)	Why Agent-Based Modeling? 1	
	A Thought Experiment 3	
	Complex Systems and Emergence 5	
	Understanding Complex Systems and Emergence 7	
	Example 1: Integrative Understanding 7	
	Example 2: Differential Understanding 8	
	Agent-Based Modeling as Representational Infrastructure for Restructurations	13
	Example: Predator-Prey Interactions 15	
	Example: Forest Fires 18	
1	What Is Agent-Based Modeling? 21	
	Ants 21	
	Creating the Ant Foraging Model 22	
	Results and Observations from the Ant Model 27	
	What Good Is an Ant Model? 28	
	What Is Agent-Based Modeling? 32	
	Agent-Based Models vs. Other Modeling Forms 32	
	Randomness vs. Determinism 34	
	When Is ABM Most Beneficial? 35	
	Trade-offs of ABM 36	
	What Is Needed to Understand ABM? 38	
	Conclusion 39	
	Explorations 40	
	Beginner NetLogo Explorations 40	
	Ants and Other Model Explorations 41	
	Concept Explorations 41	
	NetLogo Explorations 42	

2	Life 45
	Simple Economy 87
	Summary 96
	Explorations 97 Chapter Model Explorations 97
	Chapter Model Explorations 97
	NetLogo Explorations 99
3	Exploring and Extending Agent-Based Models 101
	The Fire Model 103
	Description of the Fire Model 104
	First Extension: Probabilistic Transitions 110
	Second Extension: Adding Wind 112
	Third Extension: Allow Long-Distance Transmission 115
	Summary of the Fire Model 116
	Advanced Modeling Applications 117
	The Diffusion-Limited Aggregation (DLA) Model 118
	Description of Diffusion-Limited Aggregation 119
	First Extension: Probabilistic Sticking 121
	Second Extension: Neighbor Influence 122
	Third Extension: Different Aggregates 125
	Summary of the DLA Model 127
	Advanced Modeling Applications 127
	The Segregation Model 128
	Description of the Segregation Model 131
	First Extension: Adding Multiple Ethnicities 134
	Second Extension: Allowing Diverse Thresholds 136
	Third Extension: Adding Diversity-Seeking Individuals 137
	Summary of the Segregation Model 140
	Advanced Urban Modeling Applications 140
	The El Farol Model 141
	Description of the El Farol Model 141
	First Extension: Color Agents That Are More Successful Predictors 143
	Second Extension: Average, Min, and Max Rewards 145
	Third Extension: Histogram Reward Values 146
	Summary of the El Farol Model 149
	Advanced Modeling Applications 150
	Conclusion 152
	Explorations 152

1

AA

1 -

## Creating Agent-Based Models 157 4 Designing Your Model 158 Choosing Your Questions 161 A Concrete Example 163 Choosing Your Agents 164 Choosing Agent Properties 165 Choosing Agent Behavior Choosing Parameters of the Model 168 Summary of the Wolf Sheep Simple Model Design 169 Examining a Model 189 Multiple Runs 191 Predator-Prey Models: Additional Context 193 Advanced Modeling Applications 195 Conclusion 196 Explorations 197 The Components of Agent-Based Modeling 203 5 Overview 203 205 Agents Properties 205 Behaviors (Actions) 209 Collections of Agents 211 The Granularity of an Agent 222

Agent Cognition 224 Other Kinds of Agents 232 Environments 234 Spatial Environments 235 Network-Based Environments 241 Special Environments 247 Interactions 257 Observer/User Interface 262 Schedule 268 Wrapping It All Up 271 Summary 275 Explorations 276

6 Analyzing Agent-Based Models 283
Types of Measurements 283
Modeling the Spread of Disease 283
Statistical Analysis of ABM: Moving beyond Raw Data 287

The Necessity of Multiple Runs within ABM 288
Using Graphs to Examine Results in ABM 291
Analyzing Networks within ABM 296
Environmental Data and ABM 301
Summarizing Analysis of ABMs 305
Explorations 307

## 7 Verification, Validation, and Replication 311

Correctness of a Model 311

Verification 312

Communication 313

Describing Conceptual Models 314

Verification Testing 315

Beyond Verification 317

Sensitivity Analysis and Robustness 321

Verification Benefits and Issues 324

Validation 325

Macrovalidation vs. Microvalidation 329

Face Validation vs. Empirical Validation 331

Validation Benefits and Questions 335

Replication 336

Replication of Computational Models: Dimensions and Standards 337

Benefits of Replication 340

Recommendations for Model Replicators 341

Recommendations for Model Authors 344

Summary 346

Explorations 347

## 8 Advanced Topics and Applications 351

Advanced Topics in ABM 351

Model Design Guidelines 353

Rule Extraction 356

Using ABM for Communication, Persuasion, and Education 369

Human, Embedded, and Virtual Agents through Mediation 372

Hybrid Computational Methods 383

Some Advanced Computational Methods in NetLogo 391

Extensions to ABM 401

Integration of Advanced Data Sources and Output 402

Speed 418

Applications of ABM 419
Revisiting the Trade-offs of ABM 423
The Future of ABM 424
Explorations 425

Appendix: The Computational Roots of Agent-Based Modeling 431

The Vignettes 433

Cellular Automata and Agent-Based Modeling 433

Genetic Algorithms, John Holland, and Complex Adaptive Systems

435

Seymour Papert, Logo, and the Turtle 439

Object-Oriented Programming and the Actor Model 440

Data Parallelism 442

Computer Graphics, Particle Systems, and Boids 443

Conclusion 445

References 447 Software and Models 459 Index 463