

# Contents

## Part I Introduction to Systems Science

<b>1 A Helicopter View</b> .....	3
1.1 Why Systems Science: The State of Knowledge and Understanding .....	3
1.2 The Distinctive Potential of Systems Science.....	6
1.2.1 What Is a Science? .....	7
1.2.2 What Is Systems Science?.....	8
1.3 Systems Science as a Mode of Inquiry .....	10
1.3.1 The Heritage of Atomism.....	10
1.3.2 Holism .....	11
1.3.3 System Causal Dynamics.....	12
1.3.4 Nonlinearity.....	14
1.4 The Principles of Systems Science .....	17
1.4.1 Principles as a Framework .....	17
1.4.2 Principle 1: Systemness.....	20
1.4.3 Principle 2: Systems Are Processes Organized in Structural and Functional Hierarchies.....	22
1.4.4 Principle 3: Systems Are Networks of Relations Among Components and Can Be Represented Abstractly as Such Networks of Relations .....	23
1.4.5 Principle 4: Systems Are Dynamic over Multiple Spatial and Time Scales .....	24
1.4.6 Principle 5: Systems Exhibit Various Kinds and Levels of Complexity .....	25
1.4.7 Principle 6: Systems Evolve.....	26
1.4.8 Principle 7: Systems Encode Knowledge and Receive and Send Information.....	26
1.4.9 Principle 8: Systems Have Regulatory Subsystems to Achieve Stability .....	27

- 1.4.10 Principle 9: Systems Can Contain Models of Other Systems ..... 27
- 1.4.11 Principle 10: Sufficiently Complex, Adaptive Systems Can Contain Models of Themselves ..... 28
- 1.4.12 Principle 11: Systems Can Be Understood (A Corollary of #9)..... 28
- 1.4.13 Principle 12: Systems Can Be Improved (A Corollary of #6)..... 29
- 1.5 The Exposition of Systems Science ..... 30
- 1.6 An Outline History of Systems Science..... 32
  - 1.6.1 Early Twentieth Century ..... 33
  - 1.6.2 Von Bertalanffy’s General Systems Theory ..... 33
  - 1.6.3 Cybernetics (See Chap. 9)..... 34
  - 1.6.4 Information (See Chaps. 7 and 9) ..... 35
  - 1.6.5 Computation (See Chaps. 8 and 9)..... 35
  - 1.6.6 Complex Systems (See Chap. 5)..... 36
  - 1.6.7 Modeling Complex Systems (See Chap. 13) ..... 38
  - 1.6.8 Networks (See Chap. 4) ..... 38
  - 1.6.9 Self-Organization and Evolution (See Chaps. 10 and 11) ..... 39
  - 1.6.10 Autopoiesis (See Chaps. 10 and 11) ..... 40
  - 1.6.11 Systems Dynamics (See Chaps. 6 and 13)..... 40
- Bibliography and Further Reading..... 40

**2 Systems Principles in the Real World: Understanding**

- Drug-Resistant TB ..... 43**
- 2.1 Introduction..... 43
- 2.2 Drug-Resistant TB ..... 44
  - 2.2.1 Systemness: Bounded Networks of Relations Among Parts Constitute a Holistic Unit. Systems Interact with Other Systems. The Universe Is Composed of Systems of Systems ..... 45
  - 2.2.2 Systems Are Processes Organized in Structural and Functional Hierarchies ..... 46
  - 2.2.3 Systems Are Themselves and Can Be Represented Abstractly as Networks of Relations Between Components..... 48
  - 2.2.4 Systems Are Dynamic on Multiple Time Scales..... 49
  - 2.2.5 Systems Exhibit Various Kinds and Levels of Complexity..... 51
  - 2.2.6 Systems Evolve ..... 52
  - 2.2.7 Systems Encode Knowledge and Receive and Send Information..... 54
  - 2.2.8 Systems Have Regulation Subsystems to Achieve Stability ..... 56

