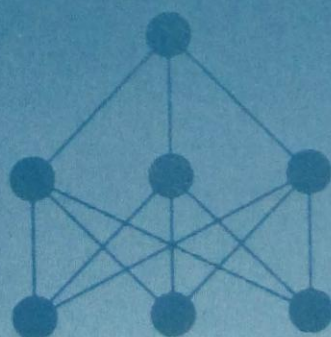


MACHINE LEARNING



TOM M. MITCHELL



McGRAW-HILL INTERNATIONAL EDITIONS
Computer Science Series

MACHINE LEARNING

Tom M. Mitchell

Carnegie Mellon University

ĐẠI HỌC QUỐC GIA HÀ NỘI
TRUNG TÂM THÔNG TIN THU VIỆN

00071001008

The McGraw-Hill Companies, Inc.

New York St. Louis San Francisco Auckland Bogotá Caracas
Lisbon London Madrid Mexico City Milan Montreal New Delhi
San Juan Singapore Sydney Tokyo Toronto

CONTENTS

Preface	xv
Acknowledgments	xvi
1 Introduction	1
1.1 Well-Posed Learning Problems	2
1.2 Designing a Learning System	5
1.2.1 Choosing the Training Experience	5
1.2.2 Choosing the Target Function	7
1.2.3 Choosing a Representation for the Target Function	8
1.2.4 Choosing a Function Approximation Algorithm	9
1.2.5 The Final Design	11
1.3 Perspectives and Issues in Machine Learning	14
1.3.1 Issues in Machine Learning	15
1.4 How to Read This Book	16
1.5 Summary and Further Reading	17
Exercises	18
References	19
2 Concept Learning and the General-to-Specific Ordering	20
2.1 Introduction	20
2.2 A Concept Learning Task	21
2.2.1 Notation	22
2.2.2 The Inductive Learning Hypothesis	23
2.3 Concept Learning as Search	23
2.3.1 General-to-Specific Ordering of Hypotheses	24
2.4 FIND-S: Finding a Maximally Specific Hypothesis	26
2.5 Version Spaces and the CANDIDATE-ELIMINATION Algorithm	29
2.5.1 Representation	29
2.5.2 The LIST-THEN-ELIMINATE Algorithm	30
2.5.3 A More Compact Representation for Version Spaces	30

2.5.4	CANDIDATE-ELIMINATION Learning Algorithm	32
2.5.5	An Illustrative Example	33
2.6	Remarks on Version Spaces and CANDIDATE-ELIMINATION	37
2.6.1	Will the CANDIDATE-ELIMINATION Algorithm Converge to the Correct Hypothesis?	37
2.6.2	What Training Example Should the Learner Request Next?	37
2.6.3	How Can Partially Learned Concepts Be Used?	38
2.7	Inductive Bias	39
2.7.1	A Biased Hypothesis Space	40
2.7.2	An Unbiased Learner	40
2.7.3	The Futility of Bias-Free Learning	42
2.8	Summary and Further Reading	45
	Exercises	47
	References	50
3	Decision Tree Learning	52
3.1	Introduction	52
3.2	Decision Tree Representation	52
3.3	Appropriate Problems for Decision Tree Learning	54
3.4	The Basic Decision Tree Learning Algorithm	55
3.4.1	Which Attribute Is the Best Classifier?	55
3.4.2	An Illustrative Example	59
3.5	Hypothesis Space Search in Decision Tree Learning	60
3.6	Inductive Bias in Decision Tree Learning	63
3.6.1	Restriction Biases and Preference Biases	63
3.6.2	Why Prefer Short Hypotheses?	65
3.7	Issues in Decision Tree Learning	66
3.7.1	Avoiding Overfitting the Data	66
3.7.2	Incorporating Continuous-Valued Attributes	72
3.7.3	Alternative Measures for Selecting Attributes	73
3.7.4	Handling Training Examples with Missing Attribute Values	75
3.7.5	Handling Attributes with Differing Costs	75
3.8	Summary and Further Reading	76
	Exercises	77
	References	78
4	Artificial Neural Networks	81
4.1	Introduction	81
4.1.1	Biological Motivation	82
4.2	Neural Network Representations	82
4.3	Appropriate Problems for Neural Network Learning	83
4.4	Perceptrons	86
4.4.1	Representational Power of Perceptrons	86
4.4.2	The Perceptron Training Rule	88
4.4.3	Gradient Descent and the Delta Rule	89
4.4.4	Remarks	94

4.5	Multilayer Networks and the BACKPROPAGATION Algorithm	95
4.5.1	A Differentiable Threshold Unit	95
4.5.2	The BACKPROPAGATION Algorithm	97
4.5.3	Derivation of the BACKPROPAGATION Rule	101
4.6	Remarks on the BACKPROPAGATION Algorithm	104
4.6.1	Convergence and Local Minima	104
4.6.2	Representational Power of Feedforward Networks	105
4.6.3	Hypothesis Space Search and Inductive Bias	106
4.6.4	Hidden Layer Representations	106
4.6.5	Generalization, Overfitting, and Stopping Criterion	108
4.7	An Illustrative Example: Face Recognition	112
4.7.1	The Task	112
4.7.2	Design Choices	113
4.7.3	Learned Hidden Representations	116
4.8	Advanced Topics in Artificial Neural Networks	117
4.8.1	Alternative Error Functions	117
4.8.2	Alternative Error Minimization Procedures	119
4.8.3	Recurrent Networks	119
4.8.4	Dynamically Modifying Network Structure	121
4.9	Summary and Further Reading	122
	Exercises	124
	References	126
5	Evaluating Hypotheses	128
5.1	Motivation	128
5.2	Estimating Hypothesis Accuracy	129
5.2.1	Sample Error and True Error	130
5.2.2	Confidence Intervals for Discrete-Valued Hypotheses	131
5.3	Basics of Sampling Theory	132
5.3.1	Error Estimation and Estimating Binomial Proportions	133
5.3.2	The Binomial Distribution	135
5.3.3	Mean and Variance	136
5.3.4	Estimators, Bias, and Variance	137
5.3.5	Confidence Intervals	138
5.3.6	Two-Sided and One-Sided Bounds	141
5.4	A General Approach for Deriving Confidence Intervals	142
5.4.1	Central Limit Theorem	143
5.5	Difference in Error of Two Hypotheses	144
5.5.1	Hypothesis Testing	145
5.6	Comparing Learning Algorithms	148
5.6.1	Paired t Tests	149
5.6.2	Practical Considerations	150
5.7	Summary and Further Reading	152
	Exercises	152
	References	154
6	Bayesian Learning	154
6.1	Introduction	156
6.2	Bayes Theorem	157
6.2.1	An Example	

6.3	Bayes Theorem and Concept Learning	158
6.3.1	Brute-Force Bayes Concept Learning	159
6.3.2	MAP Hypotheses and Consistent Learners	162
6.4	Maximum Likelihood and Least-Squared Error Hypotheses	164
6.5	Maximum Likelihood Hypotheses for Predicting Probabilities	167
6.5.1	Gradient Search to Maximize Likelihood in a Neural Net	170
6.6	Minimum Description Length Principle	171
6.7	Bayes Optimal Classifier	174
6.8	Gibbs Algorithm	176
6.9	Naive Bayes Classifier	177
6.9.1	An Illustrative Example	178
6.10	An Example: Learning to Classify Text	180
6.10.1	Experimental Results	182
6.11	Bayesian Belief Networks	184
6.11.1	Conditional Independence	185
6.11.2	Representation	186
6.11.3	Inference	187
6.11.4	Learning Bayesian Belief Networks	188
6.11.5	Gradient Ascent Training of Bayesian Networks	188
6.11.6	Learning the Structure of Bayesian Networks	190
6.12	The EM Algorithm	191
6.12.1	Estimating Means of k Gaussians	191
6.12.2	General Statement of EM Algorithm	194
6.12.3	Derivation of the k Means Algorithm	195
6.13	Summary and Further Reading	197
	Exercises	198
	References	199
7	Computational Learning Theory	201
7.1	Introduction	201
7.2	Probably Learning an Approximately Correct Hypothesis	203
7.2.1	The Problem Setting	203
7.2.2	Error of a Hypothesis	204
7.2.3	PAC Learnability	205
7.3	Sample Complexity for Finite Hypothesis Spaces	207
7.3.1	Agnostic Learning and Inconsistent Hypotheses	210
7.3.2	Conjunctions of Boolean Literals Are PAC-Learnable	211
7.3.3	PAC-Learnability of Other Concept Classes	212
7.4	Sample Complexity for Infinite Hypothesis Spaces	214
7.4.1	Shattering a Set of Instances	214
7.4.2	The Vapnik-Chervonenkis Dimension	215
7.4.3	Sample Complexity and the VC Dimension	217
7.4.4	VC Dimension for Neural Networks	218
7.5	The Mistake Bound Model of Learning	220
7.5.1	Mistake Bound for the FIND-S Algorithm	220
7.5.2	Mistake Bound for the HALVING Algorithm	221
7.5.3	Optimal Mistake Bounds	222
7.5.4	WEIGHTED-MAJORITY Algorithm	223

