

Artificial Intelligence

A Modern Approach

Third Edition

Stuart J. Russell and Peter Norvig

Contributing writers:

Ernest Davis
Douglas D. Edwards
David Forsyth
Nicholas J. Hay
Jitendra M. Malik
Vibhu Mittal
Mehran Sahami
Sebastian Thrun

PEARSON

Pearson Education Limited
Edinburgh Gate
Harlow
Essex CM20 2JE
England

and Associated Companies throughout the world

Visit us on the World Wide Web at:
www.pearsonglobaleditions.com

© Pearson Education Limited 2016

*Authorized adaptation from the United States edition, entitled
Artificial Intelligence: A Modern Approach, Third Edition,
ISBN 9780136042594, by Stuart J. Russell and Peter Norvig
published by Pearson Education © 2010.*

British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library

ISBN 10: 1292153962

ISBN 13: 9781292153964

Printed and bound in Malaysia

Preface

Artificial Intelligence (AI) is a big field, and this is a big book. We have tried to explore the full breadth of the field, which encompasses logic, probability, and continuous mathematics; perception, reasoning, learning, and action; and everything from microelectronic devices to robotic planetary explorers. The book is also big because we go into some depth.

The subtitle of this book is “A Modern Approach.” The intended meaning of this rather empty phrase is that we have tried to synthesize what is now known into a common framework, rather than trying to explain each subfield of AI in its own historical context. We apologize to those whose subfields are, as a result, less recognizable.

New to this edition

This edition captures the changes in AI that have taken place since the last edition in 2003. There have been important applications of AI technology, such as the widespread deployment of practical speech recognition, machine translation, autonomous vehicles, and household robotics. There have been algorithmic landmarks, such as the solution of the game of checkers. And there has been a great deal of theoretical progress, particularly in areas such as probabilistic reasoning, machine learning, and computer vision. Most important from our point of view is the continued evolution in how we think about the field, and thus how we organize the book. The major changes are as follows:

- We place more emphasis on partially observable and nondeterministic environments, especially in the nonprobabilistic settings of search and planning. The concepts of *belief state* (a set of possible worlds) and *state estimation* (maintaining the belief state) are introduced in these settings; later in the book, we add probabilities.
- In addition to discussing the types of environments and types of agents, we now cover in more depth the types of *representations* that an agent can use. We distinguish among *atomic* representations (in which each state of the world is treated as a black box), *factored* representations (in which a state is a set of attribute/value pairs), and *structured* representations (in which the world consists of objects and relations between them).
- Our coverage of planning goes into more depth on contingent planning in partially observable environments and includes a new approach to hierarchical planning.
- We have added new material on first-order probabilistic models, including *open-universe* models for cases where there is uncertainty as to what objects exist.
- We have completely rewritten the introductory machine-learning chapter, stressing a wider variety of more modern learning algorithms and placing them on a firmer theoretical footing.
- We have expanded coverage of Web search and information extraction, and of techniques for learning from very large data sets.
- 20% of the citations in this edition are to works published after 2003.
- We estimate that about 20% of the material is brand new. The remaining 80% reflects older work but has been largely rewritten to present a more unified picture of the field.

Overview of the book

The main unifying theme is the idea of an **intelligent agent**. We define AI as the study of agents that receive percepts from the environment and perform actions. Each such agent implements a function that maps percept sequences to actions, and we cover different ways to represent these functions, such as reactive agents, real-time planners, and decision-theoretic systems. We explain the role of learning as extending the reach of the designer into unknown environments, and we show how that role constrains agent design, favoring explicit knowledge representation and reasoning. We treat robotics and vision not as independently defined problems, but as occurring in the service of achieving goals. We stress the importance of the task environment in determining the appropriate agent design.

Our primary aim is to convey the *ideas* that have emerged over the past fifty years of AI research and the past two millennia of related work. We have tried to avoid excessive formality in the presentation of these ideas while retaining precision. We have included pseudocode algorithms to make the key ideas concrete; our pseudocode is described in Appendix B.