- 2.2.9 Systems Contain Models of Other Systems (e.g., Protocols for Interaction up to Anticipatory Models) ..... 58
- 2.2.10 Sufficiently Complex, Adaptive Systems Can Contain Models of Themselves (e.g., Brains and Mental Models) ..... 60
- 2.2.11 Systems Can Be Understood (A Corollary of #9): Science ..... 62
- 2.2.12 Systems Can Be Improved (A Corollary of #6): Engineering ..... 65
- 2.3 Conclusion ..... 68
- Bibliography and Further Reading..... 69

**Part II Structural and Functional Aspects**

- 3 Organized Wholes** ..... 73
  - 3.1 Introduction: Systems, Obvious and Not So Obvious ..... 73
    - 3.1.1 Systems from the Outside ..... 77
    - 3.1.2 Systems from the Inside ..... 79
    - 3.1.3 Systems Thinking ..... 81
  - 3.2 Philosophical Background ..... 82
    - 3.2.1 Ontological Status: Parts and Wholes ..... 82
    - 3.2.2 Epistemological Status: Knowledge and Information..... 84
      - 3.2.2.1 Information ..... 84
      - 3.2.2.2 Knowledge ..... 85
  - 3.3 Properties of Systems..... 89
    - 3.3.1 Wholeness: Boundedness..... 89
      - 3.3.1.1 Boundaries ..... 90
    - 3.3.2 Composition ..... 96
      - 3.3.2.1 Components and Their “Personalities” ..... 97
    - 3.3.3 Internal Organization and Structure ..... 99
      - 3.3.3.1 Connectivity ..... 100
      - 3.3.3.2 Systems Within Systems ..... 108
      - 3.3.3.3 Hierarchical Organization ..... 108
      - 3.3.3.4 Complexity (A Preview) ..... 108
      - 3.3.3.5 Networks (Another Preview) ..... 113
    - 3.3.4 External Organization: System and Environment ..... 116
      - 3.3.4.1 Meaning of Environment ..... 116
    - 3.3.5 System Organization Summary..... 119
  - 3.4 Conception of Systems ..... 119
    - 3.4.1 Conceptual Frameworks..... 122
      - 3.4.1.1 Patterns..... 122
      - 3.4.1.2 Properties and Their Measurement ..... 125
      - 3.4.1.3 Features ..... 127
      - 3.4.1.4 Classification..... 128
    - 3.4.2 Pattern Recognition..... 129
      - 3.4.2.1 Perception in the Human Brain..... 130

- 3.4.2.2 Machine Pattern Recognition ..... 131
- 3.4.2.3 Learning or Encoding Pattern Mappings..... 132
- 3.5 Chapter Summary ..... 134
- Bibliography and Further Reading..... 134
- 4 Networks: Connections Within and Without ..... 137**
- 4.1 Introduction: Everything Is Connected to Everything Else ..... 137
- 4.2 The Fundamentals of Networks ..... 139
  - 4.2.1 Various Kinds of Networks ..... 140
    - 4.2.1.1 Physical Versus Logical..... 140
    - 4.2.1.2 Fixed Versus Changing ..... 142
    - 4.2.1.3 Flow Networks ..... 143
  - 4.2.2 Attributes of Networks ..... 144
    - 4.2.2.1 Size and Composition..... 144
    - 4.2.2.2 Density and Coupling Strength ..... 145
    - 4.2.2.3 Dynamics (Yet Another Preview)..... 145
  - 4.2.3 Organizing Principles..... 147
    - 4.2.3.1 Networks That Grow and/or Evolve..... 147
    - 4.2.3.2 Small World Model ..... 149
    - 4.2.3.3 Hubs ..... 150
    - 4.2.3.4 Power Laws ..... 152
    - 4.2.3.5 Aggregation of Power..... 153
- 4.3 The Math of Networks ..... 154
  - 4.3.1 Graphs as Representations of Networks ..... 154
  - 4.3.2 Networks and the Structure of Systems ..... 156
- 4.4 Networks and Complexity ..... 157
- 4.5 Real-World Examples ..... 157
  - 4.5.1 Biological: A Cellular Network in the Body..... 158
  - 4.5.2 The Earth Ecosystem as a Network of Flows ..... 159
  - 4.5.3 Food Webs in a Local Ecosystem..... 161
  - 4.5.4 A Manufacturing Company as a Network..... 164
- Bibliography and Further Reading..... 168
- 5 Complexity ..... 169**
- 5.1 Introduction: A Concept in Flux ..... 169
- 5.2 What Is Complexity? ..... 170
  - 5.2.1 Intuitions About Complexity..... 172
  - 5.2.2 A Systems Definition of Complexity ..... 173
    - 5.2.2.1 Structural Hierarchy ..... 174
    - 5.2.2.2 Real Hierarchies ..... 183
    - 5.2.2.3 Functional Hierarchy ..... 191
    - 5.2.2.4 Complexity as Depth of a Hierarchical Tree ..... 193
- 5.3 Other Perspectives on Complexity ..... 197
  - 5.3.1 Algorithm-Based Complexity ..... 197
    - 5.3.1.1 Time Complexity of Problems ..... 197
    - 5.3.1.2 Algorithmic Information Complexity ..... 200

