

Contents

Part I Theory

1	Introduction: Anticipation in Natural and Artificial Cognition	3
	Giovanni Pezzulo, Martin V. Butz, Cristiano Castelfranchi, and Rino Falcone	
1.1	Introduction	3
1.2	The Path to Anticipatory Cognitive Systems	4
1.2.1	Symbolic Behavior, Representation-Less Behavior, and Their Merge to Anticipatory Behavior	5
1.2.2	The Power of Anticipation: From Reactivity to Proactivity	6
1.2.3	The Anticipatory Approach to Cognitive Systems	6
1.2.4	The Unitary Nature of Anticipation	12
1.3	Anticipation in Living Organisms	12
1.3.1	Anticipatory Natural Cognition	12
1.3.2	Anticipatory Codes in the Brain	15
1.3.3	Simulative Theories of Cognition, and Their Unifying Nature	18
1.4	Conclusions	22
2	The Anticipatory Approach: Definitions and Taxonomies	23
	Giovanni Pezzulo, Martin V. Butz, and Cristiano Castelfranchi	
2.1	Anticipatory Systems, Anticipation, and Anticipatory Behavior . . .	23
2.2	Prediction vs. Anticipation	25
2.2.1	Predictive Capabilities	25
2.2.2	Anticipatory Capabilities	31
2.3	Anticipation and Goal-Oriented Behavior	34
2.3.1	The Anticipatory Structure of Goal-Oriented Behavior . .	35
2.3.2	Not All Anticipatory Behavior Is Goal-Oriented	36
2.3.3	Which Anticipations Permit Goal-Oriented Action?	36
2.3.4	The Hierarchical Organization of Anticipatory Goal-Oriented Action	37

- 2.3.5 Additional Elements of True Goal-Oriented Behavior ... 38
- 2.4 Anticipation and Learning 39
 - 2.4.1 Learning to Predict 39
 - 2.4.2 Bootstrapping Autonomous Cognitive Development: Surprise and Curiosity 40
 - 2.4.3 From Willed to Automatic Control of Action and Vice Versa on the Basis of Surprise 41
- 2.5 Conclusions 43
- 3 Benefits of Anticipations in Cognitive Agents 45**
 - Martin V. Butz and Giovanni Pezzulo
 - 3.1 Potentials for Anticipatory Systems 45
 - 3.2 Potential Benefits of Anticipatory Mechanisms on Cognitive Functions 48
 - 3.2.1 Effective, Context-Based Action Initiation 48
 - 3.2.2 Faster and Smoother Behavior Execution 49
 - 3.2.3 Improving Top-Down Attention 50
 - 3.2.4 Improving Information Seeking 51
 - 3.2.5 Improving Decision Making 52
 - 3.2.6 Object Grounding, Categorization, and Ontologies 54
 - 3.2.7 Social Abilities 55
 - 3.2.8 Learning 57
 - 3.3 Arising Challenges Due to Anticipations and Avoiding Them 60
 - 3.4 Conclusion 61

Part II Models, Architectures, and Applications

- 4 Anticipation in Attention 65**
 - Christian Balkenius, Alexander Förster, Birger Johansson, and Vin Thorsteinsdottir
 - 4.1 Introduction 65
 - 4.2 Learning What to Look at 66
 - 4.2.1 A Learning Saliency Map 67
 - 4.3 Cue-Target Learning 70
 - 4.3.1 Cueing by a Single Stimulus 70
 - 4.3.2 Contextual Cueing 72
 - 4.3.3 Fovea Based Solution 72
 - 4.4 Attending to Moving Targets 73
 - 4.4.1 Models of Smooth Pursuit 75
 - 4.4.2 Engineering Approaches 76
 - 4.4.3 The State Based Approach 78
 - 4.4.4 The Prediction Approach 79
 - 4.4.5 The Fovea Based Approach 80
 - 4.5 Combining Bottom-Up and Top-Down Processes 81