This book is primarily intended for use in an undergraduate course or course sequence. The book has 27 chapters, each requiring about a week's worth of lectures, so working through the whole book requires a two-semester sequence. A one-semester course can use selected chapters to suit the interests of the instructor and students. The book can also be used in a graduate-level course (perhaps with the addition of some of the primary sources suggested in the bibliographical notes). Sample syllabi are available at the book's Web site, aima.cs.berkeley.edu. The only prerequisite is familiarity with basic concepts of computer science (algorithms, data structures, complexity) at a sophomore level. Freshman calculus and linear algebra are useful for some of the topics; the required mathematical background is supplied in Appendix A.

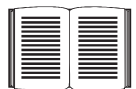
Exercises are given at the end of each chapter. Exercises requiring significant programming are marked with a **keyboard** icon. These exercises can best be solved by taking advantage of the code repository at aima.cs.berkeley.edu. Some of them are large enough to be considered term projects. A number of exercises require some investigation of the literature; these are marked with a **book** icon.

Throughout the book, important points are marked with a *pointing* icon. We have included an extensive index of around 6,000 items to make it easy to find things in the book. Whenever a **new term** is first defined, it is also marked in the margin.

About the Web site

aima.cs.berkeley.edu, the Web site for the book, contains

- implementations of the algorithms in the book in several programming languages,
- a list of over 1000 schools that have used the book, many with links to online course materials and syllabi,
- an annotated list of over 800 links to sites around the Web with useful AI content,
- a chapter-by-chapter list of supplementary material and links,
- instructions on how to join a discussion group for the book,



NEW TERM

- instructions on how to contact the authors with questions or comments,
- instructions on how to report errors in the book, in the likely event that some exist, and
- slides and other materials for instructors.

Pearson offers many different products around the world to facilitate learning. In countries outside the United States, some products and services related to this textbook may not be available due to copyright and/or permissions restrictions. If you have questions, you can contact your local office by visiting www.pearsonhighered.com/international or you can contact your local Pearson representative.

About the cover

The cover depicts the final position from the decisive game 6 of the 1997 match between chess champion Garry Kasparov and program DEEP BLUE. Kasparov, playing Black, was forced to resign, making this the first time a computer had beaten a world champion in a chess match. Kasparov is shown at the top. To his left is the Asimo humanoid robot and to his right is Thomas Bayes (1702–1761), whose ideas about probability as a measure of belief underlie much of modern AI technology. Below that we see a Mars Exploration Rover, a robot that landed on Mars in 2004 and has been exploring the planet ever since. To the right is Alan Turing (1912–1954), whose fundamental work defined the fields of computer science in general and artificial intelligence in particular. At the bottom is Shakey (1966–1972), the first robot to combine perception, world-modeling, planning, and learning. With Shakey is project leader Charles Rosen (1917–2002). At the bottom right is Aristotle (384 B.C.–322 B.C.), who pioneered the study of logic; his work was state of the art until the 19th century (copy of a bust by Lysippos). At the bottom left, lightly screened behind the authors' names, is a planning algorithm by Aristotle from *De Motu Animalium* in the original Greek. Behind the title is a portion of the CPSC Bayesian network for medical diagnosis (Pradhan *et al.*, 1994). Behind the chess board is part of a Bayesian logic model for detecting nuclear explosions from seismic signals.

Credits: Stan Honda/Getty (Kasparov), Library of Congress (Bayes), NASA (Mars rover), National Museum of Rome (Aristotle), Peter Norvig (book), Ian Parker (Berkeley skyline), Shutterstock (Asimo, Chess pieces), Time Life/Getty (Shakey, Turing).

