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Theme 1: Uncertainty and hostility management in multi-agent systems

Abstract

Software agents are considered as a new experimental embodiment of computer programs and are being advocated as a next generation model for engineering complex, heterogeneous, scalable, open, distributed and networked systems. Among other factors, what makes software be considered as an agent is its ability to interact or communicate with the other agents. Unfortunately, agent interaction is not fully understood and modeled. Most of the projects are based on the assumption that the other agents are trustworthy. This may not be true in real world application of heterogeneous software agents. There are four main objectives of this research. The first one is to formalize agents' interaction and organizational relationships. We define interactions in terms of cooperation, coordination and competition. We identify two types of organizational relationships: signal level and symbol level. The signal level accounts for dynamic message passing. At this level, messages between two communicating agents are interpreted via ascribing the same meaning to the constants used in the messages. In this way, mutual understanding of the domain constants before further message passing must be guaranteed. Symbol level relationships account for dynamic knowledge sharing. Managing organizations, i.e., organizational formation, maintenance and updating at the symbol level is a missing point in the other works. The second objective is to devise techniques to address competition within an organization. In this case, knowledge sharing is impossible, and we present an incomplete game theoretical based decision making method for competitive agents. The third objective is to develop prototype agents based on the above mentioned techniques, form agencies of prototype agents and experiment with them to verify the techniques and hold experiments to test the quality of the decision making in a competitive environment. The forth objective is to develop a library of agent components that could be used to build reliable multiagent systems for real business applications.

1. Recent Progress in Research Activities Related to the Proposal

This project encompasses three main disciplines: software engineering (SE), artificial intelligence (AI) and operational research (OR). My early background is in the AI and later SE and my recent works in system theory and OR has allowed the formation of this project.

A seminal work, that became the basis for this project was our *Software Creation* project (See [ABOLHASSANI2001]) in which we build a computer aided software engineering (CASE) tool for groupware design that can imitate the design steps of a team of human designers. By studying human knowledge in software design we understood that there are two types of knowledge involved in human design: detailing knowledge represented by conversion and detailing rules; hierarchical expansion knowledge represented by micro design rules. In this project we were highly interested in the way that humans could cooperate (i.e., share knowledge to work towards a common goal) and coordinate (i.e., share knowledge to work towards separate goals using common resources) to achieve their common or separate goals.

This led us to work on a new project concentrating on *representation and reuse of organizational knowledge* (See [FAR2000]) in which we tried to formalize the knowledge representation and sharing for cooperative and coordinative agents, based on sharing knowledge and/or goals, with the focus on reusability and applicability in large scale multi-agent system design. We actually tested the developed techniques in a *multi-agent system for electronic commerce* composed of customer, dealer, manufacturer, delivery, banking, search, catalogue and security management agents (see [FAR98]).

At this stage we found out that almost all of the multi-agent system (MAS) projects are based on the assumption that the other agents are trustworthy. This is not true in real world application of heterogeneous software agents. Even within a uniform agent framework, this may not be true. For example, if two or more dealer agents want to sell the same commodity to a customer agent they will be engaged in competitive acts and will certainly not share their knowledge and/or goals. This led us to start a new project of *dealing with uncertainty and hostility in multi-agent environments* (See [ONJO2001]) which is directly related to this current proposal. In this project we developed a multi-agent learning language (MALL) [SOUEINA98] for competitive and hostile environment. Also we could give a coherent view of the three agent interaction problems: cooperation, coordination and competition. To the best of our knowledge, no other work could present these in a unified and yet comprehensive way. (see [ONJO2001]). These together lay the basic building blocks for this project ready to be further investigated, implemented and tested.

2. Objectives

Due to the increasing popularity of the Internet, heterogeneous, scalable and networked software systems are highly desirable. However, neither of the software engineering paradigms could make software technology keep up with the current business needs. Nowadays, an increasing number of software projects are being revised, restructured and reconstructed in terms of software agents. Software agents are considered as a new experimental embodiment of computer programs and are being advocated as a next generation model for engineering complex, heterogeneous, scalable, open, distributed and networked systems.

The ultimate research goal of my lab is to devise a methodology for agent-based software engineering based on firm software and knowledge engineering techniques. This project is a step towards this goal. There are four main objectives of this proposal:

- Formalizing agents' interaction and organizational relationships: We define interactions in terms of cooperation, coordination and competition. We identify two types of organizational relationships: signal level and symbol level. The signal level accounts for dynamic message passing. At this level, messages between two communicating agents are interpreted by ascribing the same meaning to the constants used in the messages. In this way, mutual understanding of the domain constants before further message passing must be guaranteed. Symbol level relationships account for dynamic knowledge sharing. Managing organizations, i.e., organizational formation, maintenance and updating at the symbol level is a missing point in the other works. We have already proposed techniques to handle cooperation and coordination in multi-agent systems (MAS) based on sharing knowledge and/or goals (See [FAR2000]).

