

# Lecture Notes in Artificial Intelligence

1229

Subseries of Lecture Notes in Computer Science

Edited by J. G. Carbonell and J. Siekmann

## Lecture Notes in Computer Science

Edited by G. Goos, J. Hartmanis and J. van Leeuwen

Gerhard K. Kraetzschmar

# Distributed Reason Maintenance for Multiagent Systems



Springer

## Series Editors

Jaime G. Carbonell, Carnegie Mellon University, Pittsburgh, PA, USA  
Jörg Siekmann, University of Saarland, Saarbrücken, Germany

## Author

Gerhard K. Kraetzschmar  
University of Ulm, Department of Neural Information Processing  
Oberer Eselsberg, D-89069 Ulm, Germany  
E-mail: gkk@neuro.informatik.uni-ulm.de  
www: <http://www.informatik.uni-ulm.de/ni/staff/gkk.html>

Cataloging-in-Publication Data applied for

## Die Deutsche Bibliothek - CIP-Einheitsaufnahme

### **Kraetzschmar, Gerhard:**

Distributed reason maintenance for multiagent systems / Gerhard  
Kraetzschmar. - Berlin ; Heidelberg ; New York ; Barcelona ;  
Budapest ; Hong Kong ; London ; Milan ; Paris ; Santa Clara ;  
Singapore ; Tokyo : Springer, 1997

(Lecture notes in computer science ; Vol. 1229 : Lecture notes in  
artificial intelligence)

ISBN 3-540-63606-4

This book constitutes the dissertation thesis of the author  
accepted by the School of Engineering at the University of Erlangen-Nürnberg.

CR Subject Classification (1991): I.2.11, I.2, C.2.4, F.4.1

ISBN 3-540-63606-4 Springer-Verlag Berlin Heidelberg New York

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© Springer-Verlag Berlin Heidelberg 1997  
Printed in Germany

Typesetting: Camera ready by author  
SPIN 10548725 06/3142 - 5 4 3 2 1 0 Printed on acid-free paper

# Abstract

Reason maintenance technology has been successfully applied in many AI systems. Reason maintenance systems help to maintain logical dependencies between data and support assumption-based reasoning, which has useful applications in a wide spectrum of domains ranging from diagnosis to planning.

Most reason maintenance systems, however, have been developed with a single agent in mind, i.e. there is only one problem solver using the services of the reason maintenance system. Only few reason maintenance systems are known that claim to be suited for application in multiagent systems. None of these systems adequately supports multiple-context reasoning in a distributed environment, although this functionality is highly desirable in many domains, e.g. for distributed planning, scheduling, and control. Thus, as multiagent systems become increasingly attractive for solving larger and more complex problems, the need for adequate reason maintenance technology for multiagent systems arises.

This book provides an in-depth investigation of a restricted class of multiple-context assumption-based multiagent reasoning problems. Logics for formalizing the underlying kind of reasoning are provided and a description of the functionality desirable to adequately support the reasoning processes of such systems is derived. A revised reason maintenance system architecture is presented that lays a solid foundation for building distributed reason maintenance systems for use in multiagent systems. The architecture is applied in the construction of the two systems XFRMS and MXFRMS, which provide a solid foundation for building more complex utilities, such as plan or schedule maintenance systems.

The results of the problem analysis and task-specific requirements suggest several fundamental changes and extensions of existing reason maintenance technology in order to make it applicable in planning, scheduling, and control. The single agent reason maintenance system XFRMS is therefore developed first, which incorporates and illustrates the key ideas of those improvements and enhancements. XFRMS provides functionality that partially matches those of de Kleer's ATMS, but focuses on consequence finding, consistency checking, and context determination, while the generation of explanations or the con-

struction of interpretations are neglected. The main improvement in comparison with the ATMS, however, is that XFRMS tackles the key problem of using ATMS-based systems in planning domains: computational complexity, especially the predictability of resource use for particular instances of a problem class. By making context management an explicit task of XFRMS and giving the problem solver explicit control over the number of contexts under consideration, the resource demands of XFRMS can be controlled by the problem solver. The potentially exponential growth of resource demands by the ATMS can be avoided especially in those cases, where the structure of the dependency net would force the ATMS to construct exponentially many contexts, although the problem solver is interested in comparatively few contexts (maybe several dozen or a few hundred). Furthermore, the XFRMS allows the problem solver to explicitly delete contexts it no longer considers relevant.

The technology developed for the single agent case is then further enhanced to the multiagent or distributed case. The problem analysis shows that standard approaches to formalize the underlying kind of assumption-based reasoning for the multiagent case is not well-suited for the intended domain. Facetted Horn Propositional Logic (FHPL) is then developed to present a more adequate tool for the formalization of such problems.

Next, we show that the value of full ATMS functionality is rather doubtful in a multiagent setting: it easily incurs large computational cost and may have side effects that endanger agent autonomy and other desirable properties of agents. Resolving design conflicts when implementing a full ATMS-type distributed reason maintenance system requires several decisions to be made with serious consequences for functionality, efficiency, and applicability of the system. Instead of taking too many such choices and thereby restricting its possible uses, the multiagent reason maintenance system MXFRMS provides a solid base layer functionality which can build the foundation of more specialized reason maintenance services. Also, MXFRMS extends the techniques developed for XFRMS to avoid or at least control the problem of computational complexity. In particular, the XFRMS labelling scheme proves to be much better suited for distribution while giving the programmer better control on how tightly agent autonomy is to be enforced.

