

Contents

1	A Synthetic Approach to the Study of the Evolution of Communication and Language	1
	Stefano Nolfi and Marco Mirolli	
1	Introduction	1
2	Scope and Objectives of the Book	3
3	Overview	3
3.1	Theoretical Aspects of Communication and Language	4
3.2	Evolution of Communication	5
3.3	Evolution of Language	7
3.4	Conclusion	8
3.5	Appendix: Software and Hardware Tools	8
4	Major Objectives	8
5	Acknowledgements	8
	References	9

Part I Theoretical Aspects of Communication and Language

2	Artificial Organisms with Human Language	13
	Domenico Parisi	
1	Understanding the Behavior of Real Organisms by Constructing Artificial Organisms	13
2	Artificial Organisms with Human Language	15
3	Nine Properties of Human Language	16
3.1	Linguistic Signals are Arbitrarily Linked to Their Meanings	16
3.2	Language is Compositional	18
3.3	Language is Culturally Transmitted and Evolved	20
3.4	Language is Used to Talk to Oneself and Not Only to Others	21
3.5	Language is Used for Communicating About the External Environment	23
3.6	Language Uses Displaced Signals	24
3.7	Language is Intentional and Requires Recognizing the Intentions of Others	25

3.8	Language is the Product of a Complex Nervous System	27
3.9	Language Influences Human Cognition	29
4	Between Them or with Us?	31
	References	34
3	Evolution of Language as One of the Major Evolutionary Transitions	37
	Eörs Szathmáry	
1	Introduction	37
2	Notes on the Neurobiology of Language	40
3	Towards a Genetic Approach to Language	41
4	The Status of Recursion in Animals and Human	41
5	Genetic Assimilation in Language Evolution	43
6	Prerequisites for Language and the Concept of a Human-Specific Adaptive Suite	43
7	Selective Scenarios for the Origin of Language	45
8	What Made Language Origins Difficult?	46
9	A Possible Modeling Approach	48
10	Evolutionary Neurogenetic Algorithm (ENGA)	49
11	The Origin of a Language as a Proper Major Evolutionary Transition	49
	References	50
4	Strategic Aspects of Communication	55
	Edward Hagen, Peter Hammerstein, and Nicole Hess	
1	Defining the Strategy Concept	55
2	Strategy Generation	56
3	A Strategic Approach to Communication	57
4	Costly Signaling	57
5	Cooperative Signaling, Antagonistic Co-evolution, and Subversion	60
6	Signaling Between “Super-organisms”	62
7	Summary	63
	References	63
5	Theoretical Tools in Modeling Communication and Language Dynamics	67
	Vittorio Loreto	
1	Introduction	67
2	Concepts and Tools	69
2.1	Order and Disorder: The Ising Paradigm	70
2.2	Role of Topology	73
2.3	Dynamical Systems Approach	75
2.4	Agent-Based Modeling	76
3	Conclusions	78
	References	79

6	Emergence of Scale-Free Syntax Networks	83
	Bernat Corominas-Murtra, Sergi Valverde, and Ricard V. Solé	
1	Introduction	83
2	Building Syntactic Networks	85
3	Evolving Syntax Networks	87
3.1	Global Organization	88
3.2	Small World Development	88
3.3	Scale-Free Topology	91
4	Modeling Syntactic Network Evolution	91
4.1	Simple SO Graph Growth Models	92
4.2	Network Growth Model and Analysis	92
5	Discussion	97
	References	99
Part II Evolution of Communication		
7	Evolving Communication in Embodied Agents: Theory, Methods, and Evaluation	105
	Marco Mirolli and Stefano Nolfi	
1	Introduction	105
2	Theory	106
2.1	The General Framework: Embodied Cognition	106
2.2	Communication as a Complex Adaptive System	108
3	Method	109
3.1	Adaptive Methods for Designing Self-organizing Communication Systems	109
3.2	Research Methodology	113
4	Evaluation Criteria	114
4.1	Adaptive Role	114
4.2	Expressive Power and Organizational Complexity	115
4.3	Stability, Robustness, and Evolvability	117
4.4	Knowledge Gain (Modeling)	118
5	Summary and Conclusion	118
	References	119
8	Evolutionary Conditions for the Emergence of Communication	123
	Sara Mitri, Dario Floreano, and Laurent Keller	
1	Introduction	123
2	Experimental Setup	126
2.1	The Task	126
2.2	Neural Controller	126
2.3	Artificial Evolution	128
2.4	Quantifying Behavior	128
3	Honest Communication	129
4	Deceptive Communication	132
5	Conclusion	133
	References	134