Acknowledgments

This book would not have been possible without the many contributors whose names did not make it to the cover. Jitendra Malik and David Forsyth wrote Chapter 24 (computer vision) and Sebastian Thrun wrote Chapter 25 (robotics). Vibhu Mittal wrote part of Chapter 22 (natural language). Nick Hay, Mehran Sahami, and Ernest Davis wrote some of the exercises. Zoran Duric (George Mason), Thomas C. Henderson (Utah), Leon Reznik (RIT), Michael Gourley (Central Oklahoma) and Ernest Davis (NYU) reviewed the manuscript and made helpful suggestions. We thank Ernie Davis in particular for his tireless ability to read multiple drafts and help improve the book. Nick Hay whipped the bibliography into shape and on deadline stayed up to 5:30 AM writing code to make the book better. Jon Barron formatted and improved the diagrams in this edition, while Tim Huang, Mark Paskin, and Cynthia

Bruyns helped with diagrams and algorithms in previous editions. Ravi Mohan and Ciaran O'Reilly wrote and maintain the Java code examples on the Web site. John Canny wrote the robotics chapter for the first edition and Douglas Edwards researched the historical notes. Tracy Dunkelberger, Allison Michael, Scott Disanno, and Jane Bonnell at Pearson tried their best to keep us on schedule and made many helpful suggestions. Most helpful of all has been Julie Sussman, P.P.A., who read every chapter and provided extensive improvements. In previous editions we had proofreaders who would tell us when we left out a comma and said *which* when we meant *that*; Julie told us when we left out a minus sign and said x_i when we meant x_j . For every typo or confusing explanation that remains in the book, rest assured that Julie has fixed at least five. She persevered even when a power failure forced her to work by lantern light rather than LCD glow.

Stuart would like to thank his parents for their support and encouragement and his wife, Loy Sheflott, for her endless patience and boundless wisdom. He hopes that Gordon, Lucy, George, and Isaac will soon be reading this book after they have forgiven him for working so long on it. RUGS (Russell's Unusual Group of Students) have been unusually helpful, as always.

Peter would like to thank his parents (Torsten and Gerda) for getting him started, and his wife (Kris), children (Bella and Juliet), colleagues, and friends for encouraging and tolerating him through the long hours of writing and longer hours of rewriting.

We both thank the librarians at Berkeley, Stanford, and NASA and the developers of CiteSeer, Wikipedia, and Google, who have revolutionized the way we do research. We can't acknowledge all the people who have used the book and made suggestions, but we would like to note the especially helpful comments of Gagan Aggarwal, Eyal Amir, Ion Androutsopoulos, Krzysztof Apt, Warren Haley Armstrong, Ellery Aziel, Jeff Van Baalen, Darius Bacon, Brian Baker, Shumeet Baluja, Don Barker, Tony Barrett, James Newton Bass, Don Beal, Howard Beck, Wolfgang Bibel, John Binder, Larry Bookman, David R. Boxall, Ronen Brafman, John Bresina, Gerhard Brewka, Selmer Bringsjord, Carla Brodley, Chris Brown, Emma Brunskill, Wilhelm Burger, Lauren Burka, Carlos Bustamante, Joao Cachopo, Murray Campbell, Norman Carver, Emmanuel Castro, Anil Chakravarthy, Dan Chisarick, Berthe Choueiry, Roberto Cipolla, David Cohen, James Coleman, Julie Ann Comparini, Corinna Cortes, Gary Cottrell, Ernest Davis, Tom Dean, Rina Dechter, Tom Dietterich, Peter Drake, Chuck Dyer, Doug Edwards, Robert Egginton, Asma'a El-Budrawy, Barbara Engelhardt, Kutluhan Erol, Oren Etzioni, Hana Filip, Douglas Fisher, Jeffrey Forbes, Ken Ford, Eric Fosler-Lussier, John Fosler, Jeremy Frank, Alex Franz, Bob Futrelle, Marek Galecki, Stefan Gerberding, Stuart Gill, Sabine Glesner, Seth Golub, Gosta Grahne, Russ Greiner, Eric Grimson, Barbara Grosz, Larry Hall, Steve Hanks, Othar Hansson, Ernst Heinz, Jim Hendler, Christoph Herrmann, Paul Hilfinger, Robert Holte, Vasant Honavar, Tim Huang, Seth Hutchinson, Joost Jacob, Mark Jelasity, Magnus Johansson, Istvan Jonyer, Dan Jurafsky, Leslie Kaelbling, Keiji Kanazawa, Surekha Kasibhatla, Simon Kasif, Henry Kautz, Gernot Kerschbaumer, Max Khesin, Richard Kirby, Dan Klein, Kevin Knight, Roland Koenig, Sven Koenig, Daphne Koller, Rich Korf, Benjamin Kuipers, James Kurien, John Lafferty, John Laird, Gus Larsen, John Lazzaro, Jon LeBlanc, Jason Leatherman, Frank Lee, Jon Lehto, Edward Lim, Phil Long, Pierre Louveaux, Don Loveland, Sridhar Mahadevan, Tony Mancill, Jim Martin,

