$n!$	n factorial
	$f(x)$ is $\Omega(g(x))$	$f(x)$ is big-Omega of $g(x)$
	$f(x)$ is $\Theta(g(x))$	$f(x)$ is big-Theta of $g(x)$
	$\sim$	asymptotic
	$\min(x, y)$	minimum of x and y
	$\max(x, y)$	maximum of x and y
	$\approx$	approximately equal to
INTEGERS	$a \mid b$	a divides b
	$a \nmid b$	a does not divide b
	a **div** b	quotient when a is divided by b
	a **mod** b	remainder when a is divided by b
	$a \equiv b \pmod{m}$	a is congruent to b modulo m
	$a \not\equiv b \pmod{m}$	a is not congruent to b modulo m
	$\gcd(a, b)$	greatest common divisor of a and b
	$\operatorname{lcm}(a, b)$	least common multiple of a and b
	$(a_k a_{k-1} \cdots a_1 a_0)_b$	base b representation
MATRICES	$[a_{ij}]$	matrix with entries a_{ij}
	$\mathbf{A} + \mathbf{B}$	matrix sum of $\mathbf{A}$ and $\mathbf{B}$
	$\mathbf{AB}$	matrix product of $\mathbf{A}$ and $\mathbf{B}$
	$\mathbf{I}_n$	identity matrix of order n
	$\mathbf{A}^t$	transpose of $\mathbf{A}$
	$\mathbf{A} \vee \mathbf{B}$	join of $\mathbf{A}$ and $\mathbf{B}$
	$\mathbf{A} \wedge \mathbf{B}$	the meet of $\mathbf{A}$ and $\mathbf{B}$
	$\mathbf{A} \odot \mathbf{B}$	Boolean product of $\mathbf{A}$ and $\mathbf{B}$
	$\mathbf{A}^{[n]}$	nth Boolean power of $\mathbf{A}$