

# Contents

Preface — V

List of Tables — XI

List of Figures — XIII

Notation — XVII

Introduction — XIX

**1 Fundamentals and definitions — 1**

1.1 Goals of pattern recognition — 1

1.2 Structure of a pattern recognition system — 2

1.3 Abstract view of pattern recognition — 4

1.4 Design of a pattern recognition system — 5

1.5 Exercises — 9

**2 Features — 10**

2.1 Types of features and their traits — 10

2.1.1 Nominal scale — 10

2.1.2 Ordinal scale — 12

2.1.3 Interval scale — 13

2.1.4 Ratio scale and absolute scale — 13

2.2 Feature space inspection — 13

2.2.1 Projections — 14

2.2.2 Intersections and slices — 15

2.3 Transformations of the feature space — 17

2.4 Measurement of distances in the feature space — 17

2.4.1 Basic definitions — 19

2.4.2 Elementary norms and metrics — 20

2.4.3 A metric for sets — 22

2.4.4 Metrics on the ordinal scale — 23

2.4.5 The Kullback–Leibler divergence — 23

2.4.6 Tangential distance measure — 28

2.5 Normalization — 32

2.5.1 Alignment, elimination of physical dimension, and leveling of proportions — 32

2.5.2 Lighting adjustment of images — 33

2.5.3 Distortion adjustment of images — 37

2.5.4	Dynamic time warping —	<b>38</b>
2.6	Selection and construction of features —	<b>39</b>
2.6.1	Descriptive features —	<b>39</b>
2.6.2	Model-driven features —	<b>43</b>
2.6.3	Construction of invariant features —	<b>48</b>
2.7	Dimensionality reduction of the feature space —	<b>56</b>
2.7.1	Principal component analysis —	<b>57</b>
2.7.2	Kernelized principal component analysis —	<b>69</b>
2.7.3	Independent component analysis —	<b>76</b>
2.7.4	Multiple discriminant analysis —	<b>80</b>
2.7.5	Dimensionality reduction by feature selection —	<b>87</b>
2.7.6	Bag of words —	<b>88</b>
2.8	Exercises —	<b>94</b>
<b>3</b>	<b>Bayesian decision theory —</b>	<b>98</b>
3.1	General considerations —	<b>98</b>
3.2	The maximum a posteriori classifier —	<b>101</b>
3.3	Bayesian classification —	<b>104</b>
3.3.1	The Bayesian optimal classifier —	<b>104</b>
3.3.2	Reference example: Optimal decision regions —	<b>109</b>
3.3.3	The minimax classifier —	<b>111</b>
3.3.4	Normally distributed features —	<b>113</b>
3.3.5	Arbitrarily distributed features —	<b>118</b>
3.4	Exercises —	<b>119</b>
<b>4</b>	<b>Parameter estimation —</b>	<b>122</b>
4.1	Maximum likelihood estimation —	<b>130</b>
4.2	Bayesian estimation of the class-specific distributions —	<b>132</b>
4.3	Bayesian parameter estimation —	<b>137</b>
4.3.1	Least squared estimation error —	<b>138</b>
4.3.2	Constant penalty for failures —	<b>138</b>
4.4	Additional remarks on Bayesian classification —	<b>139</b>
4.5	Exercises —	<b>140</b>
<b>5</b>	<b>Parameter free methods —</b>	<b>142</b>
5.1	The Parzen window method —	<b>146</b>
5.2	The $k$ -nearest neighbor method —	<b>150</b>
5.3	$k$ -nearest neighbor classification —	<b>154</b>
5.4	Exercises —	<b>160</b>
<b>6</b>	<b>General considerations —</b>	<b>162</b>
6.1	Dimensionality of the feature space —	<b>162</b>

- 6.2 Overfitting — 169
- 6.3 Exercises — 171
  
- 7 Special classifiers — 173**
  - 7.1 Linear discriminants — 173
    - 7.1.1 More than two classes — 173
    - 7.1.2 Nonlinear separation — 175
  - 7.2 The perceptron — 177
  - 7.3 Linear regression — 179
  - 7.4 Artificial neural networks — 180
  - 7.5 Autoencoders — 184
  - 7.6 Deep learning — 184
    - 7.6.1 Historical difficulties and successful approaches — 185
    - 7.6.2 Unsupervised pre-training — 186
    - 7.6.3 Stochastic gradient descent — 187
    - 7.6.4 Rectified linear units — 188
    - 7.6.5 Convolutional neural networks — 189
  - 7.7 Support vector machines — 194
    - 7.7.1 Linear separation with maximum margin — 194
    - 7.7.2 Dual formulation — 196
    - 7.7.3 Nonlinear mapping — 198
    - 7.7.4 The kernel trick — 199
    - 7.7.5 No linear separability — 203
    - 7.7.6 Discussion — 205
  - 7.8 Matched filters — 206
  - 7.9 Classification of sequences — 210
    - 7.9.1 Markov models — 210
    - 7.9.2 Hidden states — 212
  - 7.10 Exercises — 214
  
- 8 Classification with nominal features — 215**
  - 8.1 Decision trees — 215
    - 8.1.1 Decision tree learning — 218
    - 8.1.2 Influence of the features used — 222
  - 8.2 Random forests — 222
  - 8.3 String matching — 227
  - 8.4 Grammars — 228
  - 8.5 Exercises — 229
  
- 9 Classifier-independent concepts — 231**
  - 9.1 Learning theory — 231
    - 9.1.1 The central problem of statistical learning — 232

9.1.2	Vapnik–Chervonenkis learning theory —	<b>232</b>
9.2	Empirical evaluation of classifier performance —	<b>235</b>
9.2.1	Receiver operating characteristic —	<b>238</b>
9.2.2	Multi-class setting —	<b>238</b>
9.2.3	Theoretical bounds with finite test sets —	<b>240</b>
9.2.4	Dealing with small datasets —	<b>241</b>
9.3	Boosting —	<b>242</b>
9.4	Rejection —	<b>244</b>
9.5	Exercises —	<b>247</b>

**A Solutions to the exercises — 249**

A.1	Chapter 1 —	<b>249</b>
A.2	Chapter 2 —	<b>250</b>
A.3	Chapter 3 —	<b>252</b>
A.4	Chapter 4 —	<b>255</b>
A.5	Chapter 5 —	<b>257</b>
A.6	Chapter 6 —	<b>259</b>
A.7	Chapter 7 —	<b>260</b>
A.8	Chapter 8 —	<b>261</b>
A.9	Chapter 9 —	<b>262</b>

**B A primer on Lie theory — 263**

**C Random processes — 268**

**Bibliography — 271**

**Glossary — 275**

**Index — 281**