- 5.3.2 Complexity of Behavior ..... 200
  - 5.3.2.1 Cellular Automata ..... 200
  - 5.3.2.2 Fractals and Chaotic Systems ..... 201
- 5.4 Additional Considerations on Complexity ..... 202
  - 5.4.1 Unorganized Versus Organized ..... 203
  - 5.4.2 Potential Versus Realized Complexity Parameters ..... 203
- 5.5 Limits of Complexity ..... 204
  - 5.5.1 Component Failures ..... 205
  - 5.5.2 Process Resource or Sink Failures ..... 206
  - 5.5.3 Systemic Failures: Cascades ..... 207
    - 5.5.3.1 Aging ..... 207
    - 5.5.3.2 Collapse of Complex Societies ..... 207
- 5.6 Summary of Complexity ..... 212
- Bibliography and Further Reading ..... 212
- 6 Behavior: System Dynamics ..... 213**
  - 6.1 Introduction: Changes ..... 213
  - 6.2 Kinds of Dynamics ..... 219
    - 6.2.1 Motion and Interactions ..... 219
    - 6.2.2 Growth or Shrinkage ..... 220
    - 6.2.3 Development or Decline ..... 221
    - 6.2.4 Adaptivity ..... 222
  - 6.3 Perspectives on Behavior ..... 223
    - 6.3.1 Whole System Behavior: Black Box Analysis ..... 224
    - 6.3.2 Subsystem Behaviors: White Box Analysis ..... 225
  - 6.4 Systems as Dynamic Processes ..... 226
    - 6.4.1 Energy and Work ..... 226
    - 6.4.2 Thermodynamics ..... 227
      - 6.4.2.1 Energy Gradients ..... 228
      - 6.4.2.2 Entropy ..... 228
      - 6.4.2.3 Efficiency ..... 229
    - 6.4.3 Process Description ..... 234
    - 6.4.4 Black Box Analysis: Revisited ..... 236
    - 6.4.5 White Box Analysis Revisited ..... 237
    - 6.4.6 Process Transformations ..... 239
      - 6.4.6.1 Equilibrium ..... 240
      - 6.4.6.2 Systems in Transition ..... 240
      - 6.4.6.3 Systems in Steady State ..... 241
      - 6.4.6.4 Systems Response to Disturbances ..... 242
      - 6.4.6.5 Messages, Information, and Change  
(One More Preview) ..... 246
      - 6.4.6.6 Process in Conceptual Systems ..... 248
      - 6.4.6.7 Predictable Unpredictability: Stochastic  
Processes ..... 249
      - 6.4.6.8 Chaos ..... 251

- 6.5 An Energy System Example ..... 256
  - 6.5.1 An Initial Black Box Perspective ..... 256
  - 6.5.2 Opening Up the Box..... 256
  - 6.5.3 How the System Works ..... 258
  - 6.5.4 So What? ..... 259
- 6.6 Summary of Behavior ..... 260
- Bibliography and Further Reading..... 261

