The Effect of Task and Environment Factors on M.A.S. Coordination and Reorganization

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ABSTRACT

Research on organization of Multi-Agent Systems (M.A.S.) has shown that by adapting its organization, a M.A.S. is better able to operate in dynamic environments. In this paper we describe an experiment with a M.A.S. that consists of agents where the capability to reorganize is integrated in their coordination mechanism. In the RoboCupRescue simulator we have implemented a M.A.S. where work can be coordinated according to three different coordination styles; direct supervision and standardization of skills with and without a reorganization extension. An experiment shows the effects of unknown workload distribution and incomplete information on the performance of the three styles. Results show significant interaction effects between both workload distribution and coordination mechanism, and completeness of information and coordination mechanism. Furthermore, results show that standardization of skills with reorganization performs better and is more robust to heterogeneous workload distribution and incompleteness of information.

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Multiagent systems

General Terms

Experimentation, Performance, Design

Keywords

Coordination cooperation and teamwork, Social and organizational structures

1. INTRODUCTION

In their model of organization design [7], So and Durfee state that task-environmental factors combined with the structure and behavior of the organization influence the performance of the organization. In this paper we will focus on hierarchical organizations because they tend to perform better in more complex environments and are more robust to environmental dynamics [1]. However, one of the disadvantages is that information can get lost or distorted when it is passed up or down the layers in the hierarchy [1].

Research in the field of organizational theory has shown that when an organization is able to adapt its structure, it will be able to operate more efficiently and effectively [2]. Two main types of reorganization can be distinguished; changing the coordination strategy in the organization and changing relations and interaction patterns between agents. In this paper we use the latter approach to mitigate negative effects on performance of some of the task-environment factors by So and Durfee [7].

Coordination can be defined as managing dependencies between activities [5] and it includes managing shared resources, task assignment and task/subtask dependencies. Different coordination styles are recognized in human organizations by Mintzberg [6] and have already been applied in the design of M.A.Ss [8]. Between these coordination styles, the authority to make decisions, ranges from centralized (*direct supervision*) to decentralized (*mutual adjustment*). Standardization of skills, work and output lie somewhere in between.

2. OUR APPROACH

Mintzberg has shown that the structure of the organization and the coordination style that is being used are closely related [6]. Since organizational structure and coordination are so closely related we have incorporated the process of reorganization into the overall coordination mechanism which is shown in figure 1. The ellipse shapes are sub-processes of the coordination process, the rectangles depict declarative knowledge and the rounded rectangles depict procedural knowledge. In a single iteