# Contents

Preface IX

1	Introduction to the Field of Self-Organization 1
1.1	Basic Concepts 1
1.2	History of Evolution as a Short Story 6
1.3	Structure, Self-organization, and Complexity 14
1.4	Entropy, Equilibrium, and Nonequilibrium 17
1.5	Dynamics, Stability, and Instability 25
1.6	Self-Organization of Information and Values 28
2	Fundamental Laws of Equilibrium and Nonequilibrium
	Thermodynamics 35
2.1	The Thermodynamic Way of Describing Nature – Basic
	Variables 35
2.2	Three Fundamental Laws and the Gibbs Relation
	of Thermodynamics 45
2.3	Thermodynamic Potentials, Inequalities, and Variational
	Principles 55
2.4	Irreversible Processes and Self-Organization 63
2.5	Irreversible Radiation Transport 70
2.6	Irreversible Processes and Fluctuations 76
2.7	Toward a Thermodynamics of Small Systems Far
	from Equilibrium 80
3	Evolution of Earth and the Terrestrial Climate 85
3.1	The Photon Mill 88
3.2	Black-Body Radiation Model of Earth 91
3.3	Local Seasonal Response 99
3.4	Atmospheric Cooling Rate 104
3.5	Black-Body Model with Atmosphere 106

v

VI Contents

Contents	
3.6	Humidity and Latent Heat 110
3.7	Greenhouse Effect 119
3.8	Spatial Structure of the Planet 124
3.9	Early Evolution of Earth 149
4	Nonlinear Dynamics, Instabilities, and Fluctuations 163
4.1	State Space, Dynamic Systems, and Graphs 163
4.2	Deterministic Dynamic Systems 168
4.3	Stochastic Models for Continuous Variables and Predictability 177
4.4	Graphs – Mathematical Models of Structures and Networks 187
4.5	Stochastic Models for Discrete Variables 194
4.6	Stochastic Processes on Networks 200
5	Self-Reproduction, Multistability, and Information Transfer
51	The Pole of Solf Poproduction and Multistability 211
J.1 5 つ	Deterministic Models of Self Perroduction and Pistshility 211
J.Z 5 3	Stochastic Theory of Birth and Death Processes 218
5.5 5 1	Stochastic Analyzig of the Survival of the New 222
5.4	Survival of the New in Bistable Systems 226
5.5 5.6	Multistability Information Storage and Information Transfer 230
5.0	Multistability, information Storage, and information fransier 250
6	Competition and Selection Processes 237
6.1	Discussion of Basic Terms 237
6.2	Extremum Principles 241
6.3	Dynamical Models with Simple Competition 244
6.4	Stochastic of Simple Competition Processes 253
6.5	Competition in Species Networks 264
6.6	Selection and Coexistence 278
6.7	Hyperselection 284
6.8	Selection in Ecological Systems 288
6.9	Selection with Sexual Replication 297
6.10	Selection between Microreactors 301
6.11	Selection in Social Systems 306
7	Models of Evolution Processes 311
7.1	Sequence-Evolution Models 314
7.2	Evolution on Fitness Landscapes 319
7.3	Evolution on Smooth Fisher–Eigen Landscapes 321
7.4	Evolution on Random Fisher–Eigen Landscapes 328
7.5	Evolution on Lotka–Volterra Landscapes 333
7.6	Axiomatic Evolution Models 340
7.7	Boolean Behavior in the Positive Cone 342
7.8	Axiomatic Description of a Boolean Reaction System 349
7.9	Reducible, Linear, and Ideal Boolean Reaction Systems 352

- 7.10 Minor and Major of a Boolean Reaction System 355
- 7.11 Selection and Evolution in Boolean Reaction Systems 356

# 8 Self-Organization of Information and Symbols 363

- 8.1 Symbolic Information 364
- 8.2 Structural Information 368
- 8.3 Extracting Structural Information 371
- 8.4 Physical Properties of Symbols 375
- 8.5 Properties of the Ritualization Transition 381
- 8.6 Genetic Code 384
- 8.7 Sexual Recombination 390
- 8.8 Morphogenesis 392
- 8.9 Neuronal Networks 396
- 8.10 Spoken Language 402
- 8.11 Possession 405
- 8.12 Written Language 406
- 8.13 Money 409

# 9 On the Origin of Life 413

- 9.1 Catalytic Cascades in Underoccupied Networks 415
- 9.2 Formation of Spatial Compartments 418
- 9.3 Replicating Chain Molecules 421
- 9.4 Molecular Information Processing 428
- 9.5 Darwinian Evolution 433

# **10 Conclusion and Outlook** 441

- 10.1 Basic Physical Concepts and Results 441
- 10.2 Quo Vadis Evolutio? 447

#### References 453

Index 501