**Part III The Intangible Aspects of Organization: Maintaining and Adapting**

- 7 Information, Meaning, Knowledge, and Communications** ..... 265
  - 7.1 Introduction: What Is in a Word?..... 265
  - 7.2 What Is Information? ..... 267
    - 7.2.1 Definitions ..... 271
      - 7.2.1.1 Communication ..... 271
      - 7.2.1.2 Message ..... 271
      - 7.2.1.3 Sender..... 272
      - 7.2.1.4 Receiver..... 272
      - 7.2.1.5 Observer ..... 272
      - 7.2.1.6 Channel..... 273
      - 7.2.1.7 Signal..... 274
      - 7.2.1.8 Noise..... 274
      - 7.2.1.9 Codes..... 274
      - 7.2.1.10 Protocols and Meaning..... 276
      - 7.2.1.11 Data ..... 277
  - 7.3 Information Dynamics ..... 278
    - 7.3.1 Information and Entropy ..... 280
    - 7.3.2 Transduction, Amplification, and Information Processes ..... 283
    - 7.3.3 Surprise! ..... 289
      - 7.3.3.1 Modifying Expectations: An Introduction to Adaptation and Learning ..... 290
      - 7.3.3.2 Adaptation as a Modification in Expectancies..... 291
      - 7.3.3.3 Internal Work in the Receiver..... 295
  - 7.4 What Is Knowledge?..... 297
    - 7.4.1 Context ..... 299
    - 7.4.2 Decision Processes ..... 301
      - 7.4.2.1 Decision Trees ..... 301
      - 7.4.2.2 Game Theory ..... 302
      - 7.4.2.3 Judgment ..... 302
    - 7.4.3 Anticipatory Systems ..... 303
  - 7.5 Summary of Information, Learning, and Knowledge: Along with a Surprising Result..... 307
  - Bibliography and Further Reading..... 309

- 8 Computational Systems** ..... 311
  - 8.1 Computational Process..... 311
    - 8.1.1 A Definition of Computation ..... 313
  - 8.2 Types of Computing Processes ..... 316
    - 8.2.1 Digital Computation Based on Binary Elements ..... 316
    - 8.2.2 Electronic Digital Computers..... 318
    - 8.2.3 Probabilistic Heuristic Computation..... 328
    - 8.2.4 Adaptive, “Fuzzy” Heuristic Computation ..... 331
    - 8.2.5 Biological Brain Computation ..... 333
      - 8.2.5.1 Neural Computation ..... 334
      - 8.2.5.2 Neuronal Network Computation ..... 339
      - 8.2.5.3 Other Biological Computations..... 347
  - 8.3 Purposes of Computation..... 347
    - 8.3.1 Problem Solving..... 347
      - 8.3.1.1 Mathematical Problems..... 348
      - 8.3.1.2 Path Finding ..... 349
      - 8.3.1.3 Translation..... 350
      - 8.3.1.4 Pattern Matching (Identification) ..... 351
    - 8.3.2 Data Capture and Storage..... 352
    - 8.3.3 Modeling ..... 353
  - 8.4 Summary: The Ultimate Context of Computational Processes ..... 356
  - Bibliography and Further Reading..... 358
  
- 9 Cybernetics: The Role of Information and Computation in Systems** ..... 359
  - 9.1 Introduction: Complex Adaptive Systems and Internal Control ..... 359
  - 9.2 Inter-system Communications ..... 361
    - 9.2.1 Communications and Cooperation..... 361
    - 9.2.2 Informational Transactions..... 363
    - 9.2.3 Markets as Protocols for Cooperation..... 365
  - 9.3 Formal Coordination Through Hierarchical Control Systems: Cybernetics ..... 366
    - 9.3.1 Hierarchical Control Model Preview ..... 368
  - 9.4 Basic Theory of Control..... 369
    - 9.4.1 Open Loop Control ..... 370
    - 9.4.2 Closed-Loop Control: The Control Problem..... 370
  - 9.5 Factors in Control ..... 374
    - 9.5.1 Temporal Considerations ..... 375
      - 9.5.1.1 Sampling Rates and Time Scales ..... 375
      - 9.5.1.2 Sampling Frequency and Noise Issues ..... 378
      - 9.5.1.3 Computation Delay ..... 381
      - 9.5.1.4 Reaction Delay ..... 382
      - 9.5.1.5 Synchronization..... 383
    - 9.5.2 Oscillations..... 383
    - 9.5.3 Stability ..... 384

