

# Contents

<i>List of Figures</i>	page ix
<i>List of Tables</i>	xi
<i>Preface</i>	xiii
<i>Notation</i>	xvi

## Part I Introduction and Overview

<b>1</b>	<b>Introduction</b>	3
	1.1 An Example: Autonomous Driving	4
	1.2 Pattern Recognition and Machine Learning	6
	Exercises	12
<b>2</b>	<b>Mathematical Background</b>	15
	2.1 Linear Algebra	15
	2.2 Probability	25
	2.3 Optimization and Matrix Calculus	34
	2.4 Complexity of Algorithms	39
	2.5 Miscellaneous Notes and Additional Resources	40
	Exercises	41
<b>3</b>	<b>Overview of a Pattern Recognition System</b>	44
	3.1 Face Recognition	44
	3.2 A Simple Nearest Neighbor Classifier	45
	3.3 The Ugly Details	49
	3.4 Making Assumptions and Simplifications	52
	3.5 A Framework	59
	3.6 Miscellaneous Notes and Additional Resources	59
	Exercises	61
<b>4</b>	<b>Evaluation</b>	63
	4.1 Accuracy and Error in the Simple Case	63
	4.2 Minimizing the Cost/Loss	70
	4.3 Evaluation in Imbalanced Problems	73

---

4.4	Can We Reach 100% Accuracy?	79
4.5	Confidence in the Evaluation Results	85
4.6	Miscellaneous Notes and Additional Resources	92
	Exercises	93
<b>Part II Domain-Independent Feature Extraction</b>		
<b>5</b>	<b>Principal Component Analysis</b>	101
5.1	Motivation	101
5.2	PCA to Zero-Dimensional Subspace	104
5.3	PCA to One-Dimensional Subspace	106
5.4	PCA for More Dimensions	110
5.5	The Complete PCA Algorithm	110
5.6	Variance Analysis	111
5.7	When to Use or Not to Use PCA?	115
5.8	The Whitening Transform	118
5.9	Eigen-Decomposition vs. SVD	118
5.10	Miscellaneous Notes and Additional Resources	119
	Exercises	119
<b>6</b>	<b>Fisher's Linear Discriminant</b>	123
6.1	FLD for Binary Classification	125
6.2	FLD for More Classes	132
6.3	Miscellaneous Notes and Additional Resources	135
	Exercises	136
<b>Part III Classifiers and Tools</b>		
<b>7</b>	<b>Support Vector Machines</b>	143
7.1	The Key SVM Idea	143
7.2	Visualizing and Calculating the Margin	147
7.3	Maximizing the Margin	150
7.4	The Optimization and the Solution	152
7.5	Extensions for Linearly Inseparable and Multiclass Problems	157
7.6	Kernel SVMs	161
7.7	Miscellaneous Notes and Additional Resources	167
	Exercises	167
<b>8</b>	<b>Probabilistic Methods</b>	173
8.1	The Probabilistic Way of Thinking	173
8.2	Choices	175
8.3	Parametric Estimation	178
8.4	Nonparametric Estimation	184

	8.5 Making Decisions	191
	8.6 Miscellaneous Notes and Additional Resources	192
	Exercises	192
<b>9</b>	<b>Distance Metrics and Data Transformations</b>	<b>196</b>
	9.1 Distance Metrics and Similarity Measures	196
	9.2 Data Transformation and Normalization	207
	9.3 Miscellaneous Notes and Additional Resources	213
	Exercises	213
<b>10</b>	<b>Information Theory and Decision Trees</b>	<b>219</b>
	10.1 Prefix Code and Huffman Tree	219
	10.2 Basics of Information Theory	221
	10.3 Information Theory for Continuous Distributions	226
	10.4 Information Theory in ML and PR	231
	10.5 Decision Trees	234
	10.6 Miscellaneous Notes and Additional Resources	239
	Exercises	239
	<b>Part IV Handling Diverse Data Formats</b>	
<b>11</b>	<b>Sparse and Misaligned Data</b>	<b>245</b>
	11.1 Sparse Machine Learning	245
	11.2 Dynamic Time Warping	254
	11.3 Miscellaneous Notes and Additional Resources	262
	Exercises	262
<b>12</b>	<b>Hidden Markov Model</b>	<b>266</b>
	12.1 Sequential Data and the Markov Property	266
	12.2 Three Basic Problems in HMM Learning	274
	12.3 $\alpha$ , $\beta$ , and the Evaluation Problem	275
	12.4 $\gamma$ , $\delta$ , $\psi$ , and the Decoding Problem	280
	12.5 $\xi$ and Learning HMM Parameters	283
	12.6 Miscellaneous Notes and Additional Resources	286
	Exercises	287
	<b>Part V Advanced Topics</b>	
<b>13</b>	<b>The Normal Distribution</b>	<b>293</b>
	13.1 Definition	293
	13.2 Notation and Parameterization	296
	13.3 Linear Operation and Summation	297
	13.4 Geometry and the Mahalanobis Distance	299

---

13.5	Conditioning	300
13.6	Product of Gaussians	302
13.7	Application I: Parameter Estimation	303
13.8	Application II: Kalman Filter	305
13.9	Useful Math in This Chapter	307
	Exercises	312
<b>14</b>	<b>The Basic Idea behind Expectation-Maximization</b>	<b>316</b>
14.1	GMM: A Worked Example	316
14.2	An Informal Description of the EM Algorithm	321
14.3	The Expectation-Maximization Algorithm	321
14.4	EM for GMM	328
14.5	Miscellaneous Notes and Additional Resources	330
	Exercises	331
<b>15</b>	<b>Convolutional Neural Networks</b>	<b>333</b>
15.1	Preliminaries	334
15.2	CNN Overview	336
15.3	Layer Input, Output, and Notation	341
15.4	The ReLU Layer	342
15.5	The Convolution Layer	344
15.6	The Pooling Layer	356
15.7	A Case Study: The VGG16 Net	359
15.8	Hands-On CNN Experiences	361
15.9	Miscellaneous Notes and Additional Resources	362
	Exercises	362
	<i>Bibliography</i>	365
	<i>Index</i>	379

*The plate section can be found between pages 208 and 209*