Andy Mayer, John McCarthy, David McGrane, Jay Mendelsohn, Risto Miikkulanien, Brian Milch, Steve Minton, Vibhu Mittal, Mehryar Mohri, Leora Morgenstern, Stephen Muggleton, Kevin Murphy, Ron Musick, Sung Myaeng, Eric Nadeau, Lee Naish, Pandu Nayak, Bernhard Nebel, Stuart Nelson, XuanLong Nguyen, Nils Nilsson, Illah Nourbakhsh, Ali Nouri, Arthur Nunes-Harwitt, Steve Omohundro, David Page, David Palmer, David Parkes, Ron Parr, Mark Paskin, Tony Passera, Amit Patel, Michael Pazzani, Fernando Pereira, Joseph Perla, Wim Pijs, Ira Pohl, Martha Pollack, David Poole, Bruce Porter, Malcolm Pradhan, Bill Pringle, Lorraine Prior, Greg Provan, William Rapaport, Deepak Ravichandran, Ioannis Refanidis, Philip Resnik, Francesca Rossi, Sam Roweis, Richard Russell, Jonathan Schaeffer, Richard Scherl, Hinrich Schuetze, Lars Schuster, Bart Selman, Soheil Shams, Stuart Shapiro, Jude Shavlik, Yoram Singer, Satinder Singh, Daniel Sleator, David Smith, Bryan So, Robert Sproull, Lynn Stein, Larry Stephens, Andreas Stolcke, Paul Stradling, Devika Subramanian, Marek Suchenek, Rich Sutton, Jonathan Tash, Austin Tate, Bas Terwijn, Olivier Teytaud, Michael Thielscher, William Thompson, Sebastian Thrun, Eric Tiedemann, Mark Torrance, Randall Upham, Paul Utgoff, Peter van Beek, Hal Varian, Paulina Varshavskaya, Sunil Vemuri, Vandiver Verma, Ubbo Visser, Jim Waldo, Toby Walsh, Bonnie Webber, Dan Weld, Michael Wellman, Kamin Whitehouse, Michael Dean White, Brian Williams, David Wolfe, Jason Wolfe, Bill Woods, Alden Wright, Jay Yagnik, Mark Yasuda, Richard Yen, Eliezer Yudkowsky, Weixiong Zhang, Ming Zhao, Shlomo Zilberstein, and our esteemed colleague Anonymous Reviewer.

