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David J. Hunter

Essentials of Discrete Mathematics

Third Edition

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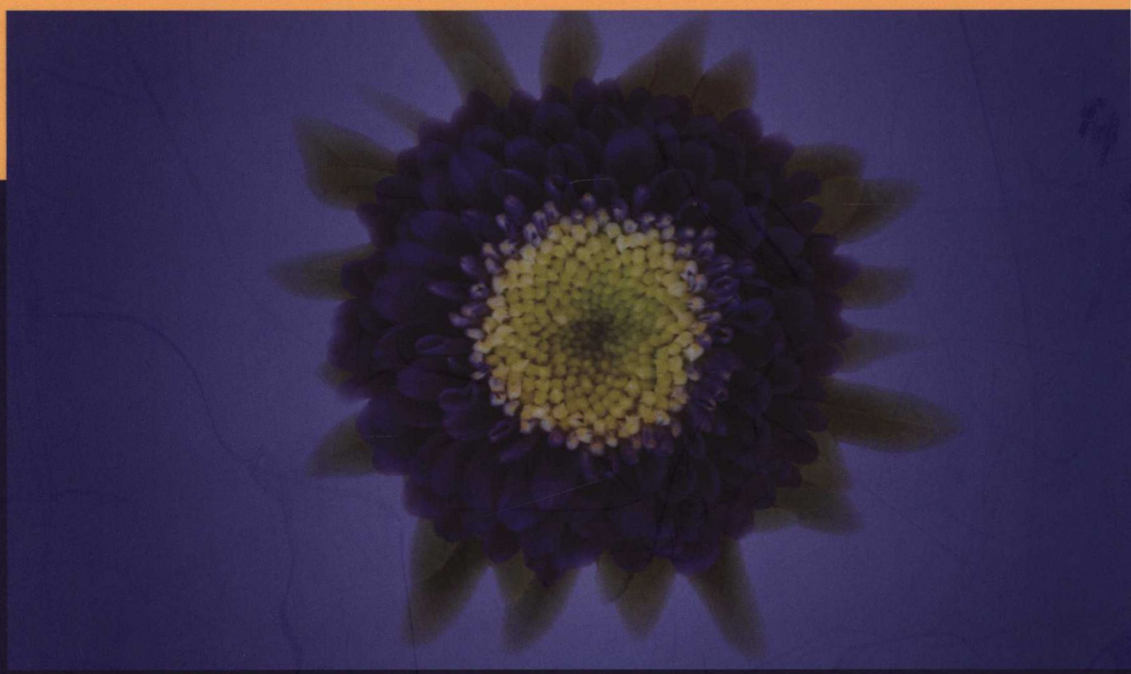

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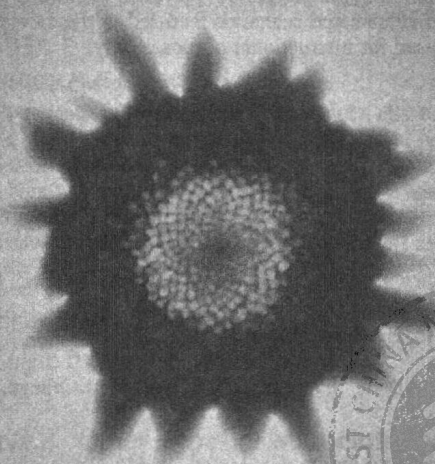
—Third Edition—

DAVID J. HUNTER
Westmont College



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Preface

Introduction

Essentials of Discrete Mathematics is designed for first- or second-year computer science and math majors in discrete mathematics courses. This text is also an excellent resource for students in other disciplines.

Unlike most other textbooks on the market, *Essentials* presents the material in a manner that is suitable for a comprehensive and cohesive one-semester course. The text is organized around five types of mathematical thinking: logical, relational, recursive, quantitative, and analytical. To reinforce this approach, graphs are introduced early and referred to throughout the text, providing a richer context for examples and applications.

Applications appear throughout the text, and the final chapter explores several uses of discrete mathematical thinking in a variety of disciplines. Case studies from biology, sociology, linguistics, economics, and music can be used as the basis for independent study or undergraduate research projects. Every section has its own set of exercises, which are designed to develop the skills of reading and writing proofs.

