

Lecture Notes in Artificial Intelligence
Subseries of Lecture Notes in Computer Science
Edited by J. Siekmann

Lecture Notes in Computer Science
Edited by G. Goos and J. Hartmanis

Editorial

Artificial Intelligence has become a major discipline under the roof of Computer Science. This is also reflected by a growing number of titles devoted to this fast developing field to be published in our Lecture Notes in Computer Science. To make these volumes immediately visible we have decided to distinguish them by a special cover as Lecture Notes in Artificial Intelligence, constituting a subseries of the Lecture Notes in Computer Science. This subseries is edited by an Editorial Board of experts from all areas of AI, chaired by Jörg Siekmann, who are looking forward to consider further AI monographs and proceedings of high scientific quality for publication.

We hope that the constitution of this subseries will be well accepted by the audience of the Lecture Notes in Computer Science, and we feel confident that the subseries will be recognized as an outstanding opportunity for publication by authors and editors of the AI community.

Editors and publisher

Lecture Notes in Artificial Intelligence

Edited by J. Siekmann

Subseries of Lecture Notes in Computer Science

422

Bernhard Nebel

Reasoning and Revision
in Hybrid Representation
Systems



Springer-Verlag

Berlin Heidelberg New York London Paris Tokyo Hong Kong

Author

Bernhard Nebel

Deutsches Forschungszentrum für Künstliche Intelligenz (DFKI)

Stuhlsatzenhausweg 3, D-6600 Saarbrücken 11, FRG

CR Subject Classification (1987): I.2.3–4

ISBN 3-540-52443-6 Springer-Verlag Berlin Heidelberg New York

ISBN 0-387-52443-6 Springer-Verlag New York Berlin Heidelberg

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, re-use of illustrations, recitation, broadcasting, reproduction on microfilms or in other ways, and storage in data banks. Duplication of this publication or parts thereof is only permitted under the provisions of the German Copyright Law of September 9, 1965, in its version of June 24, 1985, and a copyright fee must always be paid. Violations fall under the prosecution act of the German Copyright Law.

© Springer-Verlag Berlin Heidelberg 1990

Printed in Germany

Printing and binding: Druckhaus Beltz, Hemsbach/Bergstr.

2145/3140-543210 — Printed on acid-free paper

Preface

The dynamic aspects of knowledge representation systems, namely, *reasoning* with represented knowledge and *revising* represented knowledge, are the most important aspects of such systems. In this book, these aspects are investigated in the context of hybrid representation systems based on KL-ONE.

After a general introduction to knowledge representation, reasoning, and revision, a typical member of the family of hybrid representation systems based on KL-ONE is introduced and analyzed from a semantic and algorithmic point of view. This analysis leads to new complexity results about subsumption determination and a characterization of a proposed hybrid inference algorithm as conditionally complete. Additionally, it is shown that so-called terminological cycles can be integrated smoothly into the framework.

Based on the analysis of representation and reasoning in KL-ONE-based systems, the revision problem is investigated. A survey of some approaches to belief revision leads to a reconstruction of symbol-level belief revision on the knowledge level. A conceptual analysis of terminological revision demonstrates that belief revision techniques developed for the revision of assertional knowledge are not adequate for the revision of terminological knowledge. For this reason, a literal revision approach is adopted. Essentially, it amounts to minimal mutilations in the literal description of definitions. Finally, implementation techniques for terminological revision operations are described, and the interface problem for a knowledge acquisition system is discussed.

This book is a revised version of my doctoral dissertation, accepted by the University of Saarland in June 1989. Most of the work was carried out while I was a member of the KIT-BACK project at the Technical University of Berlin. The final version was written up while I participated in the LILOG project as a guest researcher at the Scientific Center IBM Germany, Institute for Knowledge-Based Systems, Stuttgart.

I am indebted to my thesis advisor Wolfgang Wahlster, who stimulated my interest in knowledge representation in the first place while I was a member of the HAM-ANS project and who encouraged me in the following years to carry out the research described here.

Additionally, I would like to express my thanks to all those people without whom this book would not be what it is now. Foremost, there are my colleagues in the KIT group at the Technical University of Berlin and in the LILOG project at the Scientific Center of IBM Germany, Stuttgart. In particular, working with Kai von Luck, Christof Peltason, and Albrecht Schmiedel in the KIT-BACK project was a pleasure and played a central role in starting the research described here.

Once started, Kai played a driving force by always asking for the next chapter.

Furthermore, I would like to thank Peter Gärdenfors for making available the manuscript of his book and for his comments on some points concerning base revision; Otthein Herzog and Claus Rollinger for inviting me to participate in the LILOG project; Bob MacGregor for a number of discussions and suggestions, including the hint that realization must be easier than subsumption; Bernd Mahr for comments on the semantics of cycles; Peter Patel-Schneider for making the KANDOR system available and for discussions on semantics and complexity; Klaus Schild for showing me that subsumption in general terminological languages is undecidable; Jim Schmolze for pointing out that cycles are a serious problem; Jörg Siekmann, who was the second reader of the thesis, for asking the right questions and giving some valuable hints; Gert Smolka for numerous helpful discussions on semantic specification, algorithms, and the relationship between feature logic and KL-ONE; Norm Sondheimer for inviting me to ISI as a guest researcher and for showing me how to use KL-TWO in a natural language system; Jay Tucker for proof-reading various versions of the thesis (I take credit for any remaining flaws, of course); Marc Vilain for discussions on realization algorithms; and a number of other people too many to be listed here.

