

Contents

| | |
|---|------------------|
| <i>List of Figures</i> | <i>page</i> xvii |
| <i>List of Tables</i> | xxiii |
| <i>Preface</i> | xxv |
| <i>Contacting the Author Regarding this Book</i> | xxv |
| <i>Book Website</i> | xxv |
| <i>Book Organization</i> | xxv |
| <i>A Message to Students</i> | xxvi |
| <i>A Message to Industry Practitioners</i> | xxviii |
| <i>A Message to Instructors</i> | xxviii |
| <i>Acknowledgements</i> | xxxi |
| PART I. HELPFUL PRELIMINARIES | |
| 1 MATLAB® as a Computational Tool | 1 |
| 1.1 Overview | 3 |
| 1.2 MATLAB Preliminaries—Before Starting | 4 |
| 1.2.1 <i>What Is MATLAB?</i> | 4 |
| 1.2.2 <i>Why MATLAB?</i> | 5 |
| 1.2.3 <i>MATLAB Toolboxes</i> | 5 |
| 1.2.4 <i>How to Use MATLAB in this Book</i> | 7 |
| 1.2.5 <i>Acquiring MATLAB</i> | 7 |
| 1.2.6 <i>MATLAB Documentation</i> | 7 |
| 1.2.7 <i>Other Software for Optimization</i> | 8 |
| 1.3 Basics of MATLAB—Getting Started | 8 |
| 1.3.1 <i>Starting and Quitting MATLAB</i> | 8 |
| 1.3.2 <i>MATLAB Desktop: Its Graphical User Interface</i> | 9 |
| 1.3.3 <i>Matrices and Variables Operations</i> | 14 |
| 1.3.4 <i>More MATLAB Expressions</i> | 19 |
| 1.4 Beyond the Basics of MATLAB | 19 |
| 1.4.1 <i>Input and Output, Directories and Files</i> | 19 |

| | | |
|----------|---|----|
| 1.4.2 | <i>Flow Control, Relational and Logical Operators</i> | 20 |
| 1.4.3 | <i>M-files</i> | 22 |
| 1.4.4 | <i>Global and Local Variables</i> | 23 |
| 1.4.5 | <i>MATLAB Help</i> | 23 |
| 1.5 | Plotting Using MATLAB | 24 |
| 1.5.1 | <i>Basic Plots</i> | 24 |
| 1.5.2 | <i>Special Plots: Contour, Scatter, fplot</i> | 26 |
| 1.5.3 | <i>3-D Mesh and Surface Plots</i> | 28 |
| 1.5.4 | <i>Using the Plot Editing Mode</i> | 29 |
| 1.6 | Optimizing with MATLAB | 30 |
| 1.7 | Popular Functions and Commands, and More | 30 |
| 1.8 | Summary | 30 |
| 1.9 | Problems | 31 |
| | Bibliography of Chapter 1 | 42 |
| 2 | Mathematical Preliminaries | 44 |
| 2.1 | Overview | 44 |
| 2.2 | Vectors and Geometry | 44 |
| 2.2.1 | <i>Dot Product</i> | 44 |
| 2.2.2 | <i>Equation of a Line</i> | 45 |
| 2.2.3 | <i>Equation of a Plane</i> | 45 |
| 2.3 | Basic Linear Algebra | 46 |
| 2.3.1 | <i>Preliminary Definitions</i> | 47 |
| 2.3.2 | <i>Matrix Operations</i> | 48 |
| 2.3.3 | <i>Determinants</i> | 51 |
| 2.3.4 | <i>Inverse</i> | 53 |
| 2.3.5 | <i>Eigenvalues</i> | 53 |
| 2.3.6 | <i>Eigenvectors</i> | 54 |
| 2.3.7 | <i>Positive Definiteness</i> | 55 |
| 2.4 | Basic Calculus: Types of Functions, Derivative, Integration and Taylor Series | 55 |
| 2.4.1 | <i>Types of Functions</i> | 56 |
| 2.4.2 | <i>Limits of Functions</i> | 59 |
| 2.4.3 | <i>Derivative</i> | 59 |
| 2.4.4 | <i>Partial Derivative</i> | 60 |
| 2.4.5 | <i>Indefinite Integration</i> | 60 |
| 2.4.6 | <i>Definite Integration</i> | 60 |
| 2.4.7 | <i>Taylor Series</i> | 61 |
| 2.5 | Optimization Basics: Single-Variable Optimality Conditions, Gradient, Hessian | 62 |
| 2.5.1 | <i>Necessary Conditions for Local Optimum</i> | 62 |
| 2.5.2 | <i>Stationary Points and Inflection Points</i> | 63 |
| 2.5.3 | <i>Sufficient Conditions for Local Optima</i> | 63 |
| 2.5.4 | <i>Gradient and Hessian of a Function</i> | 64 |