Synopsis of the Chapters

Chapter 1 introduces the reader to **Logical Thinking**. The chapter explores logic formally (symbolically) and then teaches the student to consider how logic is used in mathematical statements and arguments. The chapter begins with an introduction to formal logic, focusing on the importance of notation and symbols in mathematics, and then explains how formal logic can be applied. The chapter closes with a look at the different ways that proofs are constructed in mathematics.

As most mathematical problems contain different objects that are related to each other, Chapter 2 considers **Relational Thinking**. Finding the relationships among objects often is the first step in solving a mathematical problem. The mathematical structures of sets, relations, functions, and graphs describe these relationships, and thus this chapter focuses on exploring ways to use these structures to model mathematical relationships. Graph theory is introduced early and used throughout the chapter.

Chapter 3 describes **Recursive Thinking**. Many objects in nature have recursive structures: a branch of a tree looks like a smaller tree; an ocean swell has the same shape as the ripples formed by its splashes; an onion holds

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a smaller onion under its outer layer. Finding similar traits in mathematical objects unleashes a powerful tool. Chapter 3 begins by studying simple recurrence relations and then considers other recursive structures in a variety of contexts. Students also will cover recursive definitions, including how to write their own, and will extend the technique of induction to prove facts about recursively defined objects.

Chapter 4 engages the reader in **Quantitative Thinking**, as many problems in mathematics, computer science, and other disciplines involve counting the elements of a set of objects. The chapter examines the different tools used to count certain types of sets and teaches students to think about problems from a quantitative point of view. After exploring the different enumeration techniques, students will consider applications, including a first look at how to count operations in an algorithm. Chapter 4 also will practice the art of estimation, a valuable skill when precise enumeration is difficult.

Chapter 5 explores **Analytical Thinking**. Many applications of discrete mathematics use algorithms, and thus it is essential to be able to understand and analyze them. This chapter builds on the four foundations of thinking covered in the first four chapters, applying quantitative and relational thinking to the study of algorithm complexity, and then applying logical and recursive thinking to the study of program correctness. Finally, students will study mathematical ways to determine the accuracy and efficiency of algorithms.

The final chapter, **Thinking Through Applications**, examines different ways that discrete mathematical thinking can be applied: patterns in DNA, social networks, the structure of language, population models, and twelve-tone music.

What's New in the Third Edition

The third edition incorporates several improvements and additions designed to make teaching a course from this text more rewarding and effective. Thanks to helpful feedback from faculty and students, incremental changes in clarity and accuracy have been made, resulting in a more polished product. The early introduction to graph theory has been expanded, allowing deeper integration with later topics such as functions and relations. Perhaps most significantly, each section now opens with a set of inquiry problems designed to motivate the upcoming material. These open-ended problems can be assigned as independent work prior to a class meeting or as group work to engage students in class discussion. Unlike the end-of-section exercises, these inquiry problems often have a variety of plausible answers, prompting students to construct their own notation and conjectures. The instructor's version of the *Inquiry Problems* supplement contains pedagogical notes on each set of section-opener problems, as well as over 150 additional problems that can be used in a variety of ways.

About the Cover

The Fibonacci sequence 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, . . . is a famous example of recursion; each number in this sequence is the sum of the two numbers that precede it. The *Asteraceae* specimen pictured on the front cover of this book exhibits 21:34 Fibonacci phyllotaxis: there are 21 yellow spirals in one direction and 34 in the other. This flower continues the theme of the cover illustrations for the first and second editions of this text: an 8:13 pine cone and a 13:21 *Santolina* flower, respectively. You can read more about Fibonacci numbers in Section 3.1.2.

Supplements

- *Instructor's Solutions Manual*
- *Lecture slides in PowerPoint format*
- *WebAssign*™, developed by instructors for instructors, is a premier independent online teaching and learning environment, guiding several million students through their academic careers since 1997. With WebAssign, instructors can create and distribute algorithmic assignments using questions specific to this textbook. Instructors can also grade, record, and analyze student responses and performance instantly; offer more practice exercises, quizzes, and homework; and upload additional resources to share and communicate with their students seamlessly, such as the lecture slides in PowerPoint format supplied by Jones & Bartlett Learning.
- *eBook format*. As an added convenience, this complete textbook is now available in eBook format for purchase by the student through WebAssign.
- *Inquiry Problems*. Available in both student and instructor versions, this sequence of problems is designed to lead students through the main topics of the book using inquiry-based learning.