Contents

I Representation, Reasoning and Revision – The Idea

1	Introduction	3
1.1	A Dynamic View of Knowledge Bases	3
1.2	Hybrid Systems Based on KL-ONE	4
1.3	An Introductory Example	5
1.4	Outline	8
2	Representation and Management of Knowledge	11
2.1	Knowledge and its Representation	11
2.1.1	Knowledge and Data	12
2.1.2	The Knowledge Level	13
2.1.3	The Knowledge Representation Hypothesis	15
2.1.4	Three Approaches to Knowledge Representation	16
2.2	Knowledge Representation Formalisms	18
2.2.1	Semantics of Representation Formalisms	18
2.2.2	Adequacy Criteria	20
2.2.3	Hybrid Formalisms	21
2.2.4	Formalizing a Body of Knowledge	22
2.3	Knowledge Representation Systems	23
2.3.1	The Architecture of Knowledge-Based Systems	23
2.3.2	Services of Knowledge Representation Systems	25
2.3.3	Inferential Services	26
2.3.4	Revision Services	28
2.4	Knowledge Base Management Systems	30

II Hybrid Representation and Reasoning

3	A Hybrid Representation Formalism	37
3.1	Object-Centered Representation	37
3.1.1	Semantic Networks	38
3.1.2	Frame Systems	39
3.1.3	Structural Inheritance Networks	41
3.1.4	Terminological Knowledge Representation	44
3.2	The Terminological Formalism \mathcal{TF}	46

3.2.1	The Syntax of the Terminological Formalism	47
3.2.2	The Semantics of the Terminological Formalism	50
3.2.3	Relationships in Terminologies	52
3.2.4	Normal-Form Terminologies and Constructive Semantics	54
3.2.5	Abstracting from Term Introductions	60
3.2.6	The Significance of Term Introductions	61
3.3	The Assertional Formalism \mathcal{AF}	63
3.3.1	Syntax and Semantics of \mathcal{AF}	65
3.3.2	Hybrid Entailment and Subsumption	67
3.4	Possible Extensions of the Formalisms	68
3.4.1	Extending the Terminological Formalism	69
3.4.2	Attributive Descriptions	70
3.4.3	Extending the Assertional Formalism	71
4	Reasoning in the Formalism	73
4.1	Computing Term-Subsumption	74
4.1.1	An Algorithm for Subsumption Detection	74
4.1.2	Properties of the Algorithm	78
4.2	Analysis of the Term-Subsumption Problem	81
4.2.1	Decidability of Subsumption in \mathcal{NTF}_T	81
4.2.2	Computational Complexity of Subsumption in \mathcal{NTF}_T	87
4.2.3	Living with an Incomplete Reasoner	90
4.3	Subsumption in Terminologies Revisited	92
4.3.1	The Complexity of the Reduction to Term-Subsumption	92
4.3.2	Complexity of Subsumption in Terminologies	93
4.3.3	Efficiency of Subsumption in Practice	97
4.4	Classification	98
4.4.1	Assert-Time versus Query-Time Inferences	98
4.4.2	A Classification Algorithm	99
4.4.3	Worst Cases in Classification	101
4.5	Hybrid Inferences	102
4.5.1	Testing Instance Relationships	102
4.5.2	Realization = Propagation + Abstraction + Classification	104
4.5.3	Model-Based Terminological Reasoning	109
4.5.4	Model-Based Reasoning as the Limiting Case of Realization	113
4.6	Evaluation of the Inference Capabilities	117
5	Terminological Cycles	119
5.1	The Intuitions Behind Terminological Cycles	120
5.1.1	Recursively Defined Finite Object Structures	120
5.1.2	Infinite Object Structures	121
5.1.3	Circular Object Structures	123
5.1.4	Primitiveness and Instance Recognition	124
5.2	Semantics of Terminological Cycles	125
5.2.1	Lattices and Fixed Points	126
5.2.2	Fixed Point Semantics	127

5.2.3	Descriptive Semantics	133
5.2.4	Evaluating the Semantics	134
5.3	Consequences of the Descriptive Semantics	136
5.3.1	Circular Roles	136
5.3.2	Component-Circular Concepts	137
5.3.3	Restriction-Circular Concepts	139
5.3.4	Semantic and Syntactic Cycles	140
5.3.5	Finite, Cyclic Semantic Structures	142
5.4	Reasoning with Terminological Cycles	146

