

# Contents

|                                     |            |
|-------------------------------------|------------|
| <b>Acknowledgements</b>             | <b>xix</b> |
| <b>Preface</b>                      | <b>xxi</b> |
| References                          | xxxix      |
| <br>                                |            |
| <b>Part I Preliminaries</b>         | <b>1</b>   |
| 1 Tasks                             | 3          |
| 1.1 Introduction                    | 3          |
| 1.1.1 Knowledge                     | 4          |
| 1.1.2 Inference                     | 4          |
| 1.2 Inductive learning tasks        | 5          |
| 1.2.1 Domain                        | 5          |
| 1.2.2 Instances                     | 5          |
| 1.2.3 Attributes                    | 5          |
| 1.2.4 Target attribute              | 6          |
| 1.2.5 Input attributes              | 6          |
| 1.2.6 Training set                  | 6          |
| 1.2.7 Model                         | 7          |
| 1.2.8 Performance                   | 7          |
| 1.2.9 Generalization                | 8          |
| 1.2.10 Overfitting                  | 8          |
| 1.2.11 Algorithms                   | 8          |
| 1.2.12 Inductive learning as search | 9          |
| 1.3 Classification                  | 9          |
| 1.3.1 Concept                       | 10         |
| 1.3.2 Training set                  | 10         |
| 1.3.3 Model                         | 11         |
| 1.3.4 Performance                   | 12         |
| 1.3.5 Generalization                | 13         |
| 1.3.6 Overfitting                   | 13         |
| 1.3.7 Algorithms                    | 13         |

|       |                                       |    |
|-------|---------------------------------------|----|
| 1.4   | Regression                            | 14 |
| 1.4.1 | Target function                       | 14 |
| 1.4.2 | Training set                          | 14 |
| 1.4.3 | Model                                 | 15 |
| 1.4.4 | Performance                           | 15 |
| 1.4.5 | Generalization                        | 15 |
| 1.4.6 | Overfitting                           | 15 |
| 1.4.7 | Algorithms                            | 16 |
| 1.5   | Clustering                            | 16 |
| 1.5.1 | Motivation                            | 16 |
| 1.5.2 | Training set                          | 17 |
| 1.5.3 | Model                                 | 18 |
| 1.5.4 | Crisp vs. soft clustering             | 18 |
| 1.5.5 | Hierarchical clustering               | 18 |
| 1.5.6 | Performance                           | 18 |
| 1.5.7 | Generalization                        | 19 |
| 1.5.8 | Algorithms                            | 19 |
| 1.5.9 | Descriptive vs. predictive clustering | 19 |
| 1.6   | Practical issues                      | 19 |
| 1.6.1 | Incomplete data                       | 20 |
| 1.6.2 | Noisy data                            | 20 |
| 1.7   | Conclusion                            | 20 |
| 1.8   | Further readings                      | 21 |
|       | References                            | 22 |
| 2     | Basic statistics                      | 23 |
| 2.1   | Introduction                          | 23 |
| 2.2   | Notational conventions                | 24 |
| 2.3   | Basic statistics as modeling          | 24 |
| 2.4   | Distribution description              | 25 |
| 2.4.1 | Continuous attributes                 | 25 |
| 2.4.2 | Discrete attributes                   | 36 |
| 2.4.3 | Confidence intervals                  | 40 |
| 2.4.4 | $m$ -Estimation                       | 43 |
| 2.5   | Relationship detection                | 47 |
| 2.5.1 | Significance tests                    | 48 |
| 2.5.2 | Continuous attributes                 | 50 |
| 2.5.3 | Discrete attributes                   | 52 |
| 2.5.4 | Mixed attributes                      | 56 |
| 2.5.5 | Relationship detection caveats        | 61 |
| 2.6   | Visualization                         | 62 |
| 2.6.1 | Boxplot                               | 62 |
| 2.6.2 | Histogram                             | 63 |
| 2.6.3 | Barplot                               | 64 |
| 2.7   | Conclusion                            | 65 |
| 2.8   | Further readings                      | 66 |
|       | References                            | 67 |