5	Anticipatory, Goal-Directed Behavior	85
	Martin V. Butz, Oliver Herbort, and Giovanni Pezzulo	
5.1	A Brief History of Schemas	87
5.2	Schema Approaches	88
	5.2.1 Symbolic Schemas for Policy Learning	89
	5.2.2 Symbolic Schemas and Prediction for Selection	90
	5.2.3 Neural-Based Planning	91
	5.2.4 Neural Network-Based Dynamic Programming	92
5.3	Inverse Model Approaches	92
	5.3.1 Inverse Models in Motor Learning and Control	93
	5.3.2 Inverse Models and Schema Approaches	94
5.4	Advanced Structures	94
	5.4.1 Prediction and Action	95
	5.4.2 Coupled Forward-Inverse Models	97
	5.4.3 Hierarchical Anticipatory Systems	98
5.5	Evaluation of Predictive and Anticipatory Capabilities	99
	5.5.1 Schema-Based Systems	101
	5.5.2 Inverse Model Approaches	106
5.6	Discussion	108
	5.6.1 Contrasting Predictive System Capabilities	108
	5.6.2 Contrasting Anticipatory System Capabilities	110
	5.6.3 Integration	112
5.7	Conclusions	113
6	Anticipation and Believability	115
	Carlos Martinho and Ana Paiva	
6.1	Introduction	115
	6.1.1 Animation and Believability	115
	6.1.2 Emotion and Exaggeration	116
	6.1.3 Anticipation	117
	6.1.4 Anticipation, Emotion, and Believability	117
6.2	Related Work	119
	6.2.1 Oz Project	119
	6.2.2 EMA	119
	6.2.3 Duncan the Highland Terrier	120
6.3	Emotivector	121
	6.3.1 Architecture	121
	6.3.2 Anticipation Model	122
	6.3.3 Saliency Model	123
	6.3.4 Sensation Model	123
	6.3.5 Selection Model	123
	6.3.6 Uncertainty	124
6.4	Aini, the Synthetic Flower	125
	6.4.1 Emotivectors in Action	125
	6.4.2 Evaluation	128

- 6.5 iCat, the Affective Game Buddy 128
 - 6.5.1 Emotivectors in Action 129
 - 6.5.2 Evaluation 130
- 6.6 Emotivector Integration in Agent Architectures 132
- 6.7 Conclusions 132

- 7 Anticipation and Emotions for Goal Directed Agents 135**
Emiliano Lorini, Michele Piunti, Cristiano Castelfranchi, Rino Falcone,
and Maria Miceli
 - 7.1 Introduction 135
 - 7.2 Related Works in Affective Computing 137
 - 7.3 Expectations and Surprise 139
 - 7.3.1 A Typology of Expectations and Predictions 139
 - 7.3.2 From the Typology of Expectations to the Typology of
Surprise 142
 - 7.3.3 Roles of Surprise in Cognitive Processing 144
 - 7.4 Expectations and Emotions for Goal-Directed Agents 148
 - 7.4.1 Expectations and Decision Making 148
 - 7.4.2 Situated Agents and Affective States 153
 - 7.4.3 Confidence of Predictions and Modulation of the
Probability Function 158
 - 7.4.4 Discussion 158
 - 7.5 Conclusion 159

- 8 A Reinforcement-Learning Model of Top-Down Attention Based on
a *Potential-Action Map* 161**
Dimitri Ognibene, Christian Balkenius, and Gianluca Baldassarre
 - 8.1 Introduction 161
 - 8.2 Methods 163
 - 8.2.1 RGB Camera Input 164
 - 8.2.2 Saliency Map and Action Selection 165
 - 8.2.3 Fovea 166
 - 8.2.4 Periphery Map 166
 - 8.2.5 Inhibition-of-Return Map 167
 - 8.2.6 Potential Action Map 167
 - 8.2.7 Actor-Critic Model 168
 - 8.2.8 Parameter Settings 169
 - 8.2.9 The Tasks 169
 - 8.3 Results 172
 - 8.3.1 Learning and Performance of the Models 172
 - 8.3.2 Bottom-Up Attention: Periphery Map and
Inhibition-of-Return Map 173
 - 8.3.3 Analysis of the Vote Maps 175
 - 8.3.4 Capability of Learning to Stay, and of Staying, on the
Target 176