III Revision

6	Belief Revision	151
6.1	Problems in Belief Revision	151
6.2	The Logic of Theory Change	153
6.2.1	Expansion, Contraction, and Revision	154
6.2.2	Full Meet Contraction	156
6.2.3	Maxichoice Contraction	157
6.2.4	Partial Meet Contraction	158
6.3	Changes of Finite Theory Bases	159
6.3.1	Logical Data Bases and Diagnosis	160
6.3.2	Base Contraction is a Partial Meet Contraction	161
6.3.3	Epistemic Relevance and Reason Maintenance	163
6.3.4	Representational and Computational Issues	166
6.4	Model-Theoretic Updates	167
6.4.1	Minimal Perturbation of Models	168
6.4.2	Nonminimal Model-Theoretic Updates	170
6.5	Nonmonotonic Reasoning	171
6.5.1	Circumscription	172
6.5.2	Default Theories	173
6.5.3	Default Theories, the Logic of Theory Change, and the Knowledge Base Revision Problem	174
6.6	Reason-Maintenance Techniques	175
6.6.1	Monotonic Data-Dependency Networks	176
6.6.2	Nonmonotonic Data-Dependency Networks	180
6.6.3	Justification-Based Reason Maintenance	183
6.6.4	Assumption-Based Reason Maintenance	185
6.6.5	Utilizing Reason-Maintenance Techniques in Knowledge Base Revision	186
7	The Revision Problem in Terminological Systems	187
7.1	Terminologies in Flux	187
7.1.1	Terminologies, Analytic Knowledge, and Revisions	188
7.1.2	General Principles for Knowledge Base Revision	189
7.1.3	Problems in Revising a Terminology	191

7.2	Previous Solutions	191
7.2.1	Network Editing Approaches	192
7.2.2	Knowledge Base Editing	193
7.2.3	Adding and Deleting Definitions	195
7.2.4	Modifications Viewed as Additions	199
7.2.5	A Functional, Knowledge-Level Approach	200
7.3	A Framework for Terminological Revision	202
7.3.1	Terminological Revision Viewed as Belief Revision	202
7.3.2	Terminological Revision as Revision of Literal Definitions	204
7.3.3	Properties of the Literal Revision Approach	207
7.4	Revision in Hybrid Representation Systems	210
8	Terminological Reason Maintenance	213
8.1	Incremental Classification	213
8.1.1	What Kind of Reason Maintenance Do We Need?	214
8.1.2	Recording and Justifying Terminological Inferences	215
8.1.3	Redundancy and Functional Equivalence	217
8.2	Invariants of Revision Operations	218
8.2.1	Terminologies Related by Revision Operations	218
8.2.2	Making a Primitive Concept Defined	219
8.2.3	Adding an Expression to a Concept Definition	220
8.2.4	Exploiting the Invariants in Reclassification	221
8.3	Supporting Knowledge Acquisition	222
9	Summary and Outlook	225
9.1	Technical Contributions	225
9.2	Open Problems	227
A	The Universal Term-Forming Formalism \mathcal{U}	229
B	Overview of Formalisms and Systems	231
	Bibliography	237
	Subject Index	257
	Author Index	267

List of Figures

1.1	Informal Example of a Terminological Knowledge Base	6
1.2	Graphical Depiction of the Example Knowledge Base	7
2.1	Architecture of Knowledge-Based Systems	24
3.1	A Simple Concept Taxonomy	43
3.2	Examples of Role Restrictions and Differentiations	44
3.3	BNF Definition of \mathcal{TF}	48
3.4	A Formal Terminology Using \mathcal{TF} Syntax	50
3.5	BNF Definition of \mathcal{NTF}	55
3.6	BNF Definition of \mathcal{AF}	65
3.7	A Formal World Description Using \mathcal{AF} Syntax	65
4.1	Role-Chain Length Pruning	83
4.2	Unfolding of Assertional Cycles	84
4.3	Splitting of Shared Elements	85
4.4	A Pathological Terminology Leading to an Exponential Explosion	92
4.5	A Worst-Case Terminology for Classification	101
4.6	A Hybrid Inference Ignored by the Realization Algorithm	109
5.1	Circular Definition of Man and Male-human	120
5.2	Recursive Definition of Binary-tree	121
5.3	Some Object Structures Satisfying the Definition of Binary-tree	121
5.4	Humans and Parents	122
5.5	Definition of Human and Parent Using Cycles	122
5.6	Object Structures Intended by the Definition of Human	123
5.7	Circular Definition of Car and Car-engine	123
5.8	Object Structures Intended by the Definition of Car and Car-engine	124
5.9	Humans , Horses and Centaurs	132
5.10	General Restriction-Circular Concepts	139
5.11	Syntactic and Semantic Cycles	141
6.1	A Simple Data-Dependency Network	177
6.2	A Cyclic Justification Structure	179
6.3	A Nonmonotonic Data-Dependency Network	181
6.4	Odd and Even Nonmonotonic Loops	182
7.1	A Missing Superconcept Relationship	195
7.2	Two Terminologies Equivalent on the Knowledge Level	201

List of Tables

8.1	Invariants of Revision Operations	219
B.1	Complexity Results for Various Term-Forming Languages	232
B.2	Features of Hybrid Systems Based on KL-ONE	234
B.3	Features of Hybrid Systems Based on KL-ONE (continued)	235