|                |   |           |
|----------------|---|-----------|
| <b>Part II</b> | <b>Classification</b>                     | <b>69</b> |
| 3              | Decision trees                            | 71        |
| 3.1            | Introduction                              | 71        |
| 3.2            | Decision tree model                       | 72        |
| 3.2.1          | Nodes and branches                        | 72        |
| 3.2.2          | Leaves                                    | 74        |
| 3.2.3          | Split types                               | 74        |
| 3.3            | Growing                                   | 76        |
| 3.3.1          | Algorithm outline                         | 76        |
| 3.3.2          | Class distribution calculation            | 78        |
| 3.3.3          | Class label assignment                    | 79        |
| 3.3.4          | Stop criteria                             | 80        |
| 3.3.5          | Split selection                           | 82        |
| 3.3.6          | Split application                         | 86        |
| 3.3.7          | Complete process                          | 86        |
| 3.4            | Pruning                                   | 90        |
| 3.4.1          | Pruning operators                         | 91        |
| 3.4.2          | Pruning criterion                         | 91        |
| 3.4.3          | Pruning control strategy                  | 100       |
| 3.4.4          | Conversion to rule sets                   | 101       |
| 3.5            | Prediction                                | 103       |
| 3.5.1          | Class label prediction                    | 104       |
| 3.5.2          | Class probability prediction              | 104       |
| 3.6            | Weighted instances                        | 105       |
| 3.7            | Missing value handling                    | 106       |
| 3.7.1          | Fractional instances                      | 106       |
| 3.7.2          | Surrogate splits                          | 113       |
| 3.8            | Conclusion                                | 114       |
| 3.9            | Further readings                          | 114       |
|                | References                                | 116       |
| 4              | Naïve Bayes classifier                    | 118       |
| 4.1            | Introduction                              | 118       |
| 4.2            | Bayes rule                                | 118       |
| 4.3            | Classification by Bayesian inference      | 120       |
| 4.3.1          | Conditional class probability             | 120       |
| 4.3.2          | Prior class probability                   | 121       |
| 4.3.3          | Independence assumption                   | 122       |
| 4.3.4          | Conditional attribute value probabilities | 122       |
| 4.3.5          | Model construction                        | 123       |
| 4.3.6          | Prediction                                | 124       |
| 4.4            | Practical issues                          | 125       |
| 4.4.1          | Zero and small probabilities              | 125       |
| 4.4.2          | Linear classification                     | 126       |
| 4.4.3          | Continuous attributes                     | 127       |

|       |                                       |     |
|-------|---------------------------------------|-----|
| 4.4.4 | Missing attribute values              | 128 |
| 4.4.5 | Reducing naïvety                      | 129 |
| 4.5   | Conclusion                            | 131 |
| 4.6   | Further readings                      | 131 |
|       | References                            | 132 |
| 5     | Linear classification                 | 134 |
| 5.1   | Introduction                          | 134 |
| 5.2   | Linear representation                 | 136 |
| 5.2.1 | Inner representation function         | 137 |
| 5.2.2 | Outer representation function         | 138 |
| 5.2.3 | Threshold representation              | 139 |
| 5.2.4 | Logit representation                  | 142 |
| 5.3   | Parameter estimation                  | 145 |
| 5.3.1 | Delta rule                            | 145 |
| 5.3.2 | Gradient descent                      | 149 |
| 5.3.3 | Distance to decision boundary         | 152 |
| 5.3.4 | Least squares                         | 153 |
| 5.4   | Discrete attributes                   | 154 |
| 5.5   | Conclusion                            | 155 |
| 5.6   | Further readings                      | 156 |
|       | References                            | 157 |
| 6     | Misclassification costs               | 159 |
| 6.1   | Introduction                          | 159 |
| 6.2   | Cost representation                   | 161 |
| 6.2.1 | Cost matrix                           | 161 |
| 6.2.2 | Per-class cost vector                 | 162 |
| 6.2.3 | Instance-specific costs               | 163 |
| 6.3   | Incorporating misclassification costs | 164 |
| 6.3.1 | Instance weighting                    | 164 |
| 6.3.2 | Instance resampling                   | 167 |
| 6.3.3 | Minimum-cost rule                     | 169 |
| 6.3.4 | Instance relabeling                   | 174 |
| 6.4   | Effects of cost incorporation         | 176 |
| 6.5   | Experimental procedure                | 180 |
| 6.6   | Conclusion                            | 184 |
| 6.7   | Further readings                      | 185 |
|       | References                            | 187 |
| 7     | Classification model evaluation       | 189 |
| 7.1   | Introduction                          | 189 |
| 7.1.1 | Dataset performance                   | 189 |
| 7.1.2 | Training performance                  | 189 |
| 7.1.3 | True performance                      | 189 |
| 7.2   | Performance measures                  | 190 |
| 7.2.1 | Misclassification error               | 191 |

