

Contents

Preface	xi
About the Authors	xiii
1 Introduction to Artificial Intelligence	1
1.1 History of Artificial Intelligence	2
1.1.1 What Is Artificial Intelligence?	2
1.1.2 Emergence of AI	4
1.1.3 Cognitive Science and AI	4
1.1.4 Logical Approach to AI	4
1.1.5 Knowledge-Based Systems	5
1.1.6 Probabilistic Approach to AI	6
1.1.7 Evolutionary Computation and Swarm Intelligence	6
1.1.8 Neural Networks & Deep Learning	7
1.1.9 A Return to Creating HAL	7
1.2 Outline of This Book	7
I Logical Intelligence	9
2 Propositional Logic	11
2.1 Basics of Propositional Logic	12
2.1.1 Syntax	12
2.1.2 Semantics	13
2.1.3 Tautologies and Logical Implication	17
2.1.4 Logical Arguments	18
2.1.5 Derivation Systems	21
2.2 Resolution	24
2.2.1 Normal Forms	25
2.2.2 Derivations Using Resolution	26
2.2.3 Resolution Algorithm	30
2.3 Artificial Intelligence Applications	30
2.3.1 Knowledge-Based Systems	30
2.3.2 Wumpus World	41
2.4 Discussion and Further Reading	48
3 First-Order Logic	53
3.1 Basics of First-Order Logic	53
3.1.1 Syntax	54
3.1.2 Semantics	56

3.1.3	Validity and Logical Implication	60
3.1.4	Derivation Systems	62
3.1.5	Modus Ponens for First-Order Logic	65
3.2	Artificial Intelligence Applications	68
3.2.1	Wumpus World Revisited	69
3.2.2	Planning	69
3.3	Discussion and Further Reading	73
4	Certain Knowledge Representation	77
4.1	Taxonomic Knowledge	78
4.1.1	Semantic Nets	78
4.1.2	Model of Human Organization of Knowledge	79
4.2	Frames	80
4.2.1	Frame Data Structure	80
4.2.2	Planning a Trip Using Frames	81
4.3	Nonmonotonic Logic	84
4.3.1	Circumscription	84
4.3.2	Default Logic	85
4.3.3	Difficulties	86
4.4	Discussion and Further Reading	86
5	Learning Deterministic Models	89
5.1	Supervised Learning	89
5.2	Regression	90
5.2.1	Simple Linear Regression	91
5.2.2	Multiple Linear Regression	93
5.2.3	Overfitting and Cross Validation	94
5.3	Parameter Estimation	96
5.3.1	Estimating the Parameters for Simple Linear Regression	96
5.3.2	Gradient Descent	98
5.3.3	Logistic Regression and Gradient Descent	100
5.3.4	Stochastic Gradient Descent	101
5.4	Learning a Decision Tree	102
5.4.1	Information Theory	102
5.4.2	Information Gain and the ID3 Algorithm	106
5.4.3	Overfitting	108
II	Probabilistic Intelligence	113
6	Probability	115
6.1	Probability Basics	117
6.1.1	Probability Spaces	117
6.1.2	Conditional Probability and Independence	120
6.1.3	Bayes' Theorem	122
6.2	Random Variables	123
6.2.1	Probability Distributions of Random Variables	123
6.2.2	Independence of Random Variables	128
6.3	Meaning of Probability	131
6.3.1	Relative Frequency Approach to Probability	132
6.3.2	Subjective Approach to Probability	134

6.4	Random Variables in Applications	135
6.5	Probability in the Wumpus World	139
7	Uncertain Knowledge Representation	145
7.1	Intuitive Introduction to Bayesian Networks	147
7.2	Properties of Bayesian Networks	149
7.2.1	Definition of a Bayesian Network	149
7.2.2	Representation of a Bayesian Network	152
7.3	Causal Networks as Bayesian Networks	154
7.3.1	Causality	154
7.3.2	Causality and the Markov Condition	155
7.3.3	Markov Condition without Causality	159
7.4	Inference in Bayesian Networks	160
7.4.1	Examples of Inference	160
7.4.2	Inference Algorithms and Packages	162
7.4.3	Inference Using Netica	163
7.5	Networks with Continuous Variables	165
7.5.1	Gaussian Bayesian Networks	165
7.5.2	Hybrid Networks	168
7.6	Obtaining the Probabilities	170
7.6.1	Difficulty Inherent in Multiple Parents	170
7.6.2	Basic Noisy OR-Gate Model	170
7.6.3	Leaky Noisy OR-Gate Model	172
7.6.4	Further Models	174
7.7	Large-Scale Application: Promedas	174
8	Advanced Properties of Bayesian Networks	181
8.1	Entailed Conditional Independencies	182
8.1.1	Examples of Entailed Conditional Independencies	182
8.1.2	d-Separation	185
8.2	Faithfulness	188
8.2.1	Unfaithful Probability Distributions	188
8.2.2	Faithfulness Condition	190
8.3	Markov Equivalence	191
8.4	Markov Blankets and Boundaries	192
9	Decision Analysis	201
9.1	Decision Trees	202
9.1.1	Simple Examples	202
9.1.2	Solving More Complex Decision Trees	205
9.2	Influence Diagrams	216
9.2.1	Representing Decision Problems with Influence Diagrams	216
9.2.2	Solving Influence Diagrams	222
9.2.3	Techniques for Solving Influence Diagrams	222
9.2.4	Solving Influence Diagrams Using Netica	226
9.3	Modeling Risk Preferences	231
9.3.1	Exponential Utility Function	231
9.3.2	Assessing r	232
9.4	Analyzing Risk Directly	233
9.4.1	Using the Variance to Measure Risk	233
9.4.2	Risk Profiles	235