9.6	Control Computations .....	385
9.6.1	PID Control .....	385
9.6.1.1	PID in Social Systems.....	389
9.6.1.2	Information Feed-Forward.....	390
9.6.1.3	Multiple Parameter Algorithms.....	391
9.6.2	Systemic Costs of Non-control Versus Costs of Control.....	392
9.6.3	More Advanced Control Methods.....	393
9.6.3.1	Adaptive Control: The “A” in CAS.....	394
9.6.3.2	Anticipatory Control .....	399
9.6.4	Summary of Operational Control.....	403
9.7	Coordination Among Processes .....	404
9.7.1	From Cooperation to Coordination .....	406
9.7.2	Coordination Between Processes: Logistical Control.....	407
9.7.2.1	A Basic Logistic Controller: Distribution of Resources via Budgets.....	410
9.7.2.2	Modeling Process Matching and Coordinated Dynamics.....	412
9.7.2.3	Regulating Buffers .....	413
9.7.2.4	Regulating Set Points.....	414
9.7.2.5	Coordinating Maintenance.....	415
9.7.2.6	Time Scales for Coordination .....	416
9.7.2.7	Process Control of the Coordination Process and the Coordination of Coordination!.....	416
9.7.3	Interface with the Environment: Tactical Control.....	419
9.7.3.1	Interface Processes.....	419
9.7.3.2	Active and Passive Interfaces.....	420
9.7.3.3	The Use of Feed-Forward Information .....	421
9.7.3.4	Coordination with External Entities.....	422
9.7.4	Summary of Coordination and Its Relation to Operations.	423
9.8	Strategic Management .....	424
9.8.1	The Basic Strategic Problem.....	425
9.8.2	Basic Solutions.....	429
9.8.3	Environmental and Self-Models.....	430
9.8.4	Exploration Versus Exploitation.....	432
9.8.5	Plans (or Actually, Scenarios and Responses).....	433
9.8.6	Summary of Coordination and Strategic Management.....	433
9.9	The Control Hierarchy .....	435
9.9.1	Hierarchical Management .....	437
9.9.1.1	Examples of Hierarchical Management in Nature and Human-Built Organizations .....	437
9.10	Problems in Hierarchical Management.....	440
9.10.1	Environmental Overload .....	440
9.10.1.1	Information Overload.....	441



- 9.10.1.2 Force Overload..... 443
- 9.10.1.3 Resource Loss ..... 444
- 9.10.2 Internal Breakdown ..... 445
  - 9.10.2.1 Entropic Decay..... 445
  - 9.10.2.2 Point Mutations..... 446
- 9.10.3 Imperfect Components ..... 447
  - 9.10.3.1 Stochastic Components..... 447
  - 9.10.3.2 Heuristic Components..... 448
  - 9.10.3.3 Internally Motivated Agents..... 448
- 9.10.4 Evolving Control Systems..... 449
- 9.11 Summary of Cybernetics..... 453
- Bibliography and Further Reading..... 454