About the Authors

Stuart Russell was born in 1962 in Portsmouth, England. He received his B.A. with first-class honours in physics from Oxford University in 1982, and his Ph.D. in computer science from Stanford in 1986. He then joined the faculty of the University of California at Berkeley, where he is a professor of computer science, director of the Center for Intelligent Systems, and holder of the Smith–Zadeh Chair in Engineering. In 1990, he received the Presidential Young Investigator Award of the National Science Foundation, and in 1995 he was cowinner of the Computers and Thought Award. He was a 1996 Miller Professor of the University of California and was appointed to a Chancellor’s Professorship in 2000. In 1998, he gave the Forsythe Memorial Lectures at Stanford University. He is a Fellow and former Executive Council member of the American Association for Artificial Intelligence. He has published over 100 papers on a wide range of topics in artificial intelligence. His other books include *The Use of Knowledge in Analogy and Induction* and (with Eric Wefald) *Do the Right Thing: Studies in Limited Rationality*.

Peter Norvig is currently Director of Research at Google, Inc., and was the director responsible for the core Web search algorithms from 2002 to 2005. He is a Fellow of the American Association for Artificial Intelligence and the Association for Computing Machinery. Previously, he was head of the Computational Sciences Division at NASA Ames Research Center, where he oversaw NASA’s research and development in artificial intelligence and robotics, and chief scientist at Junglee, where he helped develop one of the first Internet information extraction services. He received a B.S. in applied mathematics from Brown University and a Ph.D. in computer science from the University of California at Berkeley. He received the Distinguished Alumni and Engineering Innovation awards from Berkeley and the Exceptional Achievement Medal from NASA. He has been a professor at the University of Southern California and a research faculty member at Berkeley. His other books are *Paradigms of AI Programming: Case Studies in Common Lisp* and *Verbmobil: A Translation System for Face-to-Face Dialog* and *Intelligent Help Systems for UNIX*.

Contents

I Artificial Intelligence

1	Introduction	1
1.1	What Is AI?	1
1.2	The Foundations of Artificial Intelligence	5
1.3	The History of Artificial Intelligence	16
1.4	The State of the Art	28
1.5	Summary, Bibliographical and Historical Notes, Exercises	29
2	Intelligent Agents	34
2.1	Agents and Environments	34
2.2	Good Behavior: The Concept of Rationality	36
2.3	The Nature of Environments	40
2.4	The Structure of Agents	46
2.5	Summary, Bibliographical and Historical Notes, Exercises	59

II Problem-solving

3	Solving Problems by Searching	64
3.1	Problem-Solving Agents	64
3.2	Example Problems	69
3.3	Searching for Solutions	75
3.4	Uninformed Search Strategies	81
3.5	Informed (Heuristic) Search Strategies	92
3.6	Heuristic Functions	102
3.7	Summary, Bibliographical and Historical Notes, Exercises	108
4	Beyond Classical Search	120
4.1	Local Search Algorithms and Optimization Problems	120
4.2	Local Search in Continuous Spaces	129
4.3	Searching with Nondeterministic Actions	133
4.4	Searching with Partial Observations	138
4.5	Online Search Agents and Unknown Environments	147
4.6	Summary, Bibliographical and Historical Notes, Exercises	153
5	Adversarial Search	161
5.1	Games	161
5.2	Optimal Decisions in Games	163
5.3	Alpha–Beta Pruning	167
5.4	Imperfect Real-Time Decisions	171
5.5	Stochastic Games	177

