Survey of Research Context: On a General Notion of Transformation for Multiagent Systems

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In this document an overview of research context for the paper [PS07] is given. Beginning with an introduction to the problem domain, next a list of other modeling approaches that are applicable is given and finally the proposed approach is summarized.

A Short Introduction to Multiagent Systems

Multiagent System modeling is part of the large field of Artificial Intelligence, and is an approach to model ”Distributed Artificial Intelligence” in literature also called ”Swarm Intelligence”.

In a MAS the different agents (or actors) cooperate or compete to achieve a task. Cooperation among agents in a MAS is mainly realized by means of communication.
The ”World” in which the agents are ”living” is called MAS, it provides basic services to the agents:

- message service - enables the agents to communicate with each other
- definition of social dependencies - how to the agents cooperate?
- security services - which agent is allowed to do what?

The characteristics of MASs are that (1) each agent has incomplete information or capabilities for solving the problem and, thus, has a limited viewpoint; (2) there is no system global control; (3) data are decentralized and (4) computation is asynchronous[Syc98]. In many cases the MAS has a system-goal [Tol03].

The most powerful tools for handling complexity are modularity and abstraction. MAS offer modularity by splitting up a problem to subproblems that are solved by specialized agents (which can be regarded as modular components).

Benefits of using MAS technologies are([Vla03] and [Syc98]):
Speedup and efficiency (achieved through asynchronous and parallel computation), robustness and reliability (if one agent fails it doesn't mean that the whole system breaks down), scalability and flexibility (adding new agents to the system is easy), development and reusability (its clear that its easier to develop and maintain modular software than a monolithic one).
Moving from single-agent to a MAS has not only advantages but also challenges, some of them are ([Vla03]):
How to decompose a problem, allocate subtasks to agents and synthesize partial results, how to implement decentralized control and build coordination mechanisms, how to design multi-agent planning and learning, how to represent knowledge, how to enable agents to communicate, how to ensure coherent and stable system behavior.

Agent Cooperation

For every agent has a limited sphere of influence, it is crucial to cooperate to solve a problem. Cooperation is an interaction between agents of a MAS whereby the agents coordinate their actions [WH03]. Communication may vary from simple forms to sophisticated ones. A simple form of communication is to restrict the agents to simple signals with fixed interpretations [For98]. To ease the task of agent communication protocols are used. Two well known are: KIF (Knowledge Interchange Format - represents the contents of a KQML message)and KQML (Knowledge Query and Manipulation Language - doesn't deal with contents but with the wrapping of the message)[Ngo]. MAS can be regarded as a distributed system and its users are the agents.
In such a distributed system the MAS has to enable the agents to communicate in a peer to peer fashion, which has to be transparent to the agents.
Possibilities to reach this kind of transparency are MAS using CORBA, RMI (Remote method invocation), RPC (remote procedure call), ROI (Remote object invocation) or some other kind of middleware allowing its users to act as if they were operating on the same machine(For example as defined in [MN]).

Approaches

In the next sections we will take a look at existing approaches that deal with agent cooperation and action planning.

Logical Fiberings

One part of work in MAS modeling concerns logical modeling aspects. It turned out that logical fiberings [Pfa91] provide a concept to assign a system of distributed logics to a MAS in a natural way. The basic idea, is to assign a logical fiber to every agent, this fiber models the local logical state space of an agent, the entire logical fiber bundle forms the global logical state space of the whole MAS. The base space of a logical fibering can carry additional information. For more details we refer to [Pfa04].

Global Modal Logics for Multiagent Systems

The use of modal logic for the study of believes and knowledge of agents in a MAS has become custom. In the paper [Edt05] a fibered global modal logic is introduced for the logical modeling of MAS on the basis of logical fiberigins. In this approach there is additional information in the base space of the fibration, holding communication information. Thus communication influences the knowledge and believes of an agent. The paper studies distributed modal logics and possible world semantics in terms of fibered structures.

Modeling Interaction by Sheaves and Geometric Logic

In the paper [SSS99] it is shown that under certain circumstances the properties of systems like actions, transitions, behavior in time, among others can be modeled by sheaves. In the sequel it is decided via geometric logic if a local property can be lifted to the global level. This is of course an essential part in MAS modeling.

Applied and Computational Category Theory (ACCAT)

Category Theory is a powerful unifying mathematical modeling language with many constructive features. It has a wide field of applications especially in computer science. Much of its power arises from the fact that category theory is an abstract modeling technique that has interdisciplinary features thus allows to establish links between different areas. The acronym ACCAT was introduced by J. Pfalzgraf during his time at RISC-Linz motivated by the book ”Computational Category Theory” by Rydeheard and Burstall. A strong feature of category Theory is that in contrast to set theory it focuses on ”functions” and structures not on ”set membership”.