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Finally, I am deeply thankful to my wife Patti, whose support, patience, and encouragement sustained me throughout this project.

David Hunter
Westmont College

How to Use This Book

This book is designed to present a coherent one-semester course in the essentials of discrete mathematics for several different audiences. Figure 1 shows a diagram describing the dependencies among the sections of this book. Regardless of audi- ence, a course should cover the sections labeled "Core" in the diagram: 1.1–1.5, 2.1–2.4, 3.1–3.4, 4.1–4.3, 4.5, and 5.1.

Beyond these 18 core sections, instructors have many options for additional sections to include, depending on the audience. A one-semester course

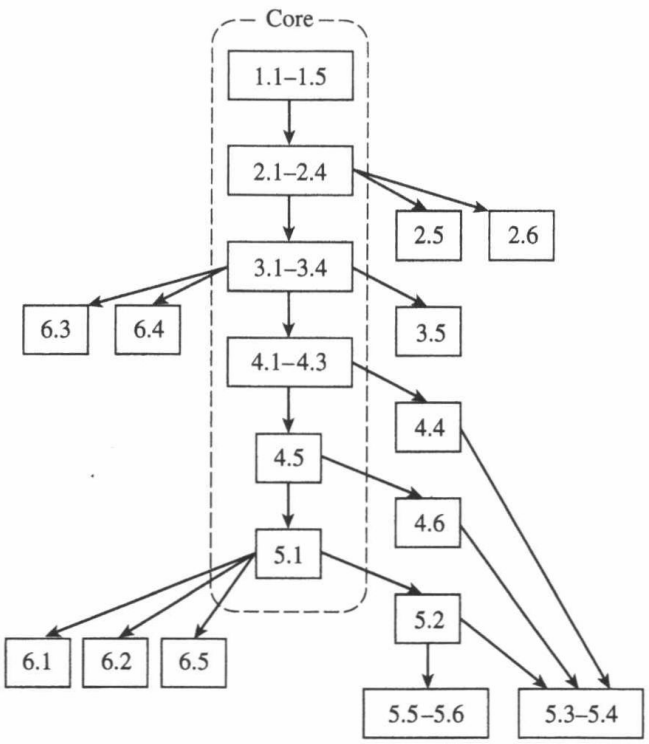

Figure 1 Dependencies among sections of this book.

Computer Science Emphasis	Mathematics Emphasis	Interdisciplinary
1.1–1.5	1.1–1.5	1.1–1.5
2.1–2.4	2.1–2.6	2.1–2.4
3.1–3.5	3.1–3.4	3.1–3.4
4.1–4.6	4.1–4.5	4.1–4.3, 4.5
5.1–5.2	5.1	5.1
5.3–5.4 and/or 5.5–5.6	6.3, 6.4, 6.5	6.1–6.5

Table 1 Three possible course outlines.

should be able to cover approximately 5–8 additional sections. Table 1 shows three possible course outlines, each with a different focus.

Some subsections in the core (3.2.2, 4.2.3, and 4.3.4) have been marked with a double-dagger symbol (‡) to indicate that these subsections may safely be omitted without disrupting the continuity of the material. Answers and hints to selected problems can be found at the end of the book. Exercises requiring extra effort or insight have been marked with an asterisk (*).

At the beginning of each section, you will find some questions labeled "Inquiry." These problems introduce and motivate the material in the section that follows. As such, they can be attempted before the corresponding material is presented in class. Instructors may elect to use these problems in a variety of ways: as group exercises, as independent student investigations, or as the basis for student presentations in class. Often these problems are open ended and can inspire class discussions. The *Inquiry Problems* supplement to this text contains all of these inquiry problems and many more, and the instructor's version of this supplement includes several notes with additional pedagogical suggestions.