5.6	Partially Observable Games	180
5.7	State-of-the-Art Game Programs	185
5.8	Alternative Approaches	187
5.9	Summary, Bibliographical and Historical Notes, Exercises	189
6	Constraint Satisfaction Problems	202
6.1	Defining Constraint Satisfaction Problems	202
6.2	Constraint Propagation: Inference in CSPs	208
6.3	Backtracking Search for CSPs	214
6.4	Local Search for CSPs	220
6.5	The Structure of Problems	222
6.6	Summary, Bibliographical and Historical Notes, Exercises	227
 III Knowledge, reasoning, and planning		
7	Logical Agents	234
7.1	Knowledge-Based Agents	235
7.2	The Wumpus World	236
7.3	Logic	240
7.4	Propositional Logic: A Very Simple Logic	243
7.5	Propositional Theorem Proving	249
7.6	Effective Propositional Model Checking	259
7.7	Agents Based on Propositional Logic	265
7.8	Summary, Bibliographical and Historical Notes, Exercises	274
8	First-Order Logic	285
8.1	Representation Revisited	285
8.2	Syntax and Semantics of First-Order Logic	290
8.3	Using First-Order Logic	300
8.4	Knowledge Engineering in First-Order Logic	307
8.5	Summary, Bibliographical and Historical Notes, Exercises	313
9	Inference in First-Order Logic	322
9.1	Propositional vs. First-Order Inference	322
9.2	Unification and Lifting	325
9.3	Forward Chaining	330
9.4	Backward Chaining	337
9.5	Resolution	345
9.6	Summary, Bibliographical and Historical Notes, Exercises	357
10	Classical Planning	366
10.1	Definition of Classical Planning	366
10.2	Algorithms for Planning as State-Space Search	373
10.3	Planning Graphs	379

10.4	Other Classical Planning Approaches	387
10.5	Analysis of Planning Approaches	392
10.6	Summary, Bibliographical and Historical Notes, Exercises	393
11	Planning and Acting in the Real World	401
11.1	Time, Schedules, and Resources	401
11.2	Hierarchical Planning	406
11.3	Planning and Acting in Nondeterministic Domains	415
11.4	Multiagent Planning	425
11.5	Summary, Bibliographical and Historical Notes, Exercises	430
12	Knowledge Representation	437
12.1	Ontological Engineering	437
12.2	Categories and Objects	440
12.3	Events	446
12.4	Mental Events and Mental Objects	450
12.5	Reasoning Systems for Categories	453
12.6	Reasoning with Default Information	458
12.7	The Internet Shopping World	462
12.8	Summary, Bibliographical and Historical Notes, Exercises	467
IV	Uncertain knowledge and reasoning	
13	Quantifying Uncertainty	480
13.1	Acting under Uncertainty	480
13.2	Basic Probability Notation	483
13.3	Inference Using Full Joint Distributions	490
13.4	Independence	494
13.5	Bayes' Rule and Its Use	495
13.6	The Wumpus World Revisited	499
13.7	Summary, Bibliographical and Historical Notes, Exercises	503
14	Probabilistic Reasoning	510
14.1	Representing Knowledge in an Uncertain Domain	510
14.2	The Semantics of Bayesian Networks	513
14.3	Efficient Representation of Conditional Distributions	518
14.4	Exact Inference in Bayesian Networks	522
14.5	Approximate Inference in Bayesian Networks	530
14.6	Relational and First-Order Probability Models	539
14.7	Other Approaches to Uncertain Reasoning	546
14.8	Summary, Bibliographical and Historical Notes, Exercises	551
15	Probabilistic Reasoning over Time	566
15.1	Time and Uncertainty	566

15.2	Inference in Temporal Models	570
15.3	Hidden Markov Models	578
15.4	Kalman Filters	584
15.5	Dynamic Bayesian Networks	590
15.6	Keeping Track of Many Objects	599
15.7	Summary, Bibliographical and Historical Notes, Exercises	603
16	Making Simple Decisions	610
16.1	Combining Beliefs and Desires under Uncertainty	610
16.2	The Basis of Utility Theory	611
16.3	Utility Functions	615
16.4	Multiattribute Utility Functions	622
16.5	Decision Networks	626
16.6	The Value of Information	628
16.7	Decision-Theoretic Expert Systems	633
16.8	Summary, Bibliographical and Historical Notes, Exercises	636
17	Making Complex Decisions	645
17.1	Sequential Decision Problems	645
17.2	Value Iteration	652
17.3	Policy Iteration	656
17.4	Partially Observable MDPs	658
17.5	Decisions with Multiple Agents: Game Theory	666
17.6	Mechanism Design	679
17.7	Summary, Bibliographical and Historical Notes, Exercises	684
V	Learning	
18	Learning from Examples	693
18.1	Forms of Learning	693
18.2	Supervised Learning	695
18.3	Learning Decision Trees	697
18.4	Evaluating and Choosing the Best Hypothesis	708
18.5	The Theory of Learning	713
18.6	Regression and Classification with Linear Models	717
18.7	Artificial Neural Networks	727
18.8	Nonparametric Models	737
18.9	Support Vector Machines	744
18.10	Ensemble Learning	748
18.11	Practical Machine Learning	753
18.12	Summary, Bibliographical and Historical Notes, Exercises	757
19	Knowledge in Learning	768
19.1	A Logical Formulation of Learning	768