|       |  |     |
|-------|--|-----|
| 7.2.2 | Weighted misclassification error                   | 191 |
| 7.2.3 | Mean misclassification cost                        | 192 |
| 7.2.4 | Confusion matrix                                   | 194 |
| 7.2.5 | ROC analysis                                       | 200 |
| 7.2.6 | Probabilistic performance measures                 | 210 |
| 7.3   | Evaluation procedures                              | 213 |
| 7.3.1 | Model evaluation vs. modeling procedure evaluation | 213 |
| 7.3.2 | Evaluation caveats                                 | 214 |
| 7.3.3 | Hold-out   | 217 |
| 7.3.4 | Cross-validation                                   | 219 |
| 7.3.5 | Leave-one-out                                      | 221 |
| 7.3.6 | Bootstrapping                                      | 223 |
| 7.3.7 | Choosing the right procedure                       | 227 |
| 7.3.8 | Evaluation procedures for temporal data            | 230 |
| 7.4   | Conclusion   | 231 |
| 7.5   | Further readings                                   | 232 |
|       | References   | 233 |

## **Part III Regression 235**

|       |                                    |     |
|-------|------------------------------------|-----|
| 8     | Linear regression                  | 237 |
| 8.1   | Introduction                       | 237 |
| 8.2   | Linear representation              | 238 |
| 8.2.1 | Parametric representation          | 239 |
| 8.2.2 | Linear representation function     | 240 |
| 8.2.3 | Nonlinear representation functions | 241 |
| 8.3   | Parameter estimation               | 242 |
| 8.3.1 | Mean square error minimization     | 242 |
| 8.3.2 | Delta rule                         | 243 |
| 8.3.3 | Gradient descent                   | 245 |
| 8.3.4 | Least squares                      | 248 |
| 8.4   | Discrete attributes                | 250 |
| 8.5   | Advantages of linear models        | 251 |
| 8.6   | Beyond linearity                   | 252 |
| 8.6.1 | Generalized linear representation  | 252 |
| 8.6.2 | Enhanced representation            | 255 |
| 8.6.3 | Polynomial regression              | 256 |
| 8.6.4 | Piecewise-linear regression        | 257 |
| 8.7   | Conclusion                         | 258 |
| 8.8   | Further readings                   | 258 |
|       | References                         | 259 |
| 9     | Regression trees                   | 261 |
| 9.1   | Introduction                       | 261 |
| 9.2   | Regression tree model              | 262 |
| 9.2.1 | Nodes and branches                 | 262 |

|        |                                    |     |
|--------|------------------------------------|-----|
| 9.2.2  | Leaves                             | 262 |
| 9.2.3  | Split types                        | 262 |
| 9.2.4  | Piecewise-constant regression      | 262 |
| 9.3    | Growing                            | 263 |
| 9.3.1  | Algorithm outline                  | 264 |
| 9.3.2  | Target function summary statistics | 265 |
| 9.3.3  | Target value assignment            | 266 |
| 9.3.4  | Stop criteria                      | 267 |
| 9.3.5  | Split selection                    | 268 |
| 9.3.6  | Split application                  | 271 |
| 9.3.7  | Complete process                   | 272 |
| 9.4    | Pruning                            | 274 |
| 9.4.1  | Pruning operators                  | 275 |
| 9.4.2  | Pruning criterion                  | 275 |
| 9.4.3  | Pruning control strategy           | 277 |
| 9.5    | Prediction                         | 277 |
| 9.6    | Weighted instances                 | 278 |
| 9.7    | Missing value handling             | 279 |
| 9.7.1  | Fractional instances               | 279 |
| 9.7.2  | Surrogate splits                   | 284 |
| 9.8    | Piecewise linear regression        | 284 |
| 9.8.1  | Growing                            | 285 |
| 9.8.2  | Pruning                            | 289 |
| 9.8.3  | Prediction                         | 290 |
| 9.9    | Conclusion                         | 292 |
| 9.10   | Further readings                   | 292 |
|        | References                         | 293 |
| 10     | Regression model evaluation        | 295 |
| 10.1   | Introduction                       | 295 |
| 10.1.1 | Dataset performance                | 295 |
| 10.1.2 | Training performance               | 295 |
| 10.1.3 | True performance                   | 295 |
| 10.2   | Performance measures               | 296 |
| 10.2.1 | Residuals                          | 296 |
| 10.2.2 | Mean absolute error                | 297 |
| 10.2.3 | Mean square error                  | 297 |
| 10.2.4 | Root mean square error             | 299 |
| 10.2.5 | Relative absolute error            | 299 |
| 10.2.6 | Coefficient of determination       | 300 |
| 10.2.7 | Correlation                        | 301 |
| 10.2.8 | Weighted performance measures      | 301 |
| 10.2.9 | Loss functions                     | 302 |
| 10.3   | Evaluation procedures              | 303 |
| 10.3.1 | Hold-out                           | 304 |
| 10.3.2 | Cross-validation                   | 304 |

|                           |  |            |
|---------------------------|--|------------|
| 10.3.3                    | Leave-one-out                          | 305        |
| 10.3.4                    | Bootstrapping                          | 305        |
| 10.3.5                    | Choosing the right procedure           | 307        |
| 10.4                      | Conclusion                             | 309        |
| 10.5                      | Further readings                       | 309        |
|                           | References                             | 310        |
| <b>Part IV Clustering</b> |  | <b>311</b> |
| 11                        | (Dis)similarity measures               | 313        |
| 11.1                      | Introduction                           | 313        |
| 11.2                      | Measuring dissimilarity and similarity | 313        |
| 11.3                      | Difference-based dissimilarity         | 314        |
| 11.3.1                    | Euclidean distance                     | 314        |
| 11.3.2                    | Minkowski distance                     | 315        |
| 11.3.3                    | Manhattan distance                     | 316        |
| 11.3.4                    | Canberra distance                      | 316        |
| 11.3.5                    | Chebyshev distance                     | 317        |
| 11.3.6                    | Hamming distance                       | 318        |
| 11.3.7                    | Gower's coefficient                    | 318        |
| 11.3.8                    | Attribute weighting                    | 320        |
| 11.3.9                    | Attribute transformation               | 320        |
| 11.4                      | Correlation-based similarity           | 321        |
| 11.4.1                    | Discrete attributes                    | 322        |
| 11.4.2                    | Pearson's correlation similarity       | 322        |
| 11.4.3                    | Spearman's correlation similarity      | 323        |
| 11.4.4                    | Cosine similarity                      | 323        |
| 11.5                      | Missing attribute values               | 324        |
| 11.6                      | Conclusion                             | 325        |
| 11.7                      | Further readings                       | 325        |
|                           | References                             | 326        |
| 12                        | <i>k</i> -Centers clustering           | 328        |
| 12.1                      | Introduction                           | 328        |
| 12.1.1                    | Basic principle                        | 328        |
| 12.1.2                    | (Dis)similarity measures               | 329        |
| 12.2                      | Algorithm scheme                       | 330        |
| 12.2.1                    | Initialization                         | 331        |
| 12.2.2                    | Stop criteria                          | 331        |
| 12.2.3                    | Cluster formation                      | 331        |
| 12.2.4                    | Implicit cluster modeling              | 332        |
| 12.2.5                    | Instantiations                         | 332        |
| 12.3                      | <i>k</i> -Means                        | 334        |
| 12.3.1                    | Center adjustment                      | 335        |
| 12.3.2                    | Minimizing dissimilarity to centers    | 336        |

|        |                                       |     |
|--------|---------------------------------------|-----|
| 12.4   | Beyond means                          | 338 |
| 12.4.1 | $k$ -Medians                          | 338 |
| 12.4.2 | $k$ -Medoids                          | 339 |
| 12.5   | Beyond (fixed) $k$                    | 342 |
| 12.5.1 | Multiple runs                         | 343 |
| 12.5.2 | Adaptive $k$ -centers                 | 343 |
| 12.6   | Explicit cluster modeling             | 343 |
| 12.7   | Conclusion                            | 345 |
| 12.8   | Further readings                      | 345 |
|        | References                            | 347 |
| 13     | Hierarchical clustering               | 349 |
| 13.1   | Introduction                          | 349 |
| 13.1.1 | Basic approaches                      | 349 |
| 13.1.2 | (Dis)similarity measures              | 349 |
| 13.2   | Cluster hierarchies                   | 351 |
| 13.2.1 | Motivation                            | 351 |
| 13.2.2 | Model representation                  | 352 |
| 13.3   | Agglomerative clustering              | 353 |
| 13.3.1 | Algorithm scheme                      | 353 |
| 13.3.2 | Cluster linkage                       | 356 |
| 13.4   | Divisive clustering                   | 361 |
| 13.4.1 | Algorithm scheme                      | 361 |
| 13.4.2 | Wrapping a flat clustering algorithm  | 361 |
| 13.4.3 | Stop criteria                         | 362 |
| 13.5   | Hierarchical clustering visualization | 364 |
| 13.6   | Hierarchical clustering prediction    | 366 |
| 13.6.1 | Cutting cluster hierarchies           | 366 |
| 13.6.2 | Cluster membership assignment         | 368 |
| 13.7   | Conclusion                            | 369 |
| 13.8   | Further readings                      | 370 |
|        | References                            | 371 |
| 14     | Clustering model evaluation           | 373 |
| 14.1   | Introduction                          | 373 |
| 14.1.1 | Dataset performance                   | 373 |
| 14.1.2 | Training performance                  | 374 |
| 14.1.3 | True performance                      | 374 |
| 14.2   | Per-cluster quality measures          | 376 |
| 14.2.1 | Diameter                              | 376 |
| 14.2.2 | Separation                            | 377 |
| 14.2.3 | Isolation                             | 378 |
| 14.2.4 | Silhouette width                      | 379 |
| 14.2.5 | Davies–Bouldin index                  | 382 |
| 14.3   | Overall quality measures              | 385 |
| 14.3.1 | Dunn index                            | 386 |
| 14.3.2 | Average Davies–Bouldin index          | 387 |

|        |   |     |
|--------|---|-----|
| 14.3.3 | C index                                 | 388 |
| 14.3.4 | Average silhouette width                | 389 |
| 14.3.5 | Loglikelihood                           | 390 |
| 14.4   | External quality measures               | 393 |
| 14.4.1 | Misclassification error                 | 393 |
| 14.4.2 | Rand index                              | 394 |
| 14.4.3 | General relationship detection measures | 396 |
| 14.5   | Using quality measures                  | 397 |
| 14.6   | Conclusion                              | 398 |
| 14.7   | Further readings                        | 398 |
|        | References                              | 399 |

