Contents

Preface *page* ix

1 The Potential of Universal Biology: Is There a Universal Nature of Life? 1
- 1.1 Introduction 1
- 1.2 Universal Nature of Life 2
- 1.3 Characteristic Features of Life 5
- 1.4 Macroscopic Theory for a Living State 12
- 1.5 View of Biocomplex Systems: Dynamic Consistency between Macro-Micro Levels 25
- 1.6 Outline 30

2 Methodology in Universal Biology 31
- 2.1 Introduction 31
- 2.2 Brief Description of Dynamical Systems Approach 31
- 2.3 Formation of Types as a Consequence of Consistency 33
- 2.4 A: Macroscopic Phenomenology 37
- 2.5 B: Statistical Laws of Consistency from Microscopic Side–Statistical Law in a Multi-component System 38
- 2.6 C: Macro-Micro Consistency 43
- 2.7 D: Consistency among Processes across Hierarchy of Time Scales 51
- 2.8 E: Experimental Approaches 55
- 2.9 F: Collapse of Consistency and Recovery of Plasticity 59
- 2.10 Summary 60

3 Reproduction of Cells: Dynamic and Thermodynamic Characteristics, Dormancy, Fluctuation, and Requisites of Protocells 61
3.1 Introduction 61
3.2 Macroscopic Phenomenology of Growing Cells (A) 65
3.3 Distribution Laws and Macroscopic Variables in Catalytic Reaction Networks (B and C) 71
3.4 Transition to Dormant State: Emergence of Slow Dynamics with the Collapse of Consistency (D and F) 73
3.5 Experimental Approaches: Growth Rate, Division Time and Fluctuation Law of Component Concentrations (E) 80
3.6 Basic Questions on the Origin and Construction of Protocells: Parasites, Central Dogma between Functional and Information Molecules, and Origin of Heredity 89
3.7 Summary: Universal Properties and Laws Discussed in This Chapter 102

4 Generic Adaptation of Cells: Attractor Selection, Stochasticity, and Consistency 103
4.1 Introduction 103
4.2 Phenomenology of General Adaptation by Activity and Fluctuation (A) 105
4.3 Example of Attractor Selection with a Two-Component System (B and E) 108
4.4 Confirmation by a Many-Component Model (B and C) 113
4.5 Significance of Noise to Cellular Adaptation (E) 117
4.6 Possible Extension of Attractor Selection for the Verification in Cells in Nature (E) 122
4.7 State Selection by Time-Scale Interference (D) 125
4.8 Collapse of Consistency: Adaptation Processes to a Novel Environment (F) 127
4.9 Summary: Universal Properties Discussed in This Chapter 127
4.10 Appendix: Gene Expression Network Model 128

5 Adaptation and Cellular Homeostasis 130
5.1 Introduction 130
5.2 Adaptation Model with Few Components: Phenomenology (A) 133
5.3 Microscopic Large-Degree-of-Freedom Model of Adaptation (B) 135
5.4 Homeostasis of Biological Clock (D) 146
5.5 Collapse of Consistency in Adaptation 153

5.6 Summary: Universal Properties and Laws Discussed in This Chapter 154
5.7 Appendix: Mathematical Analysis 155

6 Cellular Memory 157
6.1 Introduction 157
6.2 Kinetic Memory Theory with Enzyme Competitive Rates (B and D) 164
6.3 Glass-like Behavior in Chemical Reaction Networks (C and D) 167
6.4 Epigenetic Fixation to Slower Time Scales (C and D) 173
6.5 Biological Significance of Kinetic Memory and Experimental Verification (E) 177
6.6 Summary: Universal Properties Discussed in This Chapter 179
6.7 Appendix: Chain Modification Model for Kinetic Memory 180

7 Cell Differentiation through Development 181
7.1 Introduction 181
7.2 Possibility in Macroscopic Phenomenological Theory (A and E) 183
7.3 Tissue Construction Experiments from Undifferentiated Cells (A and E) 186
7.4 Coupled Dynamical Systems for Cell Differentiation (B, C, and E) 190
7.5 Epigenetic Fixation (D) 203
7.6 Cellular Reprogramming: Operation to Reverse the Irreversibility (C–E) 206
7.7 Collapse of Consistency: Metamorphosis and Cancer (F) 211
7.8 Summary: Universal Properties Discussed in the Present Chapter 214

8 Evolution of Phenotypic Plasticity and Robustness in Terms of Phenotypic Fluctuations 216
8.1 Introduction 216
8.2 Evolutionary Fluctuation–Response Relationship (A–C and E) 221
8.3 Relationship between Genetic and Developmental Robustness: V_g–V_{ip} Law (A–C and E) 228
8.4 Evolution to Sustain Plasticity and Fluctuations (C and F) 247
8.5 Summary: Universal Properties and Laws Discussed in This Chapter 258

9 Direction and Constraint in Phenotypic Evolution: Dimensional Reduction and Global Proportionality in Phenotype Fluctuation and Responses 261
9.1 Introduction 261
9.2 Global Proportional Changes in Gene Expression beyond the Simple Theory (C and E) 263
9.3 Emergence of Global Proportionality through Evolution: Formation of a Dominant Mode (C) 267
9.4 Evolutionary Dimensional Reduction Hypothesis (C) 273
9.5 Global Proportionality between Responses by Environmental and Evolutionary Adaptations (C–E) 277
9.6 Proportionality between Phenotypic Variance by Noise and by Genetic Changes across Components (C) 284
9.7 Evolution of Slow Mode (D) 287
9.8 Universality of Dimensional Reduction (C and E) 288
9.9 Toward Statistical Physics Theory for Evolutionary Dimensional Reduction 292
9.10 Collapse of Consistency in Dormant State? (F) 293
9.11 Summary: Universal Laws Discussed in this Chapter 294
9.12 Appendix: Potential Theory 295

10 Summary and Future Issues 298
10.1 Introduction 298
10.2 Origin Problems 300
10.3 Ecosystem 309
10.4 Evolution–Development Relationship 311
10.5 Memory, Cognition, and Neural Dynamics 317
10.6 Toward "Universal Theory" for Universal Biology 321

References 327
Index 343