- Devising techniques to address competition within an organization: In this case, knowledge sharing is impossible, and we present an incomplete game theoretical based decision making method for competitive agents. The preliminary works have been reported (See [ONJO2001]) but they need further extension, refinement and implementation. For example, a limitation of the proposed method in the above mention work ([ONJO2001]) is that the competitors and their strategy sets must be in the common domain. In the case of open and evolutional systems, this may not be true. There may be cases that the agent is not aware of the whole group of competitor and/or their strategies. Our proposed model should be extended to cope with this.
- Developing prototype competitive agents: That is to devise techniques for MAS design, design and implement the above mentioned techniques, form agencies of prototype agents and experiment with them to verify the techniques and hold experiments to test the quality of the decision making in a competitive environment.
- Developing a library of agent components: That is to revise the design and catalog a library of reusable software components that can be used to build reliable multi-agent systems for real business applications.

3. Literature Review

Software agents are considered as a new experimental embodiment of computer programs and are being advocated as a next generation model for engineering complex, heterogeneous, scalable, open, distributed and networked systems [JENNINGS00].

Among other factors, what causes software be considered as an agent is its ability to interact or communicate with the other agents. Unfortunately, agent interaction is not fully understood and modeled. Most of the projects are based on the assumption that the other agents are trustworthy. This may not be true in real world application of heterogeneous software agents [SUBRAMAN00].

This project is the intersection point of three main disciplines: software engineering (SE), artificial intelligence (AI) and operational research (OR). Research in the following areas is particularly important to this work:

3.1 Agent-oriented organizations

Organizations, of various forms, physical, cognitive, temporal and institutional have been studied in operation research, management and computer sciences. The game theoretic approach to study organization focuses on modeling and suggesting computational algorithms for certain aspects of the coalition, such as social welfare [SANDHOLM99], individual rationality, voting consensus, etc. The computational approach focuses on identifying general principles of organization and their exceptions. The proposed theories extend the information processing capabilities of individual agents to an organization level, through defining concepts such as, bounded rationality [SIMON]. There is another approach focusing on environment centered analysis and design of coordination mechanisms [DECKER96]. For a survey on computational organization theories see [CARLEY94].

The already proposed organizational models for multi-agent systems have certain drawbacks. First, they cannot explain the organizational knowledge in terms of its comprising agents without reference to any other intermediary concepts. Second, they cannot provide frameworks for comparing and evaluating different organizations. Third, the organizational knowledge base cannot be updated dynamically, accounting for different configuration of the participant agents. Finally, they cannot explain the need for services of a certain agent in an organization. All of these factors are necessary in organization design and are addressed in our research. Our paper [FAR2000] could address these problems.

3.2 Multi-agent system (MAS) design

Four main approaches for multi-agent system design are reported: The MAS-common KADS [IGLESAIS97]; the MASSIVE development method [LIND00]; the agent-oriented analysis and design method [WOOLDRIDGE98]; and development based on the Beliefs-Desires-Intentions (BDI) [RAO95]. The final two are commonly cited and quite popular. In [WOOLDRIDGE98] a conceptual framework - composed of agent roles, permissions, responsibilities and protocols - is proposed that maps to a methodological model for analysis (interactions and roles model) and design (agent, service and acquaintance models). Georgeff and Rao claim that the widely referenced Belief-Desire-Intention (BDI) notation is necessary in design of complex and real-time multi-agent systems [RAO95] and many research papers have been emerged from this idea.

3.3 Decision making under uncertainty and risk

John M. Keynes (1883-1946) has defined risk as a situation in which the probabilities of the various possible states are known; and uncertainty as a situation in which probabilities of the various possible states are unknown. Decision making under risk is studied extensively in risk analysis and economy [SAMUELSON48, CHIANG84]. In decision making under uncertainty (i.e., probabilities of the various possible states of the world unknown) techniques such as dominance (choose the action which leads to the most desirable outcome in all states), maximax (choose the action which maximizes the maximum outcomes for the possible states), Maximin (choose the action which maximizes the minimum outcomes of the states) and minimizing the regret (choose the action which minimizes the maximum regret) are proposed. In the latter, regret is defined as the utility of that outcome subtracted from the maximum utility of that state. We use uncertainty and risk analysis in this project.