## **Part V Getting Better Models 401**

|        |                                       |     |
|--------|---------------------------------------|-----|
| 15     | Model ensembles                       | 403 |
| 15.1   | Introduction                          | 403 |
| 15.2   | Model committees                      | 404 |
| 15.3   | Base models                           | 406 |
| 15.3.1 | Different training sets               | 406 |
| 15.3.2 | Different algorithms                  | 412 |
| 15.3.3 | Different parameter setups            | 412 |
| 15.3.4 | Algorithm randomization               | 412 |
| 15.3.5 | Base model diversity                  | 418 |
| 15.4   | Model aggregation                     | 420 |
| 15.4.1 | Voting/Averaging                      | 420 |
| 15.4.2 | Probability averaging                 | 422 |
| 15.4.3 | Weighted voting/averaging             | 424 |
| 15.4.4 | Using as attributes                   | 427 |
| 15.5   | Specific ensemble modeling algorithms | 431 |
| 15.5.1 | Bagging                               | 431 |
| 15.5.2 | Stacking                              | 433 |
| 15.5.3 | Boosting                              | 433 |
| 15.5.4 | Random forest                         | 443 |
| 15.5.5 | Random Naïve Bayes                    | 446 |
| 15.6   | Quality of ensemble predictions       | 448 |
| 15.7   | Conclusion                            | 449 |
| 15.8   | Further readings                      | 450 |
|        | References                            | 451 |
| 16     | Kernel methods                        | 454 |
| 16.1   | Introduction                          | 454 |
| 16.2   | Support vector machines               | 457 |
| 16.2.1 | Classification margin                 | 457 |
| 16.2.2 | Maximum-margin hyperplane             | 460 |
| 16.2.3 | Primal form                           | 460 |
| 16.2.4 | Dual form                             | 464 |

|        |                                 |     |
|--------|---------------------------------|-----|
| 16.2.5 | Soft margin                     | 468 |
| 16.3   | Support vector regression       | 473 |
| 16.3.1 | Regression tube                 | 474 |
| 16.3.2 | Primal form                     | 475 |
| 16.3.3 | Dual form                       | 475 |
| 16.4   | Kernel trick                    | 482 |
| 16.5   | Kernel functions                | 484 |
| 16.5.1 | Linear kernel                   | 485 |
| 16.5.2 | Polynomial kernel               | 485 |
| 16.5.3 | Radial kernel                   | 485 |
| 16.5.4 | Sigmoid kernel                  | 486 |
| 16.6   | Kernel prediction               | 487 |
| 16.7   | Kernel-based algorithms         | 489 |
| 16.7.1 | Kernel-based SVM                | 489 |
| 16.7.2 | Kernel-based SVR                | 492 |
| 16.8   | Conclusion                      | 494 |
| 16.9   | Further readings                | 495 |
|        | References                      | 496 |
| 17     | Attribute transformation        | 498 |
| 17.1   | Introduction                    | 498 |
| 17.2   | Attribute transformation task   | 499 |
| 17.2.1 | Target task                     | 499 |
| 17.2.2 | Target attribute                | 500 |
| 17.2.3 | Transformed attribute           | 500 |
| 17.2.4 | Training set                    | 500 |
| 17.2.5 | Modeling transformations        | 500 |
| 17.2.6 | Nonmodeling transformations     | 503 |
| 17.3   | Simple transformations          | 504 |
| 17.3.1 | Standardization                 | 504 |
| 17.3.2 | Normalization                   | 505 |
| 17.3.3 | Aggregation                     | 506 |
| 17.3.4 | Imputation                      | 507 |
| 17.3.5 | Binary encoding                 | 508 |
| 17.4   | Multiclass encoding             | 510 |
| 17.4.1 | Encoding and decoding functions | 511 |
| 17.4.2 | 1-ok- $k$ encoding              | 514 |
| 17.4.3 | Error-correcting encoding       | 515 |
| 17.4.4 | Effects of multiclass encoding  | 519 |
| 17.5   | Conclusion                      | 521 |
| 17.6   | Further readings                | 521 |
|        | References                      | 522 |
| 18     | Discretization                  | 524 |
| 18.1   | Introduction                    | 524 |
| 18.2   | Discretization task             | 525 |