Decision Theory

Decision Theory is a set of mathematical techniques that allow to make decisions about what action to take whereby the outcome of the decision is not known. In a MAS this corresponds to the decision an agent has to make, based on uncertain knowledge of the environment. This uncertainty arises from the fact that each agent only has a limited sphere of influence. Typically probabilities and in the sequel Bayesian networks play an important role. To be able to perform goal oriented action planning, the idea of utility is introduced. This is simply a value representing the preference of an agent for a state of the environment. Typically an agent tries to maximize this value. [PW02]

Game Theory

Game Theory is a Theory that is strongly correlated with Decision Theory. Game Theory in the field of MAS tries to give an answer the the question: What is the best action to take, for an agent. Typically the global outcome of an action will depend on the actions that every player (agent) takes. This means the agent has to strategically plan its actions. [PW02]

Multirobot Systems

Multirobot Systems is a branch of MAS, dealing with the study of algorithms for perception, cognition, and cooperation of multiple robots. It is of course a wide field [IEE06]. The bulk of research is done concerning cooperation models, cooperative sensing and especially important localization and exploration as well as control and adaption.

Marked Based Approaches to MAS Cooperation

Marked Based Approaches for MAS coordination is essentially an application of marked economies to Multiagent Systems where self interested individuals (autonomous agents) or groups of those act to maximize their own profit. Tasks are assigned to agents by marked mechanisms such as auctions. Additionally some ”virtual money” is introduced, agents pay others to perform tasks and get ”money” for providing services to others. [DZKS06]

The proposed Solution

In recent work a generic categorical model for MAS has been introduced leading to the category MAS [Pfa05]. In that category the objects are agents of various types and the morphisms represent all kinds of relations between the agents, we call it general communication and cooperation arrows. This general communication and cooperation structure is represented by a corresponding arrow diagram, called base diagram of a MAS.

Of basic importance for our work is the observation that every arrow diagram (i.e. directed graph, possibly with labels on the arrows) can be interpreted as a category named PATH - c.f. [Pfa05] - morphisms are sequences (paths) of arrows. This viewpoint leads to a general categorical semantics for relational structures. Vice versa, every category is a graphical structure (with nodes and arrows). We point out that the identity morphisms can always be assumed to exist, artificially.

The very idea of MAS is to solve problems decentralized by autonomous actors (the agents), this leads to a wide field of applications which resort to MAS techniques. Until now there is no general, unique definition of agent and Multiagent System. We are convinced that there is a strong need for a formalization of MAS. It is our goal to develop a toolbox for MAS modeling using categorical notions. Typical characteristics of Multiagent Systems can be summarized by the following statement: Each agent has only local information and a limited ”sphere of influence", there is no global system control, information is available only in a decentralized manner and the processes are asynchronous [Woo02].

A Multiagent System can be modeled with categorical notions by typed categories. The objects are the agents and the typed morphisms represent the relations between the agents. To each MAS we associate a Base Diagram $\mathbb{D}$ which represents the complete relational structure (i.e. communication in the general sense). The nodes of this arrow diagram represent agents, the arrows (and paths of arrows) are the morphisms of this category.

A MAS is a dynamical system which means that relations between agents can change. This fact gives rise to the definition of the category $\mathbb{MAS}$ of all MAS where the objects are Multiagent Systems and the morphisms are MAS-Morphisms. Based on this category $\mathbb{MAS}$ a transformation system for Multiagent Systems is introduced by applying the double pushout approach ([EPS73, EEPT06]) to Multiagent Systems. We introduce it with the aim to develop a generic method for the formal manipulation of a base diagram of a MAS.

Conclusion

The concept of $\mathbb{MAS}$ transformations, which is an adaption of graph transformations [EEPT06] to typed categories, is a natural way to describe changes in the base diagram of Multiagent Systems. Due to the categorical modeling the proposed approach is independent of the implementation of the agents (agents are analyzed via their external properties). This allows to analyze MAS on the basis of their cooperation and communication structures, which represent significant information. We can define actions and their application conditions in a MAS by productions in $\mathbb{MAS}$. Now we can ask the question: Which transformation steps lead to a desired result, such as which transformation steps have to take place that the resulting base diagram of the MAS has a limit or colimit object for one or more types. This would be a universal communicator, mediator, or steering agent [Pfa06].

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