Contents

Preface xi

How to Use This Book xv

Chapter 1 Logical Thinking 1

1.1 Formal Logic 2

1.1.1 Inquiry Problems 2

1.1.2 Connectives and Propositions 3

1.1.3 Truth Tables 5

1.1.4 Logical Equivalences 7

Exercises 1.1 10

1.2 Propositional Logic 15

1.2.1 Tautologies and Contradictions 16

1.2.2 Derivation Rules 18

1.2.3 Proof Sequences 20

1.2.4 Forward–Backward 22

Exercises 1.2 23

1.3 Predicate Logic 28

1.3.1 Predicates 29

1.3.2 Quantifiers 29

1.3.3 Translation 31

1.3.4 Negation 32

1.3.5 Two Common Constructions 34

Exercises 1.3 35

1.4 Logic in Mathematics 42

1.4.1 The Role of Definitions in Mathematics 42

1.4.2 Other Types of Mathematical Statements 44

1.4.3 Counterexamples 45

1.4.4 Axiomatic Systems 46

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Exercises 1.4 50
1.5 Methods of Proof 54
1.5.1 Direct Proofs 55
1.5.2 Proof by Contraposition 57
1.5.3 Proof by Contradiction 59
Exercises 1.5 61

Chapter 2 Relational Thinking 65
2.1 Graphs 66
2.1.1 Edges and Vertices 66
2.1.2 Terminology 67
2.1.3 Modeling Relationships with Graphs 69
Exercises 2.1 75
2.2 Sets 81
2.2.1 Membership and Containment 82
2.2.2 New Sets from Old 83
2.2.3 Identities 86
Exercises 2.2 88
2.3 Functions 92
2.3.1 Definition and Examples 93
2.3.2 One-to-One and Onto Functions 97
2.3.3 New Functions from Old 101
Exercises 2.3 103
2.4 Relations and Equivalences 107
2.4.1 Definition and Examples 108
2.4.2 Graphs of Relations 108
2.4.3 Relations vs. Functions 109
2.4.4 Equivalence Relations 111
2.4.5 Modular Arithmetic 114
Exercises 2.4 116
2.5 Partial Orderings 121
2.5.1 Definition and Examples 122
2.5.2 Hasse Diagrams 123
2.5.3 Topological Sorting 124
2.5.4 Isomorphisms 126
2.5.5 Boolean Algebras‡ 129
Exercises 2.5 131
2.6 Graph Theory 136
2.6.1 Graphs: Formal Definitions 136

2.6.2 Isomorphisms of Graphs 137
2.6.3 Degree Counting 139
2.6.4 Euler Paths and Circuits 140
2.6.5 Hamilton Paths and Circuits 141
2.6.6 Trees 144
Exercises 2.6 147

Chapter 3 Recursive Thinking 151
3.1 Recurrence Relations 152
3.1.1 Definition and Examples 153
3.1.2 The Fibonacci Sequence 154
3.1.3 Modeling with Recurrence Relations 155
Exercises 3.1 159
3.2 Closed-Form Solutions and Induction 163
3.2.1 Guessing a Closed-Form Solution 164
3.2.2 Polynomial Sequences: Using Differences‡ 165
3.2.3 Inductively Verifying a Solution 167
Exercises 3.2 171
3.3 Recursive Definitions 175
3.3.1 Definition and Examples 176
3.3.2 Writing Recursive Definitions 180
3.3.3 Recursive Geometry 181
3.3.4 Recursive Jokes 185
Exercises 3.3 185
3.4 Proof by Induction 190
3.4.1 The Principle of Induction 191
3.4.2 Examples 192
3.4.3 Strong Induction 197
3.4.4 Structural Induction 200
Exercises 3.4 202
3.5 Recursive Data Structures 205
3.5.1 Lists 206
3.5.2 Efficiency 210
3.5.3 Binary Search Trees Revisited 212
Exercises 3.5 213

Chapter 4 Quantitative Thinking 219
4.1 Basic Counting Techniques 220
4.1.1 Addition 220

4.1.2 Multiplication 221
4.1.3 Mixing Addition and Multiplication 225
Exercises 4.1 227
4.2 Selections and Arrangements 231
4.2.1 Permutations: The Arrangement Principle 232
4.2.2 Combinations: The Selection Principle 234
4.2.3 The Binomial Theorem‡ 237
Exercises 4.2 239
4.3 Counting with Functions 244
4.3.1 One-to-One Correspondences 244
4.3.2 The Pigeonhole Principle 248
4.3.3 The Generalized Pigeonhole Principle 249
4.3.4 Ramsey Theory‡ 250
Exercises 4.3 251
4.4 Discrete Probability 257
4.4.1 Definitions and Examples 257
4.4.2 Applications 259
4.4.3 Expected Value 262
Exercises 4.4 264
4.5 Counting Operations in Algorithms 268
4.5.1 Algorithms 269
4.5.2 Pseudocode 269
4.5.3 Sequences of Operations 271
4.5.4 Loops 271
4.5.5 Arrays 274
4.5.6 Sorting 276
Exercises 4.5 278
4.6 Estimation 283
4.6.1 Growth of Functions 283
4.6.2 Estimation Targets 288
4.6.3 Properties of Big-Θ 289
Exercises 4.6 291

