CONTENTS

Chapter One THE WAYS OF MODELMAKING: NATURAL SYSTEMS AND FORMAL MATHEMATICAL REPRESENTATIONS

1. A Theory of Models 1
2. States, Observables and Natural Systems 4
3. Equations of State 6
4. Equivalent Descriptions and the Fundamental Question of Modeling ..9
5. Bifurcations and Catastrophes 14
6. Complexity 17
7. Error and Surprise 19
8. Formal Systems 21
9. Modeling Relations 22

Discussion Questions 28
Problems and Exercises 32
Notes and References 36

Chapter Two PATTERN AND THE EMERGENCE OF LIVING FORMS: CELLULAR AUTOMATA AND DISCRETE DYNAMICS

1. Discrete Dynamical Systems 45
2. Cellular Automata: The Basics 47
3. One-Dimensional Cellular Automata 51
4. Local Properties of One-Dimensional Automata 56
5. Global Properties of One-Dimensional Automata 59
6. Algebraic Properties of Additive Cellular Automata 63
7. Languages: Formal and Natural 66

8. DNA Sequences and Cellular Automata 71
9. L-Systems and the Growth of Plants 75
10. Planar Automata and the Game of Life 76
11. Self-Reproducing Automata 80
12. A Cellular Automaton Model of Vertebrate Skin Patterns 84
13. Cellular Automata—Extensions and Generalizations 86
Discussion Questions 88
Problems and Exercises 96
Notes and References 101

Chapter Three THE ANALYTICAL ENGINE: A NEWTONIAN VIEW OF BRAINS, MINDS AND MECHANISMS

1. Brains and Minds 108
2. Input/Output Relations and Dynamical Control Systems 109
3. Behavioral vs. Cognitive Psychology 110
4. Stimulus-Response Patterns and External System Models 111
5. Cognitive States and Internal Models 112
6. Realizations and Canonical Models 113
7. Linear Systems and Canonical Realizations 114
8. A Realization Algorithm 120
9. Partial Realizations 123
10. The State-Space X 125
11. The Cognitive Theorem 127
12. Memory and Behavior 128
13. Thoughts and Group Invariants 130
14. Linearity? 135
Discussion Questions 136
Problems and Exercises 138
Notes and References 143

Chapter Four CATASTROPHES AND LIFE: THE SINGULARITIES OF ECOLOGICAL AND NATURAL RESOURCE SYSTEMS

1. Smoothness and Discontinuity 149
2. Smooth Functions and Critical Points 151
3. Structural Stability and Genericity 152
4. Morse's Lemma and Theorem 156
5. The Splitting Lemma and Corank 160
6. Determinacy and Codimension 162
7. Unfoldings 164
8. The Thom Classification Theorem 168
9. Electric Power Generation 171
10. Bifurcations and Catastrophes 172

11. Harvesting Processes 175
12. Forest Insect Pest Control 179
13. Mappings 182
14. Bifurcation of Vector Fields 186
Discussion Questions 191
Problems and Exercises 198
Notes and References 208

Chapter Five ORDER IN CHAOS: TURBULENCE AND PATTERN IN THE FLOW OF FLUIDS, POPULATIONS AND MONEY

1. Deterministic Mechanisms and Stochastic Behavior 216
2. Dynamical Systems, Flows and Attractors 218
3. Quasi-periodic Trajectories and the KAM Theorem 224
4. A Philosophical Digression: Randomness and Determinism in Dynamical System Modeling 227
5. Scalar Maps and the "Period-3" Theorem 231
6. Tests for Chaos 236
7. Snap-Back Repellors and High-Dimensional Chaos 241
8. Economic Chaos 243
9. Population Fluctuations 244
10. Continuous Chaos and the Lorenz Attractor 247
11. Poincaré Maps and Strange Attractors 249
12. Chaos and the Problem of Turbulence 253
13. Turbulent Behavior in the Spread of Disease 258
Discussion Questions 260
Problems and Exercises 263
Notes and References 273

Chapter Six STRATEGIES FOR SURVIVAL: COMPETITION, GAMES AND THE THEORY OF EVOLUTION

1. Evolutionary Epistemology 281
2. The Neo-Darwinian Paradigm 282
3. Genetic vs. Phenotypic Change 285
4. Game Theory—The Basics 288
5. A Typology of Mixed-Motive Games 292
6. Replicators, Hypercycles and Selection 296
7. Equilibrium Properties of Replicator Systems 299
8. Perseverance of Species in Replicator Systems 301
9. Classification of Replicator Systems 303
10. Game Theory and Replicator Systems 305
11. Desert Plant Root Systems and ESS 306
12. ESS vs. Optimality 309

13. Flowering Times for Plants under Competition 310
14. Sociobiology 313
15. The Evolution of Cooperation 318
Discussion Questions 323
Problems and Exercises 330
Notes and References 341

Chapter Seven TAMING NATURE AND MAN: CONTROL, ANTICIPATION, AND ADAPTATION IN SOCIAL AND BIOLOGICAL PROCESSES

1. Classical Optimal Control Theory 349
2. The Maximum Principle and Open-Loop Control 350
3. Feedback Control and Dynamic Programming 352
4. Anticipatory Systems 355
5. Global Failures and Perfect Subsystems 360
6. A Taxonomy of Adaptive Systems 363
7. Metabolism-Repair Systems 366
8. Linear (M,R)-Systems: Repair 370
9. Linear (M,R)-Systems: Replication 379
10. Cellular Networks and Manufacturing Processes 382
Discussion Questions 387
Problems and Exercises 391
Notes and References 404

Chapter Eight THE GEOMETRY OF HUMAN AFFAIRS: CONNECTIVE STRUCTURE IN ART, LITERATURE AND GAMES OF CHANCE

1. Geometric Paradigms 410
2. Sets and Relations 411
3. Covers and Hierarchies 412
4. Complexes and Connections 416
5. Structure Vectors and Eccentricity 418
6. Complexity 424
7. The Art of M. C. Escher 425
8. Connective Structure in the Work of Mondrian 428
9. Chance and Surprise 432
10. Simplicial Complexes and Dynamical Systems 436
Discussion Questions 438
Problems and Exercises 444
Notes and References 449
Appendix 455

Chapter Nine How Do We Know?: Myths, Models and Paradigms in the Creation of Beliefs

1. Ordering the Cosmos 456
2. Models and Theories 458
3. Paradigms, Revolutions and Normal Science 462
4. Explanations vs. Descriptions 464
5. Predictions, Simulations and Models 466
6. "Good" Models and "Bad" 469
7. Validation and Falsification 471
8. Competition among Models 472
9. Science and Pseudoscience 474
10. Science, Religion and the Nature of Belief Systems 478

Discussion Questions 480
Problems and Exercises 482
Notes and References 482

Index 487