**Part IV Evolution**

- 10 Auto-Organization and Emergence..... 461**
  - 10.1 Introduction: Toward Increasing Complexity ..... 461
  - 10.2 The Basic and General Features of Increasing Organization Over Time..... 463
    - 10.2.1 Definitions ..... 464
      - 10.2.1.1 Order and Organization (or Order Versus Organization!) ..... 464
      - 10.2.1.2 Levels of Organization..... 465
      - 10.2.1.3 Adaptation..... 468
      - 10.2.1.4 Fit and Fitness ..... 469
    - 10.2.2 Evolution as a Kind of Algorithm ..... 473
    - 10.2.3 Increasing Complexity Through Time ..... 475
    - 10.2.4 No Free Lunch! ..... 477
  - 10.3 Auto-Organization ..... 478
    - 10.3.1 The Organizing Process ..... 479
    - 10.3.2 The Principles of Auto-Organizing Processes..... 484
      - 10.3.2.1 Energy Partitioning ..... 485
      - 10.3.2.2 Energy Transfer..... 486
      - 10.3.2.3 Cycles..... 486
      - 10.3.2.4 Chance and Circumstances ..... 487
      - 10.3.2.5 Concentrations and Diffusion ..... 488
      - 10.3.2.6 Dissociation..... 488
      - 10.3.2.7 Higher-Order Principles..... 489
    - 10.3.3 Organizing, Reorganizing, and Stable Physical/Linkage Cycles ..... 493
      - 10.3.3.1 Order from Chaos ..... 493
      - 10.3.3.2 Selection of Minimum Energy Configurations..... 494
      - 10.3.3.3 Hyper-Cycles and Autocatalysis ..... 497
      - 10.3.3.4 Self-Assembly..... 500
      - 10.3.3.5 Auto-Organization and Selective Pressure..... 501
  - 10.3.4 Auto-Organization Exemplified in Social Dynamics..... 502

- 10.4 Emergence..... 504
  - 10.4.1 Emergent Properties ..... 505
    - 10.4.1.1 The Molecular Example..... 506
  - 10.4.2 Emergent Functions ..... 507
    - 10.4.2.1 An Example from Society: Money ..... 507
  - 10.4.3 Cooperation and Competition as Emergent Organizing Principles..... 508
  - 10.4.4 Emergent Complexity ..... 511
  - 10.4.5 The Emergence of Life..... 512
  - 10.4.6 Supervenience and the Emergence of Culture ..... 516
    - 10.4.6.1 Language..... 516
    - 10.4.6.2 Tool Making..... 519
- 10.5 Summary of Emergence..... 524
- Bibliography and Further Reading..... 524
- 11 Evolution..... 527**
  - 11.1 Beyond Adaptation..... 527
  - 11.2 Evolution as a Universal Principle..... 528
    - 11.2.1 The Environment Always Changes ..... 529
    - 11.2.2 Progress: As Increase in Complexity ..... 531
    - 11.2.3 The Mechanisms of Progressivity ..... 533
    - 11.2.4 Evolvability ..... 536
    - 11.2.5 Evolution as a Random Search Through Design Space..... 537
    - 11.2.6 Biological and Supra-biological Evolution: The Paradigmatic Case..... 539
    - 11.2.7 How Auto-Organization and Emergence Fit into the Models of Biological and Supra-biological Evolution..... 539
  - 11.3 Replication ..... 541
    - 11.3.1 Knowledge Representations of Systems ..... 543
    - 11.3.2 Autonomous Replication..... 545
      - 11.3.2.1 The Knowledge Medium in Biological and Supra-biological Systems..... 546
      - 11.3.2.2 Copying Knowledge Structures: The Biological Example ..... 549
      - 11.3.2.3 Copying Knowledge Structures: The Supra-biological Example ..... 551
  - 11.4 Descent with Modification ..... 552
    - 11.4.1 Mutations: One Source of Variation..... 554
    - 11.4.2 Mixing..... 555
    - 11.4.3 Epigenetics ..... 556
  - 11.5 Selection..... 557

- 11.5.1 Competition..... 560
- 11.5.2 Cooperation ..... 561
- 11.5.3 Coordination..... 565
- 11.5.4 Environmental Factors ..... 567
- 11.6 Coevolution: The Evolution of Communities ..... 568
  - 11.6.1 The Coevolution of Ecosystems..... 569
  - 11.6.2 The Coevolution of Culture..... 570
  - 11.6.3 A Coevolutionary Model of Social-Cultural Process..... 572
    - 11.6.3.1 Social Evolution..... 575
    - 11.6.3.2 Society’s Fit with the Environment..... 578
- 11.7 Summary of Evolution..... 584
- Bibliography and Further Reading..... 585