| | | |
|--|--|----|
| 2.6 | Summary | 65 |
| 2.7 | Problems | 66 |
| | Bibliography of Chapter 2 | 69 |
| PART II. USING OPTIMIZATION—THE ROAD MAP | | 71 |
| 3 | Welcome to the Fascinating World of Optimization | 73 |
| 3.1 | Overview | 73 |
| 3.2 | What Is Optimization? What Is Its Relation to Analysis and Design? | 73 |
| 3.3 | Why Should Junior and Senior College Students Study Optimization? | 77 |
| 3.4 | Why Should Graduate Students Study Optimization? | 77 |
| 3.5 | Why Should Industry Practitioners Study Optimization? | 78 |
| 3.6 | Why Use this Book, and What Should I Expect from It? | 78 |
| 3.7 | How this Book Is Organized | 79 |
| 3.8 | How to Read and Use this Book | 80 |
| 3.9 | Summary | 80 |
| 3.10 | Problems | 81 |
| | Bibliography of Chapter 3 | 81 |
| 4 | Analysis, Design, Optimization and Modeling | 82 |
| 4.1 | Overview | 82 |
| 4.2 | Analysis, Design and Optimization | 82 |
| 4.2.1 | <i>What Is Analysis?</i> | 83 |
| 4.2.2 | <i>What Is Design?</i> | 84 |
| 4.2.3 | <i>What Is Optimization?</i> | 85 |
| 4.2.4 | <i>Interdependence of Analysis, Design and Optimization</i> | 86 |
| 4.3 | Modeling System Behavior and Modeling the Optimization Problem | 88 |
| 4.3.1 | <i>Modeling System Behavior</i> | 88 |
| 4.3.2 | <i>Modeling the Optimization Problem</i> | 90 |
| 4.3.3 | <i>Interdependence of System Behavior Modeling and Optimization Modeling</i> | 90 |
| 4.4 | Summary | 91 |
| 4.5 | Problems | 91 |
| | Bibliography of Chapter 4 | 92 |
| 5 | Introducing Linear and Nonlinear Programming | 93 |
| 5.1 | Overview | 93 |
| 5.2 | Problem Classes | 93 |
| 5.3 | Single Objective Optimization—An Inclusive Notion | 98 |
| 5.4 | Solution Approaches: Analytical, Numerical, Experimental and Graphical | 98 |
| 5.4.1 | <i>Analytical Optimization</i> | 98 |

| | | |
|--|---|-----|
| 5.4.2 | <i>Numerical (or Algorithmic) Optimization</i> | 99 |
| 5.4.3 | <i>Experimental Optimization</i> | 101 |
| 5.4.4 | <i>Graphical Optimization</i> | 101 |
| 5.5 | Software Options for Optimization | 102 |
| 5.5.1 | <i>MATLAB Optimization Code—fmincon and linprog</i> | 103 |
| 5.5.2 | <i>Software for Optimization as Stand-Alone (SO-SA)</i> | 109 |
| 5.5.3 | <i>Software for Optimization Within Design Framework (SO-WDF)</i> | 111 |
| 5.5.4 | <i>Software for Optimization Within Analysis Package (SO-WAP)</i> | 112 |
| 5.6 | Summary | 114 |
| 5.7 | Problems | 115 |
| | Bibliography of Chapter 5 | 119 |
| PART III. USING OPTIMIZATION—PRACTICAL ESSENTIALS | | 121 |
| 6 | Multiobjective Optimization | 123 |
| 6.1 | Overview | 123 |
| 6.2 | The Multiobjective Problem Definition | 123 |
| 6.2.1 | <i>Example Problem</i> | 124 |
| 6.2.2 | <i>Multiobjective Optimization Problem Statement</i> | 124 |
| 6.3 | Pareto Optimal Solution | 125 |
| 6.3.1 | <i>Introducing the Pareto Solution</i> | 125 |
| 6.3.2 | <i>The Pareto Frontier</i> | 126 |
| 6.3.3 | <i>Obtaining Pareto Solutions</i> | 127 |
| 6.3.4 | <i>Aggregate Objective Function</i> | 127 |
| 6.4 | The Weighted Sum Method | 128 |
| 6.4.1 | <i>Two-Objective Case</i> | 128 |
| 6.4.2 | <i>Addressing More than Two Objectives</i> | 129 |
| 6.5 | Compromise Programming | 131 |
| 6.6 | Generating the Pareto Frontier—with MATLAB | 133 |
| 6.7 | Reaching a Target—Goal Programming | 135 |
| 6.8 | Expressing a Preference—Physical Programming | 136 |
| 6.9 | Multiobjective Optimization Using MATLAB Optimization Toolbox | 137 |
| 6.10 | Summary | 138 |
| 6.11 | Problems | 138 |
| | Bibliography of Chapter 6 | 157 |
| 7 | Numerical Essentials | 158 |
| 7.1 | Overview | 158 |
| 7.2 | Numerical Conditioning—Algorithms, Matrices and Optimization Problems | 158 |
| 7.2.1 | <i>Reasons Why the Optimization Process Sometimes Fails</i> | 159 |

