



Contents

Preface ix
To the Instructor xix
To the Student xxv

Chapter 1	Vectors 1
	1.0 Introduction: The Racetrack Game 1 1.1 The Geometry and Algebra of Vectors 3 1.2 Length and Angle: The Dot Product 18 Exploration: Vectors and Geometry 32 1.3 Lines and Planes 34 Exploration: The Cross Product 48 1.4 Applications 50 Force Vectors 50 Code Vectors 53 Vignette: The Codabar System 60 Chapter Review 61
Chapter 2	Systems of Linear Equations 63
	2.0 Introduction: Triviality 63 2.1 Introduction to Systems of Linear Equations 64 2.2 Direct Methods for Solving Linear Systems 70 Explorations: Lies My Computer Told Me 89 Partial Pivoting 90 Counting Operations: An Introduction to the Analysis of Algorithms 91 2.3 Spanning Sets and Linear Independence 94 2.4 Applications 105 Allocation of Resources 105 Balancing Chemical Equations 107 Network Analysis 108 Electrical Networks 110 Linear Economic Models 113 Finite Linear Games 115 Vignette: The Global Positioning System 127
	2.5 Iterative Methods for Solving Linear Systems 130 Chapter Review 140

Chapter 3	Matrices 142
	3.0 Introduction: Matrices in Action 142 3.1 Matrix Operations 144 3.2 Matrix Algebra 160 3.3 The Inverse of a Matrix 169 3.4 The LU Factorization 186 3.5 Subspaces, Basis, Dimension, and Rank 197 3.6 Introduction to Linear Transformations 217 Vignette: Robotics 232 3.7 Applications 236 Markov Chains 236 Linear Economic Models 241 Population Growth 245 Graphs and Digraphs 247 Error-Correcting Codes 251 Chapter Review 262
Chapter 4	Eigenvalues and Eigenvectors 264
	4.0 Introduction: A Dynamical System on Graphs 264 4.1 Introduction to Eigenvalues and Eigenvectors 265 4.2 Determinants 274 Vignette: Lewis Carroll's Condensation Method 295 Exploration: Geometric Applications of Determinants 297 4.3 Eigenvalues and Eigenvectors of n × n Matrices 303 4.4 Similarity and Diagonalization 312 4.5 Iterative Methods for Computing Eigenvalues 322 4.6 Applications and the Perron-Frobenius Theorem 336 Markov Chains 336 Population Growth 341 The Perron-Frobenius Theorem 343 Linear Recurrence Relations 346 Systems of Linear Differential Equations 351 Discrete Linear Dynamical Systems 359 Vignette: Ranking Sports Teams and Searching the Internet 367 Chapter Review 375
Chapter 5	Orthogonality 377
	5.0 Introduction: Shadows on a Wall 377 5.1 Orthogonality in \mathbb{R}^n 379 5.2 Orthogonal Complements and Orthogonal Projections 389 5.3 The Gram-Schmidt Process and the QR Factorization 399 Explorations: The Modified QR Factorization 407 Approximating Eigenvalues with the QR Algorithm 409

5.4

5.5

Index

720

Applications

Dual Codes

Quadratic Forms

	Graphing Quadratic Equations 432 Chapter Review 443
Chapter 6	Vector Spaces 445
<u>Chapter o</u>	rector opaces 110
	6.0 Introduction: Fibonacci in (Vector) Space 445
	6.1 Vector Spaces and Subspaces 447
	6.2 Linear Independence, Basis, and Dimension 461 Exploration: Magic Squares 478
	6.3 Change of Basis 481
	6.4 Linear Transformations 490
	6.5 The Kernel and Range of a Linear Transformation 499
	6.6 The Matrix of a Linear Transformation 515
	Exploration: Tilings, Lattices, and the Crystallographic Restriction 533
	6.7 Applications 536
	Homogeneous Linear Differential Equations 536
	Linear Codes 543
	Chapter Review 550
Chapter 7	Distance and Approximation 552
	7.0 Introduction: Taxicab Geometry 552
	7.1 Inner Product Spaces 554
	Explorations: Vectors and Matrices with Complex Entries 566 Geometric Inequalities and Optimization Problems 570
	7.2 Norms and Distance Functions 575
	7.3 Least Squares Approximation 591
	7.4 The Singular Value Decomposition 613
	Vignette: Digital Image Compression 630
	7.5 Applications 633
	Approximation of Functions 633
	Error-Correcting Codes 640
	Chapter Review 645
	APPENDIX A Mathematical Notation and Methods of Proof 648
	APPENDIX B Mathematical Induction 657
	APPENDIX C Complex Numbers 664
	APPENDIX D Polynomials 675
	APPENDIX E Technology Bytes Online Only
	Answers to Selected Odd-Numbered Exercises 685

Orthogonal Diagonalization of Symmetric Matrices

425

419

419

411