**Part V Methodological Aspects**

- 12 Systems Analysis ..... 589**
  - 12.1 Introduction: Metascience Methodology ..... 589
  - 12.2 Gaining Understanding ..... 590
    - 12.2.1 Understanding Organization ..... 591
    - 12.2.2 Understanding Complexity ..... 591
    - 12.2.3 Understanding Behaviors (Especially Nonlinear)..... 592
    - 12.2.4 Understanding Adaptability ..... 592
    - 12.2.5 Understanding Persistence ..... 592
    - 12.2.6 Understanding Forming and Evolving Systems..... 593
    - 12.2.7 Cautions and Pitfalls ..... 593
  - 12.3 Decomposing a System..... 595
    - 12.3.1 Language of System Decomposition ..... 596
      - 12.3.1.1 Lexical Elements..... 596
      - 12.3.1.2 Uses in Decomposition ..... 600
    - 12.3.2 A Top-Down Process..... 603
      - 12.3.2.1 Tools for Decomposition: Microscopes ..... 603
      - 12.3.2.2 Scale, Accuracy, and Precision  
of Measurements ..... 604
    - 12.3.3 Composition Hierarchy ..... 604
    - 12.3.4 Structural and Functional Decomposition..... 606
      - 12.3.4.1 The System of Interest: Starting the Process .. 607
      - 12.3.4.2 Decomposing Level 0 ..... 607
    - 12.3.5 System Knowledge Base..... 611
    - 12.3.6 The Structural Hierarchy (So Far)..... 611
    - 12.3.7 Specifics Regarding Flows, Interfaces, and the Objects  
of Interest ..... 612
    - 12.3.8 Where We Are Now..... 613
    - 12.3.9 Recursive Decomposition ..... 614
      - 12.3.9.1 When to Stop Decomposition ..... 616
      - 12.3.9.2 Tree Balance (or Not) ..... 619

12.3.10	Open Issues, Challenges, and Practice .....	619
12.3.10.1	Recognizing Boundaries for Subsystems .....	620
12.3.10.2	Adaptable and Evolvable Systems .....	620
12.3.11	The Final Products of Decomposition.....	622
12.4	Life Cycle Analysis.....	623
12.5	Modeling a System .....	624
12.5.1	Modeling Engine.....	625
12.5.1.1	System Representation.....	627
12.5.1.2	Time Steps.....	627
12.5.1.3	Input Data.....	628
12.5.1.4	Instrumentation and Data Output Recording .....	628
12.5.1.5	Graphing the Results.....	628
12.5.2	The System Knowledge Base Is the Model! .....	629
12.5.3	Top-Down Model Runs and Decomposition.....	629
12.6	Examples.....	630
12.6.1	Cells and Organisms.....	630
12.6.2	Business Process .....	632
12.6.3	Biophysical Economics.....	635
12.6.4	Human Brain and Mind.....	637
12.7	Summary of Systems Analysis.....	643
	Bibliography and Further Reading.....	644
<b>13</b>	<b>Systems Modeling.....</b>	<b>645</b>
13.1	Introduction: Coming to a Better Understanding.....	645
13.1.1	Models Contained in Systems.....	647
13.1.2	What Is a Model? .....	648
13.1.3	Deeper Understanding.....	650
13.2	General Technical Issues.....	651
13.2.1	Resolution .....	651
13.2.2	Accuracy and Precision.....	652
13.2.3	Temporal Issues.....	653
13.2.4	Verification and Validation .....	653
13.2.5	Incremental Development .....	654
13.3	A Survey of Models .....	654
13.3.1	Kinds of Systems and Their Models .....	655
13.3.1.1	Physical.....	655
13.3.1.2	Mathematical.....	655
13.3.1.3	Statistical.....	656
13.3.1.4	Computerized (Iterated Solutions).....	657
13.3.2	Uses of Models.....	658
13.3.2.1	Prediction of Behavior .....	658
13.3.2.2	Scenario Testing.....	659
13.3.2.3	Verification of Understanding.....	659