| | | |
|----------|--|-----|
| 7.2.2 | <i>Exposing Numerical Conditioning Issues—Algorithms and Matrices</i> | 160 |
| 7.2.3 | <i>Exposing Numerical Conditioning Issues—Optimization Problems</i> | 162 |
| 7.3 | Scaling and Tolerances for Design Variables, Constraints and Objective Functions | 163 |
| 7.3.1 | <i>Understanding the Accuracy of the Reported Results</i> | 165 |
| 7.3.2 | <i>Design Variable Scaling—Order of Magnitude (DV-1)</i> | 166 |
| 7.3.3 | <i>Design Variable Scaling—Tolerance Definition (DV-2)</i> | 167 |
| 7.3.4 | <i>Design Variable Scaling—Optimization Code Decimal Accuracy Setting (DV-3)</i> | 168 |
| 7.3.5 | <i>Design Variable Scaling—Combining Order of Magnitude and Desired Tolerance (DV-4)</i> | 168 |
| 7.3.6 | <i>Design Variable Scaling—Setting Scaling Parameters (DV-5)</i> | 169 |
| 7.3.7 | <i>Objective Function Scaling</i> | 170 |
| 7.3.8 | <i>Behavioral Constraints Scaling</i> | 171 |
| 7.3.9 | <i>Setting MATLAB Optimization Options and Scaling Parameters: Syntax</i> | 173 |
| 7.3.10 | <i>Simple Scaling Examples</i> | 174 |
| 7.4 | Finite Difference | 176 |
| 7.4.1 | <i>Fundamentals of Finite Difference</i> | 176 |
| 7.4.2 | <i>Accuracy of Finite Difference Approximation</i> | 179 |
| 7.5 | Automatic Differentiation | 182 |
| 7.6 | Other Important Numerical and Computational Issues | 185 |
| 7.6.1 | <i>Sensitivity of Optimal Solutions in Nonlinear Programming</i> | 185 |
| 7.6.2 | <i>Optimization Termination Criteria and Optimization Termination Causes</i> | 186 |
| 7.6.3 | <i>Developing Confidence in Optimization Results</i> | 187 |
| 7.6.4 | <i>Problem Dimension and Computational Burden</i> | 187 |
| 7.6.5 | <i>Additional Numerical Pitfalls</i> | 188 |
| 7.7 | Larger Scaling Example: Universal Motor Problem | 188 |
| 7.7.1 | <i>Universal Motor Problem Definition</i> | 188 |
| 7.7.2 | <i>Design Variable Scaling</i> | 190 |
| 7.8 | Summary | 190 |
| 7.9 | Problems | 191 |
| | Bibliography of Chapter 7 | 198 |
| 8 | Global Optimization Basics | 200 |
| 8.1 | Overview | 200 |
| 8.2 | Practical Issues in Global Optimization | 200 |
| 8.3 | Exhaustive Search | 202 |
| 8.4 | Multiple Start | 203 |

