

Studies in Computational Intelligence, Volume 11

Editor-in-chief

Prof. Janusz Kacprzyk
Systems Research Institute
Polish Academy of Sciences
ul. Newelska 6
01-447 Warsaw
Poland
E-mail: kacprzyk@ibspan.waw.pl

Further volumes of this series
can be found on our homepage:
springer.com

- Vol. 1. Tetsuya Hoya
Artificial Mind System – Kernel Memory Approach, 2005
ISBN 3-540-26072-2
- Vol. 2. Saman K. Halgamuge, Lipo Wang (Eds.)
Computational Intelligence for Modelling and Prediction, 2005
ISBN 3-540-26071-4
- Vol. 3. Bożena Kostek
Perception-Based Data Processing in Acoustics, 2005
ISBN 3-540-25729-2
- Vol. 4. Saman K. Halgamuge, Lipo Wang (Eds.)
Classification and Clustering for Knowledge Discovery, 2005
ISBN 3-540-26073-0
- Vol. 5. Da Ruan, Guoqing Chen, Etienne E. Kerre, Geert Wets (Eds.)
Intelligent Data Mining, 2005
ISBN 3-540-26256-3
- Vol. 6. Tsau Young Lin, Setsuo Ohsuga, Churn-Jung Liao, Xiaohua Hu, Shusaku Tsumoto (Eds.)
Foundations of Data Mining and Knowledge Discovery, 2005
ISBN 3-540-26257-1

- Vol. 7. Bruno Apolloni, Ashish Ghosh, Ferda Alpaslan, Lakhmi C. Jain, Srikanta Patnaik (Eds.)
Machine Learning and Robot Perception, 2005
ISBN 3-540-26549-X
- Vol. 8. Srikanta Patnaik, Lakhmi C. Jain, Spyros G. Tzafestas, Germano Resconi, Amit Konar (Eds.)
Innovations in Robot Mobility and Control, 2005
ISBN 3-540-26892-8
- Vol. 9. Tsau Young Lin, Setsuo Ohsuga, Churn-Jung Liao, Xiaohua Hu (Eds.)
Foundations and Novel Approaches in Data Mining, 2005
ISBN 3-540-28315-3
- Vol. 10. Andrzej P. Wierzbicki, Yoshiteru Nakamori
Creative Space, 2005
ISBN 3-540-28458-3
- Vol. 11. Antoni Ligęza
Logical Foundations for Rule-Based Systems, 2006
ISBN 3-540-29117-2

Antoni Ligęza

Logical Foundations for Rule-Based Systems

Second Edition

 Springer

Professor Antoni Ligęza
Institute of Automatics
AGH - University of Science and Technology
Al. Mickiewicza 30
30-059 Cracow
Poland
e-mail: ligeza@agh.edu.pl

Library of Congress Control Number: 2005932569

Originally published in Poland by AGH University of Science and Technology Press, Kraków, Poland

ISSN print edition: 1860-949X

ISSN electronic edition: 1860-9503

ISBN-10 3-540-29117-2 Springer Berlin Heidelberg New York

ISBN-13 978-3-540-29117-6 Springer Berlin Heidelberg New York

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer. Violations are liable for prosecution under the German Copyright Law.

Springer is a part of Springer Science+Business Media

springer.com

© Springer-Verlag Berlin Heidelberg 2006

Printed in The Netherlands

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Typesetting: by the author and TechBooks using a Springer L^AT_EX macro package

Printed on acid-free paper SPIN: 11506492 89/TechBooks 54321

Contents

Part I Logical Foundations of Rule-Based Systems

1	Propositional Logic	3
1.1	Alphabet of Propositional Calculus	3
1.2	Syntax of Propositional Logic	4
1.3	Semantics of Propositional Logic	5
1.4	Rules for Transforming Propositional Formulae	9
1.5	Applications	9
1.6	Normal Forms and Special Forms of Formulae	11
1.6.1	Minterms: Simple Conjunctive Formulae	11
1.6.2	Maxterms, Clauses and Rules	13
1.6.3	Conjunctive Normal Form	15
1.6.4	Disjunctive Normal Form	16
1.6.5	Transformation of a Formula into CNF/DNF	18
1.6.6	Example	19
1.7	Logical Consequence and Deduction	20
1.8	Inference Modes: Deduction, Abduction and Induction	22
1.8.1	Deduction Rules for Propositional Logic	23
1.8.2	Resolution Rule	25
1.8.3	Dual Resolution Rule	27
1.9	Abduction and Induction	30
1.9.1	Abduction	30
1.9.2	Induction	32
1.9.3	Deduction, Abduction and Induction — Mutual Relationship	33
1.10	Generic Tasks of Propositional Logic	33
1.10.1	Theorem Proving	34
1.10.2	Tautology or Completeness Verification	34
1.10.3	Minimization of Propositional Formulae	34