	13.3.2.4	Design Testing.....	660
	13.3.2.5	Embedded Control Systems.....	660
13.4		A Survey of Systems Modeling Approaches .....	661
	13.4.1	System Dynamics.....	661
	13.4.1.1	Background.....	661
	13.4.1.2	Strengths of System Dynamics.....	664
	13.4.1.3	Limitations of Stock and Flow.....	664
	13.4.2	Agent-Based Modeling .....	666
	13.4.2.1	Background.....	666
	13.4.2.2	Modeling Framework.....	666
	13.4.2.3	Definitions.....	668
	13.4.2.4	Emergence of Macrostructures and Behaviors.....	676
	13.4.2.5	Strengths of Agent-Based Modeling.....	676
	13.4.2.6	Limitations of Agent-Based Modeling.....	677
	13.4.3	Operations Research: An Overview .....	677
	13.4.3.1	Strengths of OR.....	680
	13.4.3.2	Weaknesses of OR .....	680
	13.4.4	Evolutionary Models.....	681
	13.4.4.1	Evolutionary Programming/Genetic Algorithms .....	681
	13.4.4.2	Artificial Life .....	682
13.5		Examples.....	682
	13.5.1	Modeling Population Dynamics with System Dynamics.....	682
	13.5.1.1	The Model Diagram.....	683
	13.5.1.2	Converting the Diagram to Computer Code .....	683
	13.5.1.3	Getting the Output Graphed.....	684
	13.5.1.4	Discussion.....	685
	13.5.2	Modeling Social Insect Collective Intelligence .....	686
	13.5.3	Biological Neurons: A Hybrid Agent-Based and System Dynamic Model .....	687
13.6		Summary of Modeling.....	695
	13.6.1	Completing Our Understanding .....	695
	13.6.2	Postscript: An Ideal Modeling Approach .....	696
		Bibliography and Further Reading.....	698
<b>14</b>		<b>Systems Engineering.....</b>	<b>699</b>
	14.1	Introduction: Crafting Artifacts to Solve Problems .....	699
	14.1.1	Problems to Be Solved.....	700
	14.1.2	Affordance.....	701
	14.1.3	Invention.....	701
	14.1.4	Abstract Thinking.....	702

14.1.5	Crafting by Using Language, Art, and Mathematical Relations.....	702
14.1.5.1	Engineering and Science: Relations.....	703
14.1.5.2	Mathematics in Engineering .....	704
14.2	Problem Solving.....	704
14.2.1	Defining “Problem”.....	705
14.2.1.1	Definition .....	705
14.2.2	Modern Problems .....	706
14.2.3	Enter the Engineering of Systems .....	707
14.2.3.1	Role of the Systems Engineer .....	708
14.3	The System Life Cycle.....	709
14.3.1	Prenatal Development and Birth .....	710
14.3.2	Early Development.....	711
14.3.3	Useful Life: Maturing .....	711
14.3.4	Senescence and Obsolescence.....	712
14.3.5	Death (Decommissioning) .....	713
14.4	The Systems Engineering Process .....	714
14.4.1	Needs Assessment: The Client Role .....	716
14.4.2	Systems Analysis for Artifacts to be Developed .....	718
14.4.2.1	Problem Identification.....	718
14.4.2.2	Problem Analysis .....	720
14.4.2.3	Solution Analysis .....	721
14.4.2.4	Solution Design.....	724
14.4.2.5	Solution Construction .....	724
14.4.2.6	Solution Testing .....	726
14.4.2.7	Solution Delivery (Deployment).....	726
14.4.2.8	Monitor Performance .....	726
14.4.2.9	Evaluate Performance .....	727
14.4.2.10	Performance Discrepancy Analysis .....	727
14.4.2.11	Upgrade/Modification Decision.....	728
14.4.3	Process Summary .....	729
14.5	Systems Engineering in the Real World.....	730
	Bibliography and Further Reading.....	731
	<b>Index.....</b>	<b>733</b>



<http://www.springer.com/978-1-4939-1919-2>

Principles of Systems Science

Mobus, G.E.; Kalton, M.C.

2015, XXXVI, 755 p. 199 illus., 163 illus. in color.,

Hardcover

ISBN: 978-1-4939-1919-2