

Contents

Foreword by Rodney Brooks xiii

Preface xvii

I Intelligence, Artificial Intelligence, Embodiment, and What the Book Is About 1

1 Intelligence, Thinking, and Artificial Intelligence 5

1.1 Thinking, Cognition, and Intelligence 7

1.2 The Mystery of Intelligence 11

1.3 Defining Intelligence 14

1.4 Artificial Intelligence 17

1.5 Embodiment and Its Implications 18

1.6 Summary 22

2 Artificial Intelligence: The Landscape 25

2.1 Successes of the Classical Approach 27

2.2 Problems of the Classical Approach 30

2.3 The Embodied Turn 34

2.4 The Role of Neuroscience 37

2.5 Diversification 39

2.6 Biorobotics 41

2.7 Developmental Robotics 44

2.8 Ubiquitous Computing and Interfacing Technology 47

2.9 Artificial Life and Multiagent Systems 49

2.10 Evolutionary Robotics 53

2.11 Summary 54

- II Toward a Theory of Intelligence 57**
- 3 Prerequisites for a Theory of Intelligence 61**
 - 3.1 Level of Generality and Form of Theory 62
 - 3.2 Diversity-Compliance 67
 - 3.3 Frame of Reference 72
 - 3.4 The Synthetic Methodology 77
 - 3.5 Time Perspectives 82
 - 3.6 Emergence 85
 - 3.7 Summary 88
- 4 Intelligent Systems: Properties and Principles 89**
 - 4.1 Real Worlds and Virtual Worlds 90
 - 4.2 Properties of Complete Agents 95
 - 4.3 Agent Design Principle 1: The Three-Constituents Principle 100
 - 4.4 Agent Design Principle 2: The Complete-Agent Principle 104
 - 4.5 Agent Design Principle 3: Cheap Design 107
 - 4.6 Agent Design Principle 4: Redundancy 113
 - 4.7 Agent Design Principle 5: Sensory-Motor Coordination 117
 - 4.8 Agent Design Principle 6: Ecological Balance 123
 - 4.9 Agent Design Principle 7: Parallel, Loosely Coupled Processes 134
 - 4.10 Agent Design Principle 8: Value 137
 - 4.11 Summary and Conclusions 140
- 5 Development: From Locomotion to Cognition 141**
 - 5.1 Motivation 143
 - 5.2 Toward Developmental Robot Design 145
 - 5.3 From Locomotion to Cognition: A Case Study 149
 - 5.4 From Gait Patterns to Body Image to Cognition 153
 - 5.5 The Symbol Grounding Problem 159
 - 5.6 Matching Brain and Body Dynamics 161
 - 5.7 Broadening the Scope: Other Aspects of Development 164
 - 5.8 Learning in Embodied Systems 168
 - 5.9 Social Interaction 170
 - 5.10 Development: Where Are We and Where Do We Go from Here? 173

- 5.11 Summary: Design Principles for Developmental Systems 175
- 6 Evolution: Cognition from Scratch 177**
 - 6.1 Motivation 181
 - 6.2 The Basics of Evolutionary Computation 184
 - 6.3 The Origins of Evolutionary Computation 187
 - 6.4 Artificial Evolution in the Real World: On Pipes, Antennas, and Electronic Circuits 189
 - 6.5 Evolutionary Robotics 192
 - 6.6 Evolving Morphology and Control 194
 - 6.7 Genetic Regulatory Networks and Developmental Plasticity 196
 - 6.8 Self-Organization: The Powerful Ally of Mutation and Selection 204
 - 6.9 Artificial Evolution: Where Are We and Where Do We Go from Here? 206
 - 6.10 Summary: Design Principles for Evolutionary Systems 208
- 7 Collective Intelligence: Cognition from Interaction 213**
 - 7.1 Motivation 215
 - 7.2 Agent-Based Modeling 217
 - 7.3 Simulation versus Real Robots 221
 - 7.4 Groups of Robots 222
 - 7.5 A Note on Cooperation 226
 - 7.6 Modular Robots 228
 - 7.7 Scalability, Self-Assembly, Self-Repair, Homogeneity, and Heterogeneity 232
 - 7.8 Self-Reproducing Machines 235
 - 7.9 Collective Intelligence: Where Are We and Where Do We Go from Here? 238
 - 7.10 Summary: Design Principles for Collective Systems 241
- III Applications and Case Studies 245**
- 8 Ubiquitous Computing and Interfacing Technology 249**
 - 8.1 Ubiquitous Technology as Scaffolding 251
 - 8.2 Ubiquitous Technology: Properties and Principles 253
 - 8.3 Interacting with Ubiquitous Technology 263

- 8.4 Cyborgs 264
- 8.5 Summary and Conclusions 270
- 9 Building Intelligent Companies 271**
 - 9.1 Management and Entrepreneurship: Decision and Action under Uncertainty 272
 - 9.2 Companies as Embodied Systems 274
 - 9.3 A Synthetic Approach to Management 279
 - 9.4 Design Principles for Building Intelligent Companies 282
 - 9.5 Corroborating the Speculations 293
 - 9.6 Summary and Conclusions 294
- 10 Where Is Human Memory? 295**
 - 10.1 Introduction 298
 - 10.2 The Storehouse Metaphor and Its Problems 300
 - 10.3 Concepts of Memory 302
 - 10.4 The Frame-of-Reference Problem in Memory Research: Ashby's Proposal 304
 - 10.5 The Embodied View of Memory: Applying the Design Principles for Intelligent Systems 307
 - 10.6 Implications for Memory Research: Summary and Speculations 318
- 11 Robotic Technology in Everyday Life 323**
 - 11.1 Introduction: Everyday Robots 324
 - 11.2 Vacuum Cleaners: Roomba, Trilobite, and Similar Species 327
 - 11.3 Entertainment Robots 328
 - 11.4 Therapeutic, Medical, and Rescue Robots 333
 - 11.5 Humanoid Companion Robots 335
 - 11.6 Robots Capable of Social Communication 341
 - 11.7 Robots Capable of Facial and Bodily Expression 344
 - 11.8 A Theoretical Note 346
 - 11.9 Summary and Conclusions 348
- IV Principles and Insights 351**
- 12 How the Body Shapes the Way We Think 353**
 - 12.1 Steps Toward a Theory of Intelligence 354
 - 12.2 Selected Highlights 358

12.3 Seeing Things Differently 367

12.4 Epilogue 370

Notes 373

References 375

Index 389