| | | |
|-----------|---|-----|
| 8.5 | Role of Genetic Algorithms in Global Optimization | 205 |
| 8.6 | MATLAB Global Optimization Toolbox | 209 |
| 8.7 | Summary | 210 |
| 8.8 | Problems | 211 |
| | Bibliography of Chapter 8 | 212 |
| 9 | Discrete Optimization Basics | 213 |
| 9.1 | Overview | 213 |
| 9.2 | Defining Discrete Optimization | 213 |
| 9.3 | Exhaustive Search | 214 |
| 9.4 | Relaxation Approach | 215 |
| 9.5 | Advanced Options: Genetic Algorithms, Simulated Annealing, and Branch and Bound | 217 |
| | <i>9.5.1 Genetic Algorithms</i> | 217 |
| | <i>9.5.2 Simulated Annealing</i> | 218 |
| | <i>9.5.3 Branch and Bound</i> | 218 |
| 9.6 | Summary | 221 |
| 9.7 | Problems | 221 |
| | Bibliography of Chapter 9 | 222 |
| 10 | Practicing Optimization—Larger Examples | 223 |
| 10.1 | Overview | 223 |
| 10.2 | Mechanical Engineering Example | 223 |
| | <i>10.2.1 Structural Example</i> | 223 |
| | <i>10.2.2 Tolerance Allocation Problem</i> | 225 |
| 10.3 | Aerospace Engineering Example | 229 |
| | <i>10.3.1 Ground Controllability</i> | 230 |
| | <i>10.3.2 Ground Stability</i> | 230 |
| | <i>10.3.3 Structural Integrity</i> | 231 |
| 10.4 | Mathematical Example | 232 |
| | <i>10.4.1 Data Fitting</i> | 232 |
| | <i>10.4.2 Least Squares Data Fitting</i> | 233 |
| 10.5 | Civil Engineering Example | 234 |
| 10.6 | Electrical Engineering Example | 236 |
| | <i>10.6.1 Introduction to Thermoelectric Window Design</i> | 236 |
| | <i>10.6.2 Brief Introduction to the Trust Region Method</i> | 237 |
| | <i>10.6.3 Modeling TE Units</i> | 238 |
| | <i>10.6.4 Solving Optimization Problem</i> | 239 |
| | <i>10.6.5 Results</i> | 241 |
| 10.7 | Business Example | 241 |
| 10.8 | Summary | 242 |
| 10.9 | Problems | 242 |
| | Bibliography of Chapter 10 | 246 |

| | |
|--|-----|
| PART IV. GOING DEEPER: INSIDE THE CODES AND THEORETICAL ASPECTS | 249 |
| 11 Linear Programming | 251 |
| 11.1 Overview | 251 |
| 11.2 Basics of Linear Programming | 251 |
| 11.3 Graphical Solution Approach: Types of LP Solutions | 253 |
| <i>11.3.1 The Unique Solution</i> | 253 |
| <i>11.3.2 The Segment Solution</i> | 253 |
| <i>11.3.3 No Solution</i> | 254 |
| <i>11.3.4 The Solution at Infinity</i> | 255 |
| 11.4 Solving LP Problems Using MATLAB | 255 |
| 11.5 Simplex Method Basics | 257 |
| <i>11.5.1 The Standard Form</i> | 257 |
| <i>11.5.2 Transforming into Standard Form</i> | 258 |
| <i>11.5.3 Gauss Jordan Elimination</i> | 259 |
| <i>11.5.4 Reducing to a Row Echelon Form</i> | 261 |
| <i>11.5.5 The Basic Solution</i> | 263 |
| 11.6 Simplex Algorithm | 264 |
| <i>11.6.1 Basic Algorithm</i> | 264 |
| <i>11.6.2 Special Cases</i> | 271 |
| 11.7 Advanced Concepts | 271 |
| <i>11.7.1 Duality</i> | 272 |
| <i>11.7.2 Primal-Dual Relationships</i> | 273 |
| <i>11.7.3 Interior Point Methods</i> | 274 |
| <i>11.7.4 Solution Sensitivity</i> | 274 |
| 11.8 Summary | 276 |
| 11.9 Problems | 276 |
| Bibliography of Chapter 11 | 277 |
| 12 Nonlinear Programming with No Constraints | 279 |
| 12.1 Overview | 279 |
| 12.2 Necessary and Sufficient Conditions | 279 |
| 12.3 Single Variable Optimization | 280 |
| <i>12.3.1 Interval Reduction Methods</i> | 281 |
| <i>12.3.2 Polynomial Approximations: Quadratic Approximation</i> | 285 |
| 12.4 Multivariable Optimization | 287 |
| <i>12.4.1 Zeroth-Order Methods</i> | 287 |
| <i>12.4.2 First-Order Methods</i> | 293 |
| <i>12.4.3 Second-Order Methods</i> | 298 |
| 12.5 Comparison of Computational Issues in the Algorithms | 303 |
| <i>12.5.1 Rate of Convergence</i> | 303 |