|        |                                |     |
|--------|--------------------------------|-----|
| 18.2.1 | Motivation                     | 525 |
| 18.2.2 | Task definition                | 526 |
| 18.2.3 | Discretization as modeling     | 527 |
| 18.2.4 | Discretization quality         | 529 |
| 18.3   | Unsupervised discretization    | 530 |
| 18.3.1 | Equal-width intervals          | 530 |
| 18.3.2 | Equal-frequency intervals      | 531 |
| 18.3.3 | Nonmodeling discretization     | 532 |
| 18.4   | Supervised discretization      | 533 |
| 18.4.1 | Pure-class discretization      | 533 |
| 18.4.2 | Bottom-up discretization       | 535 |
| 18.4.3 | Top-down discretization        | 546 |
| 18.5   | Effects of discretization      | 551 |
| 18.6   | Conclusion                     | 553 |
| 18.7   | Further readings               | 553 |
|        | References                     | 556 |
| 19     | Attribute selection            | 558 |
| 19.1   | Introduction                   | 558 |
| 19.2   | Attribute selection task       | 559 |
| 19.2.1 | Motivation                     | 559 |
| 19.2.2 | Task definition                | 560 |
| 19.2.3 | Algorithms                     | 561 |
| 19.3   | Attribute subset search        | 562 |
| 19.3.1 | Search task                    | 562 |
| 19.3.2 | Initial state                  | 563 |
| 19.3.3 | Search operators               | 564 |
| 19.3.4 | State selection                | 564 |
| 19.3.5 | Stop criteria                  | 565 |
| 19.4   | Attribute selection filters    | 568 |
| 19.4.1 | Simple statistical filters     | 568 |
| 19.4.2 | Correlation-based filters      | 571 |
| 19.4.3 | Consistency-based filters      | 575 |
| 19.4.4 | RELIEF                         | 577 |
| 19.4.5 | Random forest                  | 584 |
| 19.4.6 | Cutoff criteria                | 585 |
| 19.4.7 | Filter-driven search           | 586 |
| 19.5   | Attribute selection wrappers   | 588 |
| 19.5.1 | Subset evaluation              | 588 |
| 19.5.2 | Wrapper attribute selection    | 591 |
| 19.6   | Effects of attribute selection | 593 |
| 19.7   | Conclusion                     | 598 |
| 19.8   | Further readings               | 599 |
|        | References                     | 600 |

|        |                                       |            |
|--------|---------------------------------------|------------|
| 20     | Case studies                          | 602        |
| 20.1   | Introduction                          | 602        |
| 20.1.1 | Datasets                              | 603        |
| 20.1.2 | Packages                              | 603        |
| 20.1.3 | Auxiliary functions                   | 603        |
| 20.2   | Census income                         | 605        |
| 20.2.1 | Data loading and preprocessing        | 606        |
| 20.2.2 | Default model                         | 608        |
| 20.2.3 | Incorporating misclassification costs | 610        |
| 20.2.4 | Pruning                               | 616        |
| 20.2.5 | Attribute selection                   | 624        |
| 20.2.6 | Final models                          | 628        |
| 20.3   | Communities and crime                 | 631        |
| 20.3.1 | Data loading                          | 632        |
| 20.3.2 | Data quality                          | 632        |
| 20.3.3 | Regression trees                      | 634        |
| 20.3.4 | Linear models                         | 635        |
| 20.3.5 | Attribute selection                   | 636        |
| 20.3.6 | Piecewise-linear models               | 639        |
| 20.4   | Cover type                            | 640        |
| 20.4.1 | Data loading and preprocessing        | 640        |
| 20.4.2 | Class imbalance                       | 641        |
| 20.4.3 | Decision trees                        | 641        |
| 20.4.4 | Class rebalancing                     | 644        |
| 20.4.5 | Multiclass encoding                   | 647        |
| 20.4.6 | Final classification models           | 649        |
| 20.4.7 | Clustering                            | 650        |
| 20.5   | Conclusion                            | 654        |
| 20.6   | Further readings                      | 655        |
|        | References                            | 655        |
|        | Closing                               | 657        |
| A      | Notation                              | 659        |
| A.1    | Attribute values                      | 659        |
| A.2    | Data subsets                          | 659        |
| A.3    | Probabilities                         | 660        |
| B      | R packages                            | 661        |
| B.1    | CRAN packages                         | 661        |
| B.2    | DMR packages                          | 662        |
| B.3    | Installing packages                   | 663        |
|        | References                            | 664        |
| C      | Datasets                              | 666        |
|        | <b>Index</b>                          | <b>667</b> |