

# Contents

|   |           |
|---|-----------|
| <b>1. Introduction</b>  | <b>1</b>  |
| 1.1 Motivation . . . . .  | 1         |
| 1.2 Outline and Major Contributions of the Thesis . . . . .   | 2         |
| 1.3 Notation . . . . .  | 4         |
| <b>2. Machine Learning</b>  | <b>5</b>  |
| 2.1 Basics of Statistical Learning . . . . .  | 5         |
| 2.1.1 Parametric and Nonparametric Techniques for Classification . . . . .                              | 7         |
| 2.1.2 Learning and Generalization in Classification Tasks . . . . .                                     | 9         |
| 2.1.2.1 Bias-Variance Decomposition . . . . .   | 10        |
| 2.1.2.2 Evaluation of Machine Learning Algorithms in Practice . . . . .                                 | 13        |
| 2.2 Machine Learning Algorithms for Classification . . . . .  | 20        |
| 2.2.1 Linear Basis Expansion Models for Classification . . . . .  | 20        |
| 2.2.2 Multi-Layer Perceptron Neural Networks for Classification . . . . .                               | 22        |
| 2.2.3 Kernel Classifiers . . . . .  | 24        |
| 2.2.4 Classification and Regression Trees . . . . .   | 25        |
| 2.2.5 Ensemble Learning . . . . .   | 30        |
| 2.2.5.1 Bias-Variance Framework in Averaging Ensemble Models . . . . .                                  | 30        |
| 2.2.5.2 Random Forest Algorithm . . . . .   | 33        |
| 2.3 Feature Extraction . . . . .  | 39        |
| 2.3.1 Feature Generation . . . . .  | 40        |
| 2.3.2 Feature Selection . . . . .   | 43        |
| 2.3.2.1 Feature Selection with CART . . . . .   | 43        |
| 2.3.2.2 Feature Selection with RF . . . . .   | 45        |
| <b>3. Interpretable Generalized Radial Basis Function Classifiers Based on the Random Forest Kernel</b> | <b>49</b> |
| 3.1 Kernels Defined by Ensembles of CART Classifiers . . . . .  | 50        |
| 3.2 GRBF Based on the RF Kernel . . . . .   | 53        |
| 3.3 Pruning . . . . .   | 56        |
| 3.4 Experimental Results . . . . .  | 59        |
| <b>4. Classification of Temporal Data</b>   | <b>65</b> |
| 4.1 Time Series Representation and Dimensionality Reduction . . . . .                                   | 66        |
| 4.2 Difficulties in Time Series Classification . . . . .  | 75        |
| 4.3 Classical Approaches for Time Series Classification . . . . .                                       | 77        |
| 4.4 Similarity Measures for Time Series . . . . .   | 82        |
| 4.5 Feature Generation for Time Series Classification . . . . .   | 94        |
| 4.5.1 Global Features . . . . .   | 95        |
| 4.5.2 Local Features . . . . .  | 97        |

|           |   |            |
|-----------|---|------------|
| 4.5.3     | Event-Based Features . . . . .  | 100        |
| <b>5.</b> | <b>Classification in Car Safety Systems</b>   | <b>105</b> |
| 5.1       | The Car Crash Dataset . . . . .   | 105        |
| 5.2       | Evaluation of Classification Performance . . . . .  | 109        |
| <b>6.</b> | <b>Scenario-Based Random Forest for On-Line Time Series Classification</b>  | <b>113</b> |
| 6.1       | Problem Formulation . . . . .   | 113        |
| 6.2       | The Scenario-Based Random Forest Algorithm . . . . .  | 115        |
| 6.3       | Feature Selection with SBRF . . . . .   | 117        |
| 6.3.1     | Wrapper Method . . . . .  | 118        |
| 6.3.2     | Embedded Methods . . . . .  | 119        |
| 6.4       | SBRF for Car Crash Classification . . . . .   | 122        |
| <b>7.</b> | <b>Segmentation and Labeling for On-Line Time Series Classification</b>   | <b>139</b> |
| 7.1       | On-Line Segmentation of Time Series . . . . .   | 140        |
| 7.1.1     | Reduction of the Number of Change Detectors . . . . .   | 145        |
| 7.1.2     | Linear Change Detectors . . . . .   | 146        |
| 7.1.3     | Segmentation for Car Crash Classification . . . . .   | 149        |
| 7.2       | Labeling Classifiers for On-Line Time Series Classification . . . . .   | 152        |
| 7.2.1     | GRBF for Car Crash Classification . . . . .   | 153        |
| 7.2.2     | Temporal Prototypes for Car Crash Classification . . . . .  | 162        |
| <b>8.</b> | <b>Conclusions</b>  | <b>175</b> |
| 8.1       | Comparison of the Presented Methods for Car Crash Classification . . . . .  | 175        |
| 8.2       | Contributions and Future Work . . . . .   | 178        |
|           | <b>Appendices</b>   | <b>181</b> |
| <b>A.</b> | <b>Appendix on Machine Learning Procedures</b>  | <b>183</b> |
| A.1       | Bias-Variance Decomposition for Regression . . . . .  | 183        |
| A.2       | Example for the Bias-Variance Decomposition for Classification . . . . .  | 183        |
| A.3       | Bias-Variance Decomposition for Classification . . . . .  | 185        |
| A.4       | Computation of $\mathbf{W}$ and $\boldsymbol{\theta}$ with $\mathbf{p}(\mathbf{y} \mathbf{x})$ Versus $\bar{\mathbf{y}}$ as Target Vector . . . . . | 185        |
| A.5       | Confidence Mapping . . . . .  | 186        |
| A.6       | Support Vector Machines . . . . .   | 188        |
| A.7       | Minimum Local Risk in CART Classification . . . . .   | 190        |
| A.8       | Random Forests Do Not Overfit . . . . .   | 191        |
| A.9       | Computation of the Gradient for the GRBF Algorithm . . . . .  | 192        |
| A.10      | The AdaTron Algorithm . . . . .   | 192        |
| <b>B.</b> | <b>List of Frequently Used Symbols</b>  | <b>195</b> |
|           | <b>Bibliography</b>   | <b>199</b> |