| | | |
|---|--|-----|
| 12.5.2 | <i>Line Search Methods</i> | 304 |
| 12.5.3 | <i>Comparison of Different Methods</i> | 305 |
| 12.6 | Summary | 306 |
| 12.7 | Problems | 306 |
| | Bibliography of Chapter 12 | 308 |
| 13 | Nonlinear Programming with Constraints | 310 |
| 13.1 | Overview | 310 |
| 13.2 | Structure of Constrained Optimization | 310 |
| 13.3 | Elimination Method | 312 |
| 13.4 | Penalty Methods | 313 |
| 13.5 | Karush-Kuhn-Tucker Conditions | 317 |
| 13.6 | Sequential Linear Programming | 323 |
| 13.7 | Sequential Quadratic Programming | 326 |
| 13.8 | Comparison of Computational Issues | 328 |
| 13.9 | Summary | 329 |
| 13.10 | Problems | 329 |
| | Bibliography of Chapter 13 | 331 |
| PART V. MORE ADVANCED TOPICS IN OPTIMIZATION | | 333 |
| 14 | Discrete Optimization | 335 |
| 14.1 | Overview | 335 |
| 14.2 | Problem Classes, Examples and Definition | 335 |
| 14.2.1 | <i>Problem Classes</i> | 336 |
| 14.2.2 | <i>Popular Example Problems</i> | 336 |
| 14.2.3 | <i>Problem Definition and Computational Complexity</i> | 337 |
| 14.3 | Solution Approaches | 339 |
| 14.3.1 | <i>Brute Force Method: Exhaustive Search</i> | 340 |
| 14.3.2 | <i>Graphical Method</i> | 341 |
| 14.3.3 | <i>Relaxation Approach: Solve as Continuous Problem</i> | 341 |
| 14.3.4 | <i>Branch and Bound Method</i> | 342 |
| 14.3.5 | <i>Cutting Plane Method</i> | 343 |
| 14.3.6 | <i>Evolutionary Algorithms</i> | 351 |
| 14.3.7 | <i>Software Options for Discrete Optimization</i> | 351 |
| 14.4 | Summary | 352 |
| 14.5 | Problems | 352 |
| | Bibliography of Chapter 14 | 353 |
| 15 | Modeling Complex Systems: Surrogate Modeling and Design Space Reduction | 355 |
| 15.1 | Overview | 355 |
| 15.2 | Modeling Challenges in Complex Optimization Problems | 355 |
| 15.3 | Impact of Problem Dimension | 357 |
| 15.3.1 | <i>Design Variable Linking</i> | 357 |

| | | |
|-----------|--|-----|
| 15.3.2 | <i>Design of Experiments</i> | 359 |
| 15.4 | Surrogate Modeling | 363 |
| 15.4.1 | <i>Surrogate Modeling Process</i> | 364 |
| 15.4.2 | <i>Polynomial Response Surface Methodology</i> | 365 |
| 15.4.3 | <i>Radial Basis Function Method</i> | 367 |
| 15.4.4 | <i>Kriging Method</i> | 371 |
| 15.4.5 | <i>Artificial Neural Networks (ANN)</i> | 371 |
| 15.5 | Summary | 372 |
| 15.6 | Problems | 372 |
| | Bibliography of Chapter 15 | 373 |
| 16 | Design Optimization Under Uncertainty | 376 |
| 16.1 | Overview | 376 |
| 16.2 | Chapter Example | 377 |
| 16.3 | Generic Components/STEPS of Design Under Uncertainty | 378 |
| 16.4 | STEP 1: Identifying Types of Uncertainty | 380 |
| 16.5 | STEP 2: Uncertainty Quantification | 382 |
| 16.5.1 | <i>Sufficient Data Available: Probability Theory</i> | 382 |
| 16.5.2 | <i>Insufficient Data: Non-Probabilistic Methods</i> | 384 |
| 16.6 | STEP 3: Uncertainty Propagation | 385 |
| 16.6.1 | <i>Sampling Methods</i> | 385 |
| 16.6.2 | <i>First-Order and Second-Order Reliability Methods (FORM and SORM)</i> | 387 |
| 16.6.3 | <i>Polynomial Approximation Using Taylor Series</i> | 387 |
| 16.6.4 | <i>Advanced Methods Overview</i> | 389 |
| 16.6.5 | <i>An Important Note on Uncertainty: Analysis vs. Optimization</i> | 389 |
| 16.7 | STEP 4: Embedding Uncertainty into an Optimization Framework | 389 |
| 16.7.1 | <i>Reliability-Based Design Optimization (RBDO)</i> | 391 |
| 16.7.2 | <i>Use of Approximation Methods Under Uncertainty</i> | 392 |
| 16.7.3 | <i>Robust Design Optimization (RDO)</i> | 393 |
| 16.8 | STEP 5: How to Analyze the Results | 396 |
| 16.8.1 | <i>Mean Performance and Robustness Trade-off</i> | 397 |
| 16.8.2 | <i>Deterministic vs. Robust Solutions</i> | 397 |
| 16.8.3 | <i>Constraint Trade-offs</i> | 398 |
| 16.8.4 | <i>Final Design Choice</i> | 398 |
| 16.8.5 | <i>Multiojective Problems Under Uncertainty: Decision-Making Problem</i> | 398 |
| 16.9 | Other Popular Methods | 399 |
| 16.9.1 | <i>Taguchi's Robust Design Methods</i> | 399 |
| 16.9.2 | <i>Stochastic Programming</i> | 399 |
| 16.10 | Summary | 399 |