9 Producer Biases and Kin Selection in the Evolution of Communication	135
Marco Mirolli and Domenico Parisi	
1 Introduction	135
2 Two Problems in the Evolution of Communication	137
2.1 The Biological Literature and the Manipulation Bias	137
2.2 The Phylogenetic Problem	138
2.3 The Adaptive Problem	139
2.4 Disentangling the Two Problems	140
3 Experimental Set-Up	141
3.1 The Environment and the Task	141
3.2 The Neural Network	142
3.3 Individual Life and the Fitness Formula	142
3.4 The Genetic Algorithm	143
3.5 Measuring Communication System Quality	144
4 Cognitive, Genetic, and Adaptive Factors in the Evolution of Communication	144
5 The Kin-Selection Simulation	147
5.1 Simulation	147
5.2 Results	147
6 The No-Cognitive-Pressure and No-Communication Simulations	148
6.1 Simulations	148
6.2 Results	150
7 Discussion	152
7.1 The Producer Bias Hypothesis	153
7.2 Adaptive Factors	156
References	157
10 Evolution of Signaling in a Multi-Robot System: Categorization and Communication	161
Christos Ampatzis, Elio Tuci, Vito Trianni, and Marco Dorigo	
1 Introduction	162
2 Methods	162
2.1 Description of the Task	162
2.2 The Simulation Model	164
2.3 The Controller and the Evolutionary Algorithm	165
2.4 The Fitness Function	166
3 Results	167
3.1 A First Series of Post-evaluation Tests	168
3.2 Sound Signaling and Communication	169
3.3 On the Adaptive Significance of Signaling	172
4 Conclusions	176
References	178

11 Evolution of Implicit and Explicit Communication in Mobile Robots	179
Joachim de Greeff and Stefano Nolfi	
1 Introduction	179
2 Experimental Setup	180
2.1 The Environment and the Robots	181
2.2 The Neural Controller	181
2.3 The Evolutionary Algorithm	183
3 Results	185
3.1 Symmetrical Strategy	187
3.2 Asymmetrical Strategy	196
4 Discussion	204
Appendix	210
5.1 Sensors and Actuators	210
5.2 Update Functions of the Neurons	211
5.3 Simulation	211
5.4 Criteria Used to Identify the Behavior Exhibited by the Robots Analyzed in Sect. 3.2	212
Supplementary Data	213
References	213
12 Evolving Communication in Embodied Agents: Assessment and Open Challenges	215
Stefano Nolfi and Marco Mirolli	
1 Introduction	215
2 Adaptive Role	215
3 Expressive Power and Organization Complexity	216
4 Stability, Robustness, and Evolvability	217
5 Knowledge Gain (Modeling)	218
6 Open Questions for Future Research	219
References	219
Part III Evolution of Language	
13 Modeling The Formation of Language in Embodied Agents: Methods and Open Challenges	223
Luc Steels	
1 Introduction	223
2 Methods	224
3 Challenges	226
3.1 Mechanism Design of Language Games	226
3.2 Concept Formation	228
3.3 Lexicon Formation	229
3.4 Grammar Formation	230
References	232

14	Modeling the Formation of Language: Embodied Experiments	235
Luc Steels		
1	Introduction	235
2	The Grounded Naming Game	236
2.1	Sensori-motor Aspects	237
2.2	Conceptual Aspects	239
2.3	Linguistic Aspects	242
2.4	Establishing Object Identity	244
2.5	Experimental Results	245
3	Spatial Language and Perspective Reversal	247
3.1	Sensori-motor Aspects	247
3.2	Conceptual and Linguistic Aspects	249
3.3	Results	250
4	The Case Experiment	253
4.1	Sensori-motor Aspects	254
4.2	Linguistic Aspects	255
5	Conclusion	260
	References	261
15	Mathematical Modeling of Language Games	263
Vittorio Loreto, Andrea Baronchelli, and Andrea Puglisi		
1	Introduction	263
2	The Naming Game	264
2.1	Symmetry Breaking: A Controlled Case	268
2.2	The Role of the Interaction Topology	269
2.3	Variants of the Naming Game	270
3	The Category Game	270
3.1	The Category Game Model	272
3.2	Hierarchical Coordination	274
4	Conclusions	278
	References	279
16	Modeling the Formation of Language in Embodied Agents: Conclusions and Future Research	283
Luc Steels and Vittorio Loreto		
1	Introduction	283
2	Embodiment	283
3	Language Games	284
4	Concept Formation	284
5	Lexicon	285
6	Grammar	286
7	Mathematical Modeling	286
	References	288

Part IV Conclusion

17 Embodied and Communicating Agents: Towards the Establishment of a Solid Theoretical and Methodological Framework	291
Stefano Nolfi and Marco Mirolli	
References	293

Part V Appendix: Software and Hardware Tools

18 Evorobot*	297
Stefano Nolfi and Onofrio Gigliotta	
1 Introduction	297
2 Evorobot* Features	298
3 Using Evorobot*	300
4 User Manual, Tutorials & Download Instructions	301
References	301
19 E-puck	303
Dario Floreano, Sara Mitri, and Julien Hubert	
1 Introduction	303
2 The E-puck Robot	304
3 Communication Turrets	304
3.1 LED Light Turret	304
3.2 Omni-directional Camera Turret	305
4 Communication Experiments	305
References	306
20 Babel	307
Luc Steels and Martin Loetzsch	
1 Introduction	307
2 Overview	308
3 Illustration	310
4 Outlook	313