2	Predicate Calculus	37
2.1	Alphabet and Notation	37
2.1.1	The Role of Variables	38
2.1.2	Function and Predicate Symbols	39
2.2	Terms in First-Order Logic	39
2.2.1	Applications of Terms	40
2.3	Formulae	41
2.4	Special Forms of Formulae	43
2.5	Semantics of First-Order Logic	46
2.5.1	Herbrand Interpretation	48
3	Attribute Logic	51
3.1	Alphabet and Notation	52
3.1.1	The Role of Variables	53
3.2	Atomic Formulae	54
3.3	Formulae in Attribute Logic	55
3.4	Semantics of Attribute Logic	57
3.5	Issues Specific to Attribute-Based Logic	59
3.5.1	Internal Conjunction	59
3.5.2	Internal Disjunction	60
3.5.3	Explicit and Implicit Negation	61
3.6	Inference Rules Specific to Attributive Logic	62
4	Resolution	65
4.1	Substitution and Unification	65
4.1.1	Substitutions	65
4.1.2	Unification	67
4.1.3	Algorithm for Unification	68
4.2	Clausal Form	69
4.3	Resolution Rule	70
5	Dual Resolution	73
5.1	Minterm Form	73
5.2	Introduction to Dual Resolution	75
5.3	Dual Resolution Rule	76
5.4	BD-Derivation	78
5.5	Properties of BD-Resolution	79
5.5.1	Soundness of BD-Resolution	80
5.5.2	Completeness of BD-Resolution	81
5.6	Generalized Dual Resolution Rule	86

Part II Principles of Rule-Based Systems

6	Basic Structure of Rule-Based Systems	91
6.1	Basic Concepts in Rule-Based Systems	92
7	Rule-Based Systems in Propositional Logic	97
7.1	Notation for Propositional Rule-Based Systems	97
7.2	Basic Propositional Rules	98
7.3	Propositional Rules with Complex Precondition Formulae	100
7.4	Activation of Rules	101
7.5	Deducibility and Transitive Closure of Fact Knowledge Base ..	102
7.6	Various Forms of Propositional Rule-Based Systems	105
7.6.1	Example	108
7.6.2	Binary Decision Tables	109
7.6.3	Binary Decision Lists	112
7.6.4	Binary Decision Rules with Control Statements	115
7.6.5	Binary Decision Trees	116
7.6.6	Binary Decision Diagrams	122
7.7	Dynamic and Non-Monotonic Systems	127
8	Rule-Based Systems in Attributive Logic	129
8.1	Attributive Decision Tables	130
8.1.1	Basic Attributive Decision Tables	131
8.1.2	Information Systems	132
8.1.3	Attributive Decision Tables with Atomic Values of Attributes	134
8.1.4	Example: Opticians Decision Table	135
8.2	Extended Attributive Decision Systems	137
8.3	Example	139
8.4	Attributive Rule-Based Systems	139
8.4.1	Rule Format	140
8.4.2	Rule Firing	141
8.5	Extended Tabular Trees	143
8.5.1	Cells	143
8.5.2	Rules	144
8.5.3	XT — Extended Table	145
8.5.4	Connections and Their Properties	146
8.6	Example: Thermostat	147
9	Rule-Based Systems in First-Order Logic	155
9.1	Basic Form of Rules	155
9.2	FOPC Rule-Base Example: Thermostat	156
9.3	Extended Form of FOPC Rules	157
9.4	Further Extensions in Rule Format	160

10 Inference Control in Rule-Based Systems	163
10.1 Problem Statement	164
10.1.1 Basic Problem Formulation	164
10.1.2 Advanced Problem Formulation	165
10.2 Rule Interpretation Algorithm	167
10.3 Inference Control at the Rules Level: Advanced Problem	169
10.3.1 A Simple Linear Strategy	170
11 Logic Programming and Prolog	173
11.1 Introductory Example	175
11.2 PROLOG Syntax	177
11.3 Unification in PROLOG	178
11.4 Resolution in PROLOG	179
11.5 PROLOG Inference Strategy	180
11.6 Inference Control and Negation in PROLOG	181
11.6.1 The <i>cut</i> Predicate	182
11.6.2 The <i>fail</i> Predicate	182
11.6.3 The <i>not</i> Predicate	183
11.7 Dynamic Global Memory in PROLOG	183
11.8 Lists in PROLOG	184
11.9 Rule Interpreters in PROLOG	185