9.4.3	Dominance	236
9.5	Good Decision versus Good Outcome	239
9.6	Sensitivity Analysis	239
9.7	Value of Information	241
9.7.1	Expected Value of Perfect Information	242
9.7.2	Expected Value of Imperfect Information	244
9.8	Discussion and Further Reading	245
9.8.1	Academics	246
9.8.2	Business and Finance	247
9.8.3	Capital Equipment	247
9.8.4	Computer Games	247
9.8.5	Computer Vision	247
9.8.6	Computer Software	247
9.8.7	Medicine	248
9.8.8	Natural Language Processing	248
9.8.9	Planning	248
9.8.10	Psychology	248
9.8.11	Reliability Analysis	248
9.8.12	Scheduling	249
9.8.13	Speech Recognition	249
9.8.14	Vehicle Control and Malfunction Diagnosis	249
10	Learning Probabilistic Model Parameters	257
10.1	Learning a Single Parameter	257
10.1.1	Binomial Random Variables	258
10.1.2	Multinomial Random Variables	260
10.2	Learning Parameters in a Bayesian Network	261
10.2.1	Procedure for Learning Parameters	262
10.2.2	Equivalent Sample Size	263
10.3	Learning Parameters with Missing Data★	266
11	Learning Probabilistic Model Structure	275
11.1	Structure Learning Problem	276
11.2	Score-Based Structure Learning	276
11.2.1	Bayesian Score	276
11.2.2	BIC Score	283
11.2.3	Consistent Scoring Criteria	284
11.2.4	How Many DAGs Must We Score?	285
11.2.5	Using the Learned Network to Do Inference	285
11.2.6	Learning Structure with Missing Data★	286
11.2.7	Approximate Structure Learning	293
11.2.8	Model Averaging	297
11.2.9	Approximate Model Averaging★	300
11.3	Constraint-Based Structure Learning	303
11.3.1	Learning a DAG Faithful to P	303
11.3.2	Learning a DAG in which P Is Embedded Faithfully	307
11.4	Application: MENTOR	308
11.4.1	Developing the Network	308
11.4.2	Validating MENTOR	310
11.5	Software Packages for Learning	311
11.6	Causal Learning	312

11.6.1	Causal Faithfulness Assumption	312
11.6.2	Causal Embedded Faithfulness Assumption	314
11.6.3	Application: College Student Retention Rate	317
11.7	Class Probability Trees	320
11.7.1	Theory of Class Probability Trees	320
11.7.2	Application to Targeted Advertising	322
11.8	Discussion and Further Reading	325
11.8.1	Biology	325
11.8.2	Business and Finance	326
11.8.3	Causal Learning	326
11.8.4	Data Mining	326
11.8.5	Medicine	326
11.8.6	Weather Forecasting	326
12	Unsupervised Learning and Reinforcement Learning	331
12.1	Unsupervised Learning	331
12.1.1	Clustering	331
12.1.2	Automated Discovery	333
12.2	Reinforcement Learning	333
12.2.1	Multi-Armed Bandit Algorithms	333
12.2.2	Dynamic Networks★	336
12.3	Discussion and Further Reading	345
III	Emergent Intelligence	349
13	Evolutionary Computation	351
13.1	Genetics Review	352
13.2	Genetic Algorithms	354
13.2.1	Algorithm	354
13.2.2	Illustrative Example	355
13.2.3	Traveling Salesperson Problem	357
13.3	Genetic Programming	364
13.3.1	Illustrative Example	365
13.3.2	Artificial Ant	367
13.3.3	Application to Financial Trading	370
13.4	Discussion and Further Reading	373
14	Swarm Intelligence	377
14.1	Ant System	377
14.1.1	Real Ant Colonies	378
14.1.2	Artificial Ants for Solving the TSP	378
14.2	Flocks	381
14.3	Discussion and Further Reading	383
IV	Neural Intelligence	387
15	Neural Networks and Deep Learning	389
15.1	The Perceptron	389
15.1.1	Learning the Weights for a Perceptron	391
15.1.2	The Perceptron and Logistic Regression	394

15.2	Feedforward Neural Networks	395
15.2.1	Modeling XOR	395
15.2.2	Example with Two Hidden Layers	398
15.2.3	Structure of a Feedforward Neural Network	401
15.3	Activation Functions	403
15.3.1	Output Nodes	403
15.3.2	Hidden Nodes	405
15.4	Application to Image Recognition	407
15.5	Discussion and Further Reading	407
V	Language Understanding	413
16	Natural Language Understanding	415
16.1	Parsing	417
16.1.1	Recursive Parser	418
16.1.2	Ambiguity	420
16.1.3	Dynamic Programming Parser	422
16.1.4	Probabilistic Parser	426
16.1.5	Obtaining Probabilities for a PCFG	428
16.1.6	Lexicalized PCFG	428
16.2	Semantic Interpretation	430
16.3	Concept/Knowledge Interpretation	431
16.4	Information Extraction	432
16.4.1	Applications of Information Extraction	432
16.4.2	Architecture for an Information Extraction System	433
16.5	Discussion and Further Reading	435
References		437
Index		459