| | | |
|-----------|--|-----|
| 16.11 | Problems | 400 |
| | Bibliography of Chapter 16 | 402 |
| 17 | Methods for Pareto Frontier Generation/Representation | 406 |
| 17.1 | Overview | 406 |
| 17.2 | Mathematical Preliminaries | 406 |
| 17.3 | Normal Boundary Intersection Method | 408 |
| 17.4 | Normalized Normal Constraint Method | 410 |
| 17.5 | Pareto Filter | 416 |
| 17.6 | Examples | 419 |
| 17.7 | Summary | 427 |
| 17.8 | Problems | 427 |
| | Bibliography of Chapter 17 | 428 |
| 18 | Physical Programming for Multiobjective Optimization | 429 |
| 18.1 | Overview | 429 |
| 18.2 | Linear Physical Programming (LPP) | 430 |
| | <i>18.2.1 Classification of Preferences: Soft and Hard</i> | 430 |
| | <i>18.2.2 Ranges of Desirability for Various Classes</i> | 430 |
| | <i>18.2.3 Inter-Criteria Preferences: OVO Rule</i> | 432 |
| | <i>18.2.4 LPP Class Function Definition</i> | 433 |
| | <i>18.2.5 LPP Weight Algorithm</i> | 435 |
| | <i>18.2.6 LPP Problem Formulation</i> | 435 |
| 18.3 | Nonlinear Physical Programming (NPP) | 436 |
| | <i>18.3.1 LPP vs. NPP</i> | 436 |
| | <i>18.3.2 NPP Class Function Definition</i> | 437 |
| | <i>18.3.3 NPP Problem Model</i> | 437 |
| 18.4 | Comparison of LPP with Goal Programming | 439 |
| 18.5 | Numerical Example | 439 |
| | <i>18.5.1 Goal Programming Solution</i> | 442 |
| | <i>18.5.2 Linear Physical Programming Solution</i> | 442 |
| 18.6 | Summary | 443 |
| 18.7 | Problems | 444 |
| | Bibliography of Chapter 18 | 444 |
| 19 | Evolutionary Algorithms | 445 |
| 19.1 | Overview | 445 |
| 19.2 | Genetic Algorithms | 446 |
| | <i>19.2.1 Basics of Genetic Algorithms</i> | 446 |
| | <i>19.2.2 Options in MATLAB</i> | 449 |
| 19.3 | Multiobjective Optimization Using Genetic Algorithms | 451 |
| | <i>19.3.1 Example</i> | 451 |
| 19.4 | Other Evolutionary Algorithms | 453 |
| | <i>19.4.1 Ant Colony Optimization</i> | 454 |
| | <i>19.4.2 Simulated Annealing</i> | 454 |

| | |
|---|-----|
| <i>Contents</i> | xv |
| <i>19.4.3 Tabu Search</i> | 454 |
| <i>19.4.4 Particle Swarm Optimization (PSO)</i> | 455 |
| 19.5 Summary | 455 |
| 19.6 Problems | 455 |
| Bibliography of Chapter 19 | 459 |
| | |
| <i>Author Index</i> | 461 |
| <i>Subject Index</i> | 465 |