Chapter 5 Analytical Thinking 295
5.1 Algorithms 296
5.1.1 More Pseudocode 296
5.1.2 Preconditions and Postconditions 298
5.1.3 Iterative Algorithms 300
5.1.4 Functions and Recursive Algorithms 301

Exercises 5.1 305
5.2 Three Common Types of Algorithms 309
5.2.1 Traversal Algorithms 310
5.2.2 Greedy Algorithms 314
5.2.3 Divide-and-Conquer Algorithms 317
Exercises 5.2 320
5.3 Algorithm Complexity 325
5.3.1 The Good, the Bad, and the Average 326
5.3.2 Approximate Complexity Calculations 330
Exercises 5.3 333
5.4 Bounds on Complexity 339
5.4.1 Algorithms as Decisions 339
5.4.2 A Lower Bound 342
5.4.3 Searching an Array 343
5.4.4 Sorting 344
5.4.5 *P* vs. *NP* 345
Exercises 5.4 346
5.5 Program Verification 350
5.5.1 Verification vs. Testing 351
5.5.2 Verifying Recursive Algorithms 351
5.5.3 Searching and Sorting 354
5.5.4 Towers of Hanoi 356
Exercises 5.5 358
5.6 Loop Invariants 362
5.6.1 Verifying Iterative Algorithms 363
5.6.2 Searching and Sorting 366
5.6.3 Using Invariants to Design Algorithms 370
Exercises 5.6 371

Chapter 6 Thinking Through Applications 377
6.1 Patterns in DNA 378
6.1.1 Mutations and Phylogenetic Distance 379
6.1.2 Phylogenetic Trees 380
6.1.3 UPGMA 382
Exercises 6.1 386
6.2 Social Networks 388
6.2.1 Definitions and Terminology 388
6.2.2 Notions of Equivalence 390

6.2.3 Hierarchical Clustering 394
6.2.4 Signed Graphs and Balance 396
Exercises 6.2 400
6.3 Structure of Languages 402
6.3.1 Terminology 403
6.3.2 Finite-State Machines 404
6.3.3 Recursion 407
6.3.4 Further Issues in Linguistics 411
Exercises 6.3 412
6.4 Discrete-Time Population Models 414
6.4.1 Recursive Models for Population Growth 415
6.4.2 Fixed Points, Equilibrium, and Chaos 417
6.4.3 Predator–Prey Systems 419
6.4.4 The SIR Model 421
Exercises 6.4 423
6.5 Twelve-Tone Music 426
6.5.1 Twelve-Tone Composition 426
6.5.2 Listing All Permutations 427
6.5.3 Transformations of Tone Rows 429
6.5.4 Equivalence Classes and Symmetry 430
Exercises 6.5 432

Hints, Answers, and Solutions to Selected Exercises 435
1.1 Formal Logic 435
1.2 Propositional Logic 437
1.3 Predicate Logic 439
1.4 Logic in Mathematics 441
1.5 Methods of Proof 442
2.1 Graphs 444
2.2 Sets 445
2.3 Functions 446
2.4 Relations and Equivalences 448
2.5 Partial Orderings 450
2.6 Graph Theory 453
3.1 Recurrence Relations 454
3.2 Closed-Form Solutions and Induction 455
3.3 Recursive Definitions 458
3.4 Proof by Induction 459
3.5 Recursive Data Structures 462

4.1 Basic Counting Techniques 463
4.2 Selections and Arrangements 464
4.3 Counting with Functions 465
4.4 Discrete Probability 466
4.5 Counting Operations in Algorithms 467
4.6 Estimation 469
5.1 Algorithms 470
5.2 Three Common Types of Algorithms 471
5.3 Algorithm Complexity 473
5.4 Bounds on Complexity 474
5.5 Program Verification 475
5.6 Loop Invariants 476

Selected References 479

Index 483

Index of Symbols 491

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