Study of Virtual Organizations Using Multi-Agent System *

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1. INTRODUCTION

Virtual organization refers to the temporary teaming of enterprises. To realize this new generation of business model, the ability to form and operate virtual organization is very important. The paper describes our experience gained by implementing a multi-agent system that simulates an artificial marketplace, from which we have derived several decision-making mechanisms in various stages of a virtual organization. A negotiation protocol and a bid selection algorithm are developed for agents to form a virtual organization. MQ framework is adopted to support the agent's local reasoning process. In order to better understand the organizational problem, we adapt a statistical model that predicts the expected rewards of individual agents and the performance of the virtual organization. The comparison and analysis of the results from both the simulation and the model prediction are also presented in this paper.

2. SCENARIO: VIRTUAL BUILDING ORGANIZATION

In order to simulate the virtual organization, we have developed a scenario as the base of our model. A real estate developer, named Concrete Developer, has recently won the right to develop a large suburban area for residential use. Concrete Developer has always relied on a single outside contractor, who in turn enlists a group of sub-contractors, to construct the residential buildings. However, after a careful analysis, Concrete Developer decided that it would be much more profitable and effective to form a virtual organization. The developer partitions the building process into five partial processes (subtasks), namely framing, foundation, electrical work, plumbing, and finishing, assuming they must be completed in sequence. The developer makes the initial proposal of forming a virtual building company to the sub-contractors in the marketplace. The individual enterprises (sub-contractors) can then bid for those partial processes. After the developer has received substantial bids from the individual contractors, it then selects a group of bids that meets its highest expectation based on multiple criteria, such as competence, availability and etc. Once the virtual organization is formed, it goes into the operational phase. During the operational phase, a buyer may request for a house at any given time (the negotiation process between the buyer and the developer is omitted here for simplicity). After receiving a buyer request, the developer notifies the individual participants of the virtual organization, who may or may not commit to the subtasks depending on their current problem-solving context and their local decision-making mechanisms. The developer accepts a buyer's request only when it has all the necessary commitments to complete the whole construction task. Only when all the subtasks are completed, the developer can collect money from the buyer. An agent may receive service request from the developer agent, it may also receive service request directly from the buyers or another virtual organization that the agent also belongs to.

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3. THE FORMATION AND OPERATION PROCESS

3.1 Negotiation Protocol

A negotiation protocol is developed to support the formation process of the VO. In this protocol, the proposal sent by the initiator agent includes the following information: the types of the subtasks needed for the organization, the estimated workload for each type of subtask (partial processes), and the estimated profit of the organization. The bid from the potential participant includes the following information: the type of subtask the agent is capable of, the number of units it will contribute to the organization (capability), and the profit sharing rate (how much it requests from the virtual organization's profit). In our simple model, this protocol is sufficient for individual agent to decide whether or not to join a virtual organization and for an initiator to select a group of partners.

3.2 Partner Selection Process

The objective of the selection process is to form a virtual organization that would maximize the initiator's profit. The initiator's profit depends on the profit of the organization and the profit to be handed out to other agents in this organization. Assume that a bid B_i contains the following information: type of task T_{bi}, number of commitments promised L_{bi}, profit sharing rate S_{bi}, then the profit for the initiator would be: $R \cdot L' \cdot (1 - Sum(S_{bi}))$ where L' is the practical workload ($L' = min(L_{bi})$, and $L' <= L$).

The core of this procedure is a recursive best-first search algorithm (RBFS) with some heuristics. It works in the following way.

First, it groups the bids into different bins according to which task they are bidding on. Then it selects one bid from the first bin which will maximize the initiator's profit, but it also remembers the second best choice. It goes to the next bin and finds the best bid that can be combined with the choice from the previous bin: if the initiator's expected profit from this set of combined bids is no less than the second best choice of the previous bin, it continues to the next bin; otherwise, it will unwind to the previous bin and choose the second best and proceeds from there. It continues this process until an optimal solution is found.

