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F. von Martial

Coordinating Plans of Autonomous Agents

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Jörg Siekmann
University of Saarland
German Research Center for Artificial Intelligence (DFKI)
Stuhlsatzenhausweg 3, W-6600 Saarbrücken 11, FRG

Author

Frank von Martial
DETECON GMBH
Aennchenstr. 19, W-5300 Bonn 2, FRG

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Foreword

The use of computers to support collaborative work is an emerging trend that will have a significant impact on how we do our daily work, especially as our work becomes mediated by computerized intelligent assistants that understand our goals and plans. This book represents an important contribution to the field of *Computer-Supported Cooperative Work*. However, this book is also equally important to the area of *Distributed Artificial Intelligence* because of the techniques it develops for agent coordination, specifically multi-agent planning. It considers the issue of how plans that are developed autonomously by individual agents should be restructured when other agent plans are in conflict or when there exist beneficial relationships among them. The basic approach to the recognition of these relationships among agents' plans and their resolution is a distributed one.

This work is not only interesting for the computational techniques developed for plan coordination but also for the formal framework that underlies these techniques. The characterization of plan interactions among agents is built on a formal logical framework based on an event-based characterization of actions. This framework allows for the representation of concurrent actions in multiple agent plans, temporal relationships among actions, and plans at multiple levels of abstraction. Based on this framework, a taxonomy of plan relationships is defined that includes both positive and negative relationships among plans.

Negative relationships are those that may prevent either or both plans from carrying out their intended purpose. The basis for these negative relationships are due to shared resource usage or incompatible actions. Actions are incompatible when the action of one plan creates a logical state of the world which precludes another agent from successfully completing its action. Resource conflicts due to shared resource usage are further broken down into two categories, one involving consumable resources and the other non-consumable resources.

Positive relationships are also broken into categories involving equality, subsumption and favor. An equality relationship indicates the ability of an agent to carry out an action in another agent's plan and is the basis of task sharing. A subsumption relationship indicates that one agent's actions will make unnecessary an action of another agent. A favor relationship indi-

cates one agent has the potential for slightly altering its plan in such a way that the number of actions required by another agent to carry out the intended purpose of its plan is reduced. The formal specification of these relationships among agents' plans and how these relationships can be used to improve overall network problem solving is an important aspect of this work.

The major emphasis in the discussion on resolving negative conflicts is on those caused by shared access to non-consumable resources. The techniques for handling other types of conflicts are more domain-dependent in character and are not treated in detail. In a principled way, the alternative strategies for resolving this type of conflict are detailed based on temporal ordering constraints; additionally, heuristics are specified for choosing the order of resolving multiple conflicts among agents and for choosing among alternative strategies for resolving conflicts. The protocol for exploiting the favor relationship is also explored in detail. Especially interesting is the quantitative heuristics for deciding when the favor relationship should lead to agents restructuring their plans. The techniques for resolving non-consumable resource conflicts and exploiting favor relationships are explained through a number of examples which provide a good understanding.

The distributed negotiation protocols used by agents to recognize and resolve/exploit these plan relationships are some of the most sophisticated strategies yet devised for coordinating agent activities. They exploit the hierarchical nature of plan descriptions to reduce communication among agents, and can work with only partially expanded plan networks. These complex, multi-step, asynchronous protocols are extremely hard to verify for correctness. This work reworks and applies verification techniques, developed for the analysis of low-level network communication protocols, so that they can be used to verify these high-level negotiation protocols.

The final part of this book examines the design of a prototype system that supports collaborative work in the office domain based on the plan coordination techniques developed in early parts of the book. As part of the system, a planning subsystem is described, which is used to generate the activity plans of individual agents.

In summary, this book represents a thorough and deep investigation of an important topic in distributed AI and computer-supported collaborative work. It is clearly written with many examples and background material that should allow readers of both fields to understand it.

University of Massachusetts at Amherst, January 1992 Victor R. Lesser

Preface

The ability to coordinate and negotiate is part of almost any intelligent behavior and, hence, reasoning about coordination is one of its fundamental components. This work deals with the coordination of distributed agents which have planning and communicative competence.

Important issues in this book are:

- How to recognize and reconcile conflicting intentions among a collection of agents.
- How to recognize and take advantage of favorable interactions.
- How to enable individual agents to represent and reason about the actions, plans, and knowledge of other agents in order to coordinate with them.
- When to call a set of plans "coordinated" and what operations are possible to transform uncoordinated plans into coordinated ones.
- How to enable agents to communicate and interact: what communication languages or protocols to use, and what and when to communicate.

We will present a novel approach to coordinate activities of autonomous agents. The intended actions of agents are described as plans. The coordination of plans is triggered by the relations which exist between the actions of different plans. With the help of an explicit model of multiagent plan relations a powerful approach for coordination is realized. Our model covers the whole spectrum from negative to positive relations between plans. Negative relations may prevent one or several of the plans from being executed as intended. Positive relations are all those relations between plans where some benefit to the agents can be derived by combining the plans. The handling of plan relations includes both the operations for conflict resolution and for the utilization of favorable relations and the way agents can interact and negotiate about their relations.

The main contributions of our work include:

- a detailed taxonomy of relations between plans of different agents,
- strategies for coordination and plan modifications based on these relations, and
- a negotiation framework for synchronizing activities.

The reader may also appreciate the thorough introduction to the field of *distributed artificial intelligence* and its subarea *multiagent planning*.

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My very special thanks go to my wife Suha and our kids Rascha, Simon and Marius for tolerating my not being available to them so often. Although highly motivated to study the mentally produced artificial agents of my research, I am much more fascinated by my physically produced human agents, namely our children. Suha also helped me very much with her encouraging and optimistic spirit to pursue my goal of writing this book.

Siegburg, April 1992 Frank von Martial

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