7.6	Summary and Further Reading	225
	Exercises	227
	References	229
8	Instance-Based Learning	230
8.1	Introduction	230
8.2	<i>k</i> -NEAREST NEIGHBOR LEARNING	231
8.2.1	Distance-Weighted NEAREST NEIGHBOR Algorithm	233
8.2.2	Remarks on <i>k</i> -NEAREST NEIGHBOR Algorithm	234
8.2.3	A Note on Terminology	236
8.3	Locally Weighted Regression	236
8.3.1	Locally Weighted Linear Regression	237
8.3.2	Remarks on Locally Weighted Regression	238
8.4	Radial Basis Functions	238
8.5	Case-Based Reasoning	240
8.6	Remarks on Lazy and Eager Learning	244
8.7	Summary and Further Reading	245
	Exercises	247
	References	247
9	Genetic Algorithms	249
9.1	Motivation	249
9.2	Genetic Algorithms	250
9.2.1	Representing Hypotheses	252
9.2.2	Genetic Operators	253
9.2.3	Fitness Function and Selection	255
9.3	An Illustrative Example	256
9.3.1	Extensions	258
9.4	Hypothesis Space Search	259
9.4.1	Population Evolution and the Schema Theorem	260
9.5	Genetic Programming	262
9.5.1	Representing Programs	262
9.5.2	Illustrative Example	263
9.5.3	Remarks on Genetic Programming	265
9.6	Models of Evolution and Learning	266
9.6.1	Lamarckian Evolution	266
9.6.2	Baldwin Effect	267
9.7	Parallelizing Genetic Algorithms	268
9.8	Summary and Further Reading	270
	Exercises	270
	References	274
10	Learning Sets of Rules	274
10.1	Introduction	275
10.2	Sequential Covering Algorithms	277
10.2.1	General to Specific Beam Search	279
10.2.2	Variations	280
10.3	Learning Rule Sets: Summary	

10.4	Learning First-Order Rules	283
10.4.1	First-Order Horn Clauses	283
10.4.2	Terminology	284
10.5	Learning Sets of First-Order Rules: FOIL	285
10.5.1	Generating Candidate Specializations in FOIL	287
10.5.2	Guiding the Search in FOIL	288
10.5.3	Learning Recursive Rule Sets	290
10.5.4	Summary of FOIL	290
10.6	Induction as Inverted Deduction	291
10.7	Inverting Resolution	293
10.7.1	First-Order Resolution	296
10.7.2	Inverting Resolution: First-Order Case	297
10.7.3	Summary of Inverse Resolution	298
10.7.4	Generalization, θ -Subsumption, and Entailment	299
10.7.5	PROGOL	300
10.8	Summary and Further Reading	301
	Exercises	303
	References	304
11	Analytical Learning	307
11.1	Introduction	307
11.1.1	Inductive and Analytical Learning Problems	310
11.2	Learning with Perfect Domain Theories: PROLOG-EBG	312
11.2.1	An Illustrative Trace	313
11.3	Remarks on Explanation-Based Learning	319
11.3.1	Discovering New Features	320
11.3.2	Deductive Learning	321
11.3.3	Inductive Bias in Explanation-Based Learning	322
11.3.4	Knowledge Level Learning	323
11.4	Explanation-Based Learning of Search Control Knowledge	325
11.5	Summary and Further Reading	328
	Exercises	330
	References	331
12	Combining Inductive and Analytical Learning	334
12.1	Motivation	334
12.2	Inductive-Analytical Approaches to Learning	337
12.2.1	The Learning Problem	337
12.2.2	Hypothesis Space Search	339
12.3	Using Prior Knowledge to Initialize the Hypothesis	340
12.3.1	The KBANN Algorithm	340
12.3.2	An Illustrative Example	341
12.3.3	Remarks	344
12.4	Using Prior Knowledge to Alter the Search Objective	346
12.4.1	The TANGENTPROP Algorithm	347
12.4.2	An Illustrative Example	349
12.4.3	Remarks	350
12.4.4	The EBNN Algorithm	351
12.4.5	Remarks	355

12.5	Using Prior Knowledge to Augment Search Operators	357
12.5.1	The FOCL Algorithm	357
12.5.2	Remarks	360
12.6	State of the Art	361
12.7	Summary and Further Reading	362
	Exercises	363
	References	364
13	Reinforcement Learning	367
13.1	Introduction	367
13.2	The Learning Task	370
13.3	Q Learning	373
13.3.1	The Q Function	374
13.3.2	An Algorithm for Learning Q	374
13.3.3	An Illustrative Example	376
13.3.4	Convergence	377
13.3.5	Experimentation Strategies	379
13.3.6	Updating Sequence	379
13.4	Nondeterministic Rewards and Actions	381
13.5	Temporal Difference Learning	383
13.6	Generalizing from Examples	384
13.7	Relationship to Dynamic Programming	385
13.8	Summary and Further Reading	386
	Exercises	388
	References	388
Appendix	Notation	391
	Indexes	
	Author Index	394
	Subject Index	400