3.3 Penalties for Lack-of-commitment

An enterprise needs an incentive to encourage the agents to fulfill its promise to the VO. A penalty for lack-of-commitment is the most straightforward incentive and is also easy to be implemented. Depending on how the penalty is calculated, there are different penalty policies. A linear penalty policy has a fixed penalty rate for each unfulfilled commitment. A progress-based penalty policy has a decreasing penalty rate as more commitments have been fulfilled. It charges a heavy penalty if the agent can not fulfill a minimum percentage of its promise, and it charges a much less penalty if the agent has fulfilled a certain percentage of the obligation. To react rationally toward the penalty of lack-of-commitment, the agent needs to incorporate the penalty policy into its local decision-making process. In our model, this is implemented by introducing a control parameter in the utility mapping function (See Section 3.4 for more detail) associated with the organization task. By adjusting this parameter, different penalty policies can be reflected in the agent's decision-making process, so the agent can balance the profit and penalty when making decision on which task to perform.

3.4 Utility Mapping Function of MQ

In a virtual organization, each member agent receives service requests not only from this organization (referred as *organization task*), but also from other organizations (if the agent belongs to multiple organizations) or directly from customers (referred as *outside task*). When there is a conflict between different tasks, the agent needs to decide which task to commit. The MQ framework[4] provides such a mechanism for keeping the different motivational concerns separated, because they represent progress that are not interchangeable. Based on MQ framework, we assume that each different type of task produces a different type of MQ. For instance, tasks from organization A produce $MQ_{organizationA}$, tasks from organization B produce $MQ_{organizationB}$, and tasks from direct customers produce MQ_{direct}. There is a utility mapping function associated with each type of MQ, and it reflects how the agent evaluates this task in terms of the contribution to its local goals and objectives. To focus on the study of virtual organization, we assume that the outside tasks only produce monetary value, the mapping function for MQ_{direct} is expressed as $f(x) = x$, which maps each unit of monetary value into one unit of local utility.

The mapping function is expressed as $f(x) = a \cdot \frac{1}{b} \cdot (1 - ((1 - b)^{\frac{1}{c}})^x)$, where a is the expected utility from/of the virtual organization depending on how important the agent feels about the organization's achievement. b is a control parameter and $0 < b < 1$, which works with c together to reflect the penalty policy (See details in the following example). By adding a third variable c to the formula, the agent has more control on how to fulfill its promise to the organization. The intention is the agent tries to fulfill its promise to the organization; afterwards the utility gain from performing organization tasks would slow down.

4. EXPERIMENTS

The experiments were designed to verify the correctness of a set of mechanisms we developed and also to unveil any relevant information based on the data we gathered from both the simulation and the statistical prediction. Furthermore, we would like to study the agent's behavior under different control settings. By alternating the parameters of different types of tasks for an agent, we would like to see the effect of the mapping function on agent's promise to the organization, the agent's local utility, and the organization's utility. Space limitation precludes the results and discussion, which can be found in [5].

5. RELATED WORK

Multi-Agent system has been used to simulate different types of organizations. [2] used a multi-agent system to model a set of firms in competition with each other within a shared market. [1] presented an approach towards process-oriented collaborative inventory management in supply chains, taking advantage of multi-agent technology in terms of modeling and simulation. [3] has studied market-based approaches for task-assignment multi-agent systems. Our work has a different emphasis from the above work.

6. CONCLUSION AND FUTURE WORK

This paper describes our experience in the study of virtual organizations by implementing a multi-agent system to simulate the virtual organization. We proposed a negotiation protocol for automatic formation of a virtual organization. We also presented a RBFS algorithm to find the optimal membership for the virtual organization. This solution we applied to the virtual building company may not be adequate for a large number of agents and bids, some sort of heuristics or filters are needed for the screening of bids in order to reduce the complexity. We have incorporated the motivational quantities framework for the task selection process so that agents can make rational decision during their operation. We presented a utility mapping function that can model the agent's preference, promise and the penalty policy of the organization. We adapted a statistical model that allows us to predict and analyze the agent's behavior and the influence on the organization utility. We have performed experiments to verify and evaluate these mechanisms.

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