

Contents

Abstract	i
Zusammenfassung	iii
Contents	v
1. Introduction	1
1.1. A Brief History of Conventional and Fuzzy Rule-Based Classification	2
1.2. Purpose of this Thesis	4
1.3. Contribution of this Thesis	4
1.4. Publications in the Context of this Thesis	5
1.5. Software Developments in the Context of this Thesis	6
1.6. Outline	7
2. Foundations	9
2.1. Classification	9
2.2. Binary Decomposition Techniques for Multi-Class Problems .	11
2.2.1. 1-vs-All Decomposition	11
2.2.2. All-vs-All Decomposition	11
2.2.3. Comparison of 1-vs-All and All-vs-All Decomposition	13
2.3. Rule-Based Classification	15
2.3.1. Separate-and-Conquer Rule Learning	15
2.3.2. Rule Learning with FOIL, REP and IREP	17
2.3.3. RIPPER	20
2.4. Fuzzy Rule-Based Classification	22
2.4.1. Fuzzy Logic	23

2.4.2.	Fuzzy Classification Rules	29
2.4.3.	Linguistic Fuzzy Classification Rules	29
2.4.4.	Fuzzy Reasoning Methods	31
2.5.	Experimental Settings	32
2.5.1.	Testing Environment	32
2.5.2.	Data Sets	33
2.5.3.	Benchmark Classifiers	33
2.5.4.	Performance Measures	35
2.5.5.	Test Setup	38
2.5.6.	Statistical Evaluation	39
2.6.	Summary	42
3.	FURIA: Fuzzy Unordered Rule Induction Algorithm	43
3.1.	Introduction	43
3.2.	Fuzzy Unordered Rule Induction Algorithm	44
3.2.1.	Learning Unordered Rulesets	44
3.2.2.	Pruning Modifications	45
3.2.3.	Rule Fuzzification	46
3.2.4.	Classifier Output	53
3.2.5.	Rule Stretching	55
3.3.	Experiments	57
3.3.1.	Classification Performance Analysis	57
3.3.2.	Ranking Performance Analysis	59
3.3.3.	Fuzzification Analysis	61
3.3.4.	Model Complexity Analysis	67
3.3.5.	Rule Stretching Analysis	67
3.3.6.	Runtime Analysis	69
3.4.	Summary	73
4.	HELLFIRE: Learning Linguistic Fuzzy Classification Rules	75
4.1.	Introduction	75
4.2.	High-End Learning of Linguistic Fuzzy Interval Rule Expertise	76
4.2.1.	Rule Learning	76
4.2.2.	From Split-Based Rules to Interval-Based Rules	86

4.2.3.	Pruning	90
4.2.4.	Rule Selection	91
4.2.5.	Interval Fuzzification	91
4.2.6.	Rule Weighting	95
4.2.7.	Handling of Missing Values	95
4.2.8.	Classification with Rule Stretching	96
4.2.9.	Complexity Analysis	96
4.3.	Comparing HELLFIRE with Other Discretization Techniques	98
4.4.	Experiments	100
4.4.1.	Classification Performance Analysis	100
4.4.2.	Ranking Performance Analysis	102
4.4.3.	Fuzzification Analysis	104
4.4.4.	Comparison between the Discretization Procedures of HELLFIRE and MDLP	113
4.4.5.	Interpretability Analysis	114
4.5.	Exemplary Model	122
4.6.	Summary	124
5.	FR3: Learning Fuzzy Preference Structures using Fuzzy Rules	127
5.1.	Introduction	128
5.2.	Preference Relations and Structures	130
5.3.	Learning Valued Preference Structures for Classification . . .	133
5.4.	Fuzzy Round Robin RIPPER	134
5.4.1.	Pairwise Decomposition	135
5.4.2.	Fuzzy Rules for Learning Fuzzy Preference Structures	136
5.4.3.	Making Classification Decisions Based on Fuzzy Pref- erence Structures	140
5.5.	Visualization of Fuzzy Preference Structures	141
5.6.	Experiments	142
5.6.1.	Classification Performance Analysis	142
5.6.2.	Ranking Performance Analysis	144
5.6.3.	Fuzzification Analysis	146
5.6.4.	Model Complexity Analysis	147

5.6.5.	Analysis of Conflict and Ignorance as Measures of Uncertainty	147
5.7.	Summary	149
6.	Comparison of FURIA, HELLFIRE and FR3	153
6.1.	Comparison of Motivations and Methods	153
6.1.1.	Motivation	153
6.1.2.	Problem Decomposition Technique	154
6.1.3.	Rule Learning Strategy	154
6.1.4.	Fuzzy Partitioning	154
6.1.5.	Fuzzification Technique	154
6.1.6.	Handling of Uncovered Instances	155
6.1.7.	Score Aggregation	155
6.2.	Experimental Comparison	156
6.2.1.	Binary Data Sets	156
6.2.2.	Multi-class Data Sets	157
6.2.3.	Summary	159
6.3.	Discussion	160
7.	Related Work	163
7.1.	Conventional Rule-Based Classifiers	163
7.1.1.	Separate-and-Conquer Rule Learning	163
7.1.2.	Decision Tree Rule Learning	165
7.1.3.	AUC-Optimizing Rule Learning	166
7.1.4.	Nearest Generalized Examples	167
7.2.	Fuzzy Rule-Based Classifiers	168
7.2.1.	Grid-Oriented Approaches	168
7.2.2.	Non-Grid-Oriented Approaches	169
7.2.3.	Fuzzy Propositional and Fuzzy First-Order Logic Rule Learning	170
7.2.4.	Fuzzy Set Covering	170
7.2.5.	Hybrid Approaches	171
7.2.6.	Clustering-Based Techniques	175
7.2.7.	Divide-and-Conquer	176

7.2.8. Conventional vs. Fuzzy Partitions	177
7.2.9. Rule Weights and Confidence Factors	177
7.3. Dealing with Uncertainty	178
7.4. Interpretability	179
7.5. Discussion	180
7.5.1. FURIA	180
7.5.2. HELLFIRE	181
7.5.3. FR3	182
7.6. Summary	182
8. Conclusion and Outlook	183
8.1. Conclusion	183
8.2. Future Work	184
8.2.1. FURIA	184
8.2.2. FR3	184
8.2.3. HELLFIRE	185
8.2.4. General Directions	185
8.2.5. Outlook	186
A. Tables	187
Acknowledgements	197
Glossary	199
List of Tables	201
List of Figures	205
Bibliography	207
Erklärung	229
Resume	231
Index	233