The two systems XFRMS and MXFRMS now provide a solid foundation for building more complex utilities, such as plan or schedule maintenance systems. The final chapter gives a perspective on potential uses and future extensions.

# Preface

This book investigates the problem of maintaining and managing data dependencies in multiagent systems, a particular type of distributed system. The work described in this text is part of my thesis work and was developed in the context of the PEDE research project [Stoyan et al., 1992], which dealt with planning and execution in distributed environments. The PEDE project served as a unifying framework for research done both at the Knowledge Acquisition Research Group (FG WE) at FORWISS Erlangen and at the Artificial Intelligence Department of the University of Erlangen (IMMD-8), both of which are led by Prof. Dr. Herbert Stoyan. The PEDE project was loosely associated with the Special Research Area 182 on Multiprocessor and Network Configurations (SFB 182, see e.g. [Wedekind, 1992] and [Wedekind, 1994]), a large nationally-funded research effort that was coordinated and headed by Prof. Dr. Hartmut Wedekind.

## Acknowledgements

My thesis project benefitted from the support provided to me by a number of people, whose efforts I hereby would like to gratefully acknowledge. Sorry to all those I have forgotten to mention.

Unquestionably, my thesis advisor Prof. Dr. Herbert Stoyan played a key role during my thesis work. He created the lively and inspiring work environment in which my thesis work was done and was also a constant source of questions and new ideas. Prof. Dr. Hartmut Wedekind made it possible for me to come to FORWISS. He provided support and advice throughout my time in Erlangen. I also thank Prof. Dr. Peter Mertens for giving advice and supporting me first during my time as student and later on as a researcher at FORWISS. The early work for this thesis, in particular the system DARMS described later on, was done jointly with Prof. Dr. Clemens Beckstein. This fruitful cooperation is documented by several papers accepted at international workshops. He continued to support my thesis work by carefully reviewing drafts.

I now work in the group of Prof. Dr. Günther Palm at University of Ulm and I am very grateful to Prof. Palm for making it possible for me to finish this work. With Prof. Dr. Bernhard Nebel I had several valuable discussions regarding the parts of my thesis related to logics. I am very grateful to

Prof. Dr. Jörg Siekmann for accepting my thesis for publication in the Lecture Notes in Artificial Intelligence series, published by Springer-Verlag. Many thanks also to Alfred Hofmann and Anna Kramer of Springer-Verlag for their help and their patience.

My colleague and friend Dr. Josef Schneeberger did an outstanding job in motivating and supporting my effort to finish this thesis. When he came to FORWISS in late 1992, he took over a good deal of the administrative duties and management tasks that until then had accumulated on me. As a consequence, I was able to free my mind for doing this research. His interest in my work and his advice were always very inspiring and helpful. Both Josef and myself would never have managed to do all the work we did in the last few years without the help and support of Margarethe Griffaton, the secretary of both the Knowledge Acquisition Research Group and the Knowledge Processing Group at FORWISS. She is a real jewel and I hope she will always get the recognition she deserves for her work and commitment.

My colleagues Christiane Förtsch, Rainer Gastner, Ernst Lutz, Michael Müller, and Gerhard Tobermann at FORWISS, and Markus Kessler, Hans Weber, and Thomas Stürmer at IMMD-8, created a stimulating and fruitful atmosphere. I thank them all for the good time I had in Erlangen. I also owe a lot to the students that I advised during my time at FORWISS: Rainer Basler, Christoph Dotzel, Robert Fuhge, Tim Geisler, Jürgen Gövert, Sabine Iserhardt, Joachim Klausner, Jörn Kriegel, Rolf Reinema, Joachim Rick, and Martin Riederer.

I had many great discussions on various topics related to my thesis with my long-time friend Michael Beetz from Yale University and many other people from the German and the international DAI community: Jürgen Müller, Donald Steiner, Kurt Sundermeyer, Klaus Fischer, Ed Durfee, Yoav Shoham, Mike Wooldridge, Mike Huhns, Gilad Zlotkin, Jeff Rosenschein, Mike Wellman, and Les Gasser, to mention just a few.

My brother Alfred and his wife Sabine, my sister Renate with her friend Horst, and my friends Elisabeth and Winfried Barth with their daughter Luisa, Annette and Michael Beetz with Nicola, Monique Neumann and Roger Knab with sons Julian and Marius, Lisa and Ernst Lutz, and Gabi and Thomas Ruf with their kids Maximilian and Stefanie, all helped to make life enjoyable for my family, despite my never having enough time to contribute much myself. My parents showed extremely good farsight in the early stages of my education, thereby laying the foundation for my career, and provided moral and financial support later on. They continue to give me the security of a good and intact family. For this and a thousand other reasons, my thesis is devoted to my parents.

More than everybody else, my wife Iris and my son Thomas had to take the heaviest load of long nights and weekends spent in the office. Iris and Thomas, I thank you with all my love.

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