Part III Verification of Rule-Based Systems

12 Principles of Verification of Rule-Based Systems	191
12.1 Validation, Verification, Testing and Optimization of Rule-Based Systems	192
12.2 Verification: from General Requirements to Verifiable Characteristics	193
12.3 Taxonomies of Verifiable Features	195
12.3.1 Verification of RBS: a Short Review	195
12.3.2 Functional Quality Assignment	196
12.4 A Taxonomy of Verifiable Characteristics	197
13 Analysis of Redundancy	199
13.1 Redundancy of Knowledge Representation	199
13.2 Subsumption	201
13.2.1 Subsumption in First Order Logic	202
13.2.2 Subsumption in Tabular Systems	202
13.3 Verification of Subsumption in XTT — a Prolog Code	203
14 Analysis of Indeterminism and Inconsistency	207
14.1 Indeterminism and Inconsistency of Rules	207
14.2 Consistency Analysis	208

14.2.1	Determinism	209
14.2.2	Conflict and Inconsistency	209
14.3	Verification of Indeterminism: a PROLOG Code	210
15	Reduction of Rule-Based Systems	213
15.1	Generation of Minimal Forms of Tabular Rule-Based Systems	214
15.1.1	Total and Partial Reduction	214
15.1.2	Specific Partial Reduction	216
15.2	Reduction of Tabular Systems — a PROLOG Code Example...	217
16	Analysis of Completeness	219
16.1	Completeness of Rules	219
16.2	Verification of Completeness	220
16.2.1	Logical Completeness of Rule-Based Systems	221
16.2.2	Specific Completeness of Rule-Based Systems	222
16.2.3	Missing Precondition Identification	224
16.3	Verification of Completeness in XTT — a PROLOG Code	226
<hr/>		
Part IV Design of Rule-Based Systems		
<hr/>		
17	An Introduction to Design of Rule-Based Systems	231
17.1	Problems of Rule-Based Systems Design	231
17.2	Knowledge Engineering	233
17.2.1	Knowledge Acquisition	234
17.2.2	Knowledge Verification	235
17.2.3	Knowledge Management.....	235
17.3	Design of Rule-Based Systems: Abstract Methodology.....	235
17.4	Rule-Based Systems Design: Basic Stages	238
18	Logical Foundations: the Ψ-Trees Based Approach	241
18.1	An Intuitive Introductory Example	241
18.2	The Ψ -Trees for Design Support	244
18.2.1	OSIRIS — a Design Tool.....	248
19	Design of Tabular Rule-Based Systems with XTT	251
19.1	Principles the ARD/XTT Approach	251
19.2	Principles of the Integrated Design Process	252
19.3	Conceptual Design Phase with ARD Diagrams	253
19.3.1	Conceptual Modelling using ARD	254
19.3.2	Attributes Definition with the Attribute Creator	257
19.4	Logical Design Phase with XTT	258
19.5	The Analysis and Verification Framework.....	259
19.6	Implementation Phase	260
19.6.1	Testing the Prototype.....	260

19.6.2	Debugging the Prototype	260
19.6.3	Generating Stand-Alone Application	261
20	Design Example: Thermostat	263
20.1	Thermostat Control System.....	264
21	Concluding Remarks	277
<hr/>		
Part V Closing Remarks and Appendices		
<hr/>		
A	Selected Rule-Based Systems and Tools.....	283
A.1	Related Work and Knowledge Verification Tools	283
A.1.1	Kheops System	283
A.1.2	Prologa	284
A.1.3	KbBuilder	284
A.1.4	KRUST	285
A.1.5	IN-DEPTH	285
A.1.6	COVER.....	285
A.2	Expert Systems Shells.....	285
A.2.1	OPS5	285
A.2.2	CLIPS	285
A.2.3	Jess	286
A.2.4	Sphinx	286
A.2.5	Oryx/Mandarax.....	286
A.2.6	G2	286
A.2.7	XpertRule.....	286
A.2.8	ILOG.....	286
A.3	Experimental Systems and New Developments	287
A.4	IxTeT System	287
A.5	The Qualitative Engine CA-EN	287
A.6	TIGER: a Real-Time Gas Turbine Monitoring System	287
A.7	RuleML	287
A.8	VisiRule.....	288
B	Selected Web Resources	289
B.1	Expert and Rule-Based Systems Resources	289
B.2	RBS-related XML Resources	290
B.3	Selected AI Links.....	291
B.4	Selected Prolog Compilers and Environments	292
B.5	Books and Tutorials	293
B.6	Selected Resources.....	294
References		297
Index		307



<http://www.springer.com/978-3-540-29117-6>

Logical Foundations for Rule-Based Systems

Ligeza, A.

2006, XX, 309 p. 33 illus., Hardcover

ISBN: 978-3-540-29117-6