8.3.5	Potential Action Map: An Action-Oriented Memory of Cue Information	177
8.3.6	Potential Action Map: Capacity to Integrate Multiple Sources of Information	179
8.4	Conclusions	182
9	Anticipation by Analogy	185
	Boicho Kokinov, Maurice Grinberg, Georgi Petkov, and Kiril Kiryazov	
9.1	Introduction	185
9.2	The Anticipation by Analogy Scenario	186
9.3	Models of Analogy-Making	188
9.4	AMBR Model of Analogy-Making	191
9.5	Integrating Visual Perception and Motor Control in AMBR	191
9.5.1	Top-Down Perception	195
9.5.2	Attention	197
9.5.3	Transfer of the Solution	198
9.5.4	Action Execution	199
9.6	Running the Simulated Model and Comparing It with Human Data	200
9.6.1	Comparing with Human Data	203
9.7	Running the Real Robot Model in the Real World	204
9.7.1	Ikaros	206
9.7.2	AMBR2Robot	208
9.7.3	Tests	209
9.8	Mechanisms for Active Vision	211
9.9	Discussion and Conclusion	213
10	Anticipation in Coordination	215
	Maurice Grinberg and Emilian Lalev	
10.1	Introduction	215
10.1.1	The Prisoner's Dilemma Game	216
10.2	Related Research	217
10.2.1	Fictitious Play	218
10.2.2	Strategic Teaching and Reputation Formation	218
10.2.3	Social Order and Coordination	220
10.2.4	Anticipation and Information Processing in Societies	220
10.3	Agent Architecture and Decision Making Model	221
10.3.1	The Model	221
10.3.2	Judgment and Decision Making	223
10.4	Game Simulations with Individual Agents: Comparison with Experimental Results	224
10.4.1	Comparison of the Model with Experimental Results	224
10.5	Multi-Agent Simulations	227
10.5.1	Agent Societies	228
10.5.2	Simulation Results and Discussions	229
10.6	Conclusion	235

- 11 Endowing Artificial Systems with Anticipatory Capabilities:**
- Success Cases** 237
- Giovanni Pezzulo, Martin V. Butz, Cristiano Castelfranchi,
Rino Falcone, Gianluca Baldassarre, Christian Balkenius,
Alexander Förster, Maurice Grinberg, Oliver Herbort, Kiril Kiryazov,
Boicho Kokinov, Birger Johansson, Emilian Lalev, Emiliano Lorini,
Carlos Martinho, Maria Miceli, Dimitri Ognibene, Ana Paiva,
Georgi Petkov, Michele Piunti, and Vin Thorsteinsdottir
- 11.1 Introduction 237
- 11.2 Flexible Goal-Directed Arm Control: The SURE_REACH
Architecture 238
- 11.3 Learning Cognitive Maps for Anticipatory Control: Time
Growing Neural Gas 239
- 11.4 Learning Effective Directional Arm Control: The Evolutionary
System XCSF 240
- 11.5 Anticipatory Target Motion Prediction 241
- 11.6 Anticipatory Spatial Attention with Saliency Maps 242
- 11.7 Behavior Prediction in a Group of Robots 242
- 11.8 Enhanced Adaptivity in a Predator-Prey Scenario 243
- 11.9 Adaptive Navigation and Control with Anticipation 245
- 11.10 Mental Experiments for Selecting Actions 245
- 11.11 Anticipations for Believable Behavior 246
- 11.12 Anticipatory Behavior in a Searching-for-an-Object Task 247
- 11.13 The Role of Anticipation in Cooperation and Coordination 248
- 11.14 Anticipatory Effects of Expectations and Emotions 249
- 11.15 On-Line and Off-Line Anticipation for Action Control 252
- 11.16 Conclusion 254

- References** 255