3.4 Game theory

Game theory [OSBORNE94] and specially games with incomplete information [HARSANYI68] are studied extensively in computer and management sciences. However, in game theory, there is no clear cut distinction between the value and utility concepts. But the pragmatics of this seems to be quite important in MAS. Specifically, value is the nominal value or the nominal profit. e.g., cash value, and utility represents what the outcome is worth to the agent. The nominal value of an outcome is not necessarily the utility a particular agent places on that outcome. Therefore in multi-agent systems (MAS) the conventional two or multi-player strategic games should be revised to account for this.

4. Methods and Proposed Approach

Phase 1 implementing Objective 1: For a pair of agents to interact, each should maintain a model of the other agent, as well as a model of future interactions [HUHNS99]. In cooperative and coordinative environments the agents can share their knowledge and/or goals. In this phase, the Symbol Structure model [FAR2000] for knowledge sharing and the algorithm for deriving organizational properties in multi-agent systems (MAS) will be implemented.

Phase 2 implementing Objective 2: In a competitive environment the information obtained from the other agents' behaviour might be incomplete since agents try to mask their knowledge and/or hide their strategies. In order to cope with this, the agent must predict environment's parameters, other agents' future moves, and successfully explain self and the other agents' actions. The crucial factors are both the amount and specification of the information.

Using game theoretic approach, the process for deciding competitive strategy involves the following steps:

- First, each agent tries to predict opponents' strategy.
- Second, the agent selects the best response strategy based on previous predictions.
- Third, each agent will get a payoff by using a utility function.

Then we model competitive environment for the two cases that agents' preference relations are either known or unknown. As for the first, we can use the conventional game theory. For the second, we regard the agents' strategies as state of nature and treat them by lumping up all of the natural objects as uncertainty. Following Keynes' (1883-1946) definition, we define three levels of decision making in competitive environment:

1. Decision making under certainty: (state of nature and strategies are known) Game theory will be used in this case.
2. Decision making under risk: (exact state of the nature is unknown but probability distribution of the states is known) A risk management method to reflect agent's attitude towards risk is devised and will be implemented.
3. Decision making under uncertainty: (exact states of the nature is unknown and their probability distribution is also unknown) In this case the agent has to assign its belief without using a probability distribution. A method to measure and set the degree of optimism based on Ordered Weighted Averaging (OWA) operator [YAGER88] is proposed and will be implemented.

Finally, a method the analyze opponents' move will be used to assign and update agent's belief about the state of the world.

Phase 3 implementing Objective 3: Prototype agents will be developed to incorporate these and experiments will follow to verify the techniques and the quality of the decision making in a competitive environment.

Phase 4 implementing Objective 4: Each of the decision making and knowledge sharing components will be modularized and implemented in a library of agent components. This library will be used to build business quality multi-agent systems (MAS) applications.

5. Anticipated Significance of the Work

This research shall have significant impacts for the economy, the software engineering discipline and for the society as a whole.

Economical impact of the project is enormous. The factors that can make software systems useful assistant to human counterparts are the *knowledge* and *decision making* to make good use of knowledge. An important aspect of decision making is to get engaged in a competitive task to increase the profitability of self, company and society. A theory that can address this and a software system that can implement this feature will be highly appreciated in the areas such as marketing, setting price for a new product, setting target for production and particularly in electronic commerce providing services and/or selling goods online. Also because of introduction of the degree of optimism (See [ONJO2001]), the agent that helps a human counterpart, can select the competitive strategy even if probability of competitors' moves is completely unknown. From the viewpoint of behavioural psychology, utilization of degree of optimism is natural and from engineering point of view is practical.

For society, this work has the potential of providing a significant amount of empowerment to the casual computer user. Decision making mechanism implemented in electronic commerce software products will help the average computer user do profitable business on the Internet and always be sure that the decision making under uncertainty or under risk modules are there as watch dogs. The agents can reflect opinion of users (such as degree of risk aversion and degree of optimism). From the viewpoint of human computer interaction (HCI), it is an important function for the decision support system in order to make users have the trust to the system.

Finally, the main impact in the discipline of software engineering will be in the multi-agent systems (MAS) area. This research shows how agent architectures and implementations can be extended to handle both signals (i.e., messages) and symbols (i.e., knowledge). It allows deriving properties for random and/or purposeful coalition of agents dynamically and simplifies the requirement analysis and early steps of design because the designer need not predict and document all possible interactions at the outset. This simplifies the design task of MAS system and increases productivity.

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