

# Bio-Inspired Artificial Intelligence

## Theories, Methods, and Technologies

Dario Floreano  
Claudio Mattiussi

The MIT Press  
Cambridge, Massachusetts  
London, England

# Contents

*Preface*      xi

*Acknowledgments*      xiii

<b>1</b>	<b><i>Evolutionary Systems</i></b>	<b>1</b>
1.1	Pillars of Evolutionary Theory	2
1.2	The Genotype	5
1.3	Artificial Evolution	13
1.4	Genetic Representations	16
1.5	Initial Population	21
1.6	Fitness Functions	22
1.7	Selection and Reproduction	23
1.8	Genetic Operators	26
1.9	Evolutionary Measures	29
1.10	Types of Evolutionary Algorithms	33
1.11	Schema Theory	37
1.12	Human-Competitive Evolution	39
1.13	Evolutionary Electronics	42
1.14	Lessons from Evolutionary Electronics	43
1.15	The Role of Abstraction	45
1.16	Analog and Digital Circuits	49
1.17	Extrinsic and Intrinsic Evolution	53
1.18	Digital Design	58
1.19	Evolutionary Digital Design	62
1.20	Analog Design	77
1.21	Evolutionary Analog Design	79
1.22	Multiple Objectives and Constraints	85

1.23	Design Verification	90
1.24	Closing Remarks	92
1.25	Suggested Readings	97
<b>2</b>	<b><i>Cellular Systems</i></b>	<b>101</b>
2.1	The Basic Ingredients	101
2.2	Cellular Automata	107
2.3	Modeling with Cellular Systems	110
2.4	Some Classic Cellular Automata	118
2.5	Other Cellular Systems	124
2.6	Computation	134
2.7	Artificial Life	138
2.8	Complex Systems	145
2.9	Analysis and Synthesis of Cellular Systems	153
2.10	Closing Remarks	159
2.11	Suggested Readings	160
<b>3</b>	<b><i>Neural Systems</i></b>	<b>163</b>
3.1	Biological Nervous Systems	167
3.2	Artificial Neural Networks	175
3.3	Neuron Models	177
3.4	Architecture	189
3.5	Signal Encoding	191
3.6	Synaptic Plasticity	196
3.7	Unsupervised Learning	198
3.8	Supervised Learning	219
3.9	Reinforcement Learning	235
3.10	Evolution of Neural Networks	238
3.11	Neural Hardware	250
3.12	Hybrid Neural Systems	256
3.13	Closing Remarks	261
3.14	Suggested Readings	265
<b>4</b>	<b><i>Developmental Systems</i></b>	<b>269</b>
4.1	Potential Advantages of a Developmental Representation	270
4.2	Rewriting Systems	272
4.3	Synthesis of Developmental Systems	296
4.4	Evolution and Development	298
4.5	Defining Artificial Evolutionary Developmental Systems	299

4.6	Evolutionary Rewriting Systems	301	
4.7	Evolutionary Developmental Programs	310	
4.8	Evolutionary Developmental Processes	315	
4.9	Closing Remarks	332	
4.10	Suggested Readings	334	
<b>5</b>	<b><i>Immune Systems</i></b>	<b>335</b>	
5.1	How Biological Immune Systems Work	337	
5.2	The Constituents of Biological Immune Systems	353	
5.3	Lessons for Artificial Immune Systems	366	
5.4	Algorithms and Applications	373	
5.5	Shape Space	375	
5.6	Negative Selection Algorithm	384	
5.7	Clonal Selection Algorithm	388	
5.8	Examples	390	
5.9	Closing Remarks	395	
5.10	Suggested Readings	396	
<b>6</b>	<b><i>Behavioral Systems</i></b>	<b>399</b>	
6.1	Behavior in Cognitive Science	400	
6.2	Behavior in Artificial Intelligence	403	
6.3	Behavior-Based Robotics	407	
6.4	Biological Inspiration for Robots	419	
6.5	Robots as Biological Models	437	
6.6	Robot Learning	449	
6.7	Evolution of Behavioral Systems	460	
6.8	Evolution and Learning in Behavioral Systems	482	
6.9	Evolution and Neural Development in Behavioral Systems	494	
6.10	Coevolution of Body and Control	499	
6.11	Toward Self-Reproduction	504	
6.12	Simulation and Reality	507	
6.13	Closing Remarks	511	
6.14	Suggested Readings	513	
<b>7</b>	<b><i>Collective Systems</i></b>	<b>515</b>	
7.1	Biological Self-Organization	516	
7.2	Particle Swarm Optimization	524	
7.3	Ant Colony Optimization	527	
7.4	Swarm Robotics	531	

7.5	Coevolutionary Dynamics: Biological Models	547
7.6	Artificial Evolution of Competing Systems	554
7.7	Artificial Evolution of Cooperation	572
7.8	Closing Remarks	581
7.9	Suggested Readings	583
	<b>Conclusion</b>	<b>585</b>
	<b>References</b>	<b>587</b>
	<b>Index</b>	<b>651</b>