19.2	Knowledge in Learning	777
19.3	Explanation-Based Learning	780
19.4	Learning Using Relevance Information	784
19.5	Inductive Logic Programming	788
19.6	Summary, Bibliographical and Historical Notes, Exercises	797
20	Learning Probabilistic Models	802
20.1	Statistical Learning	802
20.2	Learning with Complete Data	806
20.3	Learning with Hidden Variables: The EM Algorithm	816
20.4	Summary, Bibliographical and Historical Notes, Exercises	825
21	Reinforcement Learning	830
21.1	Introduction	830
21.2	Passive Reinforcement Learning	832
21.3	Active Reinforcement Learning	839
21.4	Generalization in Reinforcement Learning	845
21.5	Policy Search	848
21.6	Applications of Reinforcement Learning	850
21.7	Summary, Bibliographical and Historical Notes, Exercises	853
VI	Communicating, perceiving, and acting	
22	Natural Language Processing	860
22.1	Language Models	860
22.2	Text Classification	865
22.3	Information Retrieval	867
22.4	Information Extraction	873
22.5	Summary, Bibliographical and Historical Notes, Exercises	882
23	Natural Language for Communication	888
23.1	Phrase Structure Grammars	888
23.2	Syntactic Analysis (Parsing)	892
23.3	Augmented Grammars and Semantic Interpretation	897
23.4	Machine Translation	907
23.5	Speech Recognition	912
23.6	Summary, Bibliographical and Historical Notes, Exercises	918
24	Perception	928
24.1	Image Formation	929
24.2	Early Image-Processing Operations	935
24.3	Object Recognition by Appearance	942
24.4	Reconstructing the 3D World	947
24.5	Object Recognition from Structural Information	957

24.6	Using Vision	961
24.7	Summary, Bibliographical and Historical Notes, Exercises	965
25	Robotics	971
25.1	Introduction	971
25.2	Robot Hardware	973
25.3	Robotic Perception	978
25.4	Planning to Move	986
25.5	Planning Uncertain Movements	993
25.6	Moving	997
25.7	Robotic Software Architectures	1003
25.8	Application Domains	1006
25.9	Summary, Bibliographical and Historical Notes, Exercises	1010
VII	Conclusions	
26	Philosophical Foundations	1020
26.1	Weak AI: Can Machines Act Intelligently?	1020
26.2	Strong AI: Can Machines Really Think?	1026
26.3	The Ethics and Risks of Developing Artificial Intelligence	1034
26.4	Summary, Bibliographical and Historical Notes, Exercises	1040
27	AI: The Present and Future	1044
27.1	Agent Components	1044
27.2	Agent Architectures	1047
27.3	Are We Going in the Right Direction?	1049
27.4	What If AI Does Succeed?	1051
A	Mathematical background	1053
A.1	Complexity Analysis and $O()$ Notation	1053
A.2	Vectors, Matrices, and Linear Algebra	1055
A.3	Probability Distributions	1057
B	Notes on Languages and Algorithms	1060
B.1	Defining Languages with Backus–Naur Form (BNF)	1060
B.2	Describing Algorithms with Pseudocode	1061
B.3	Online Help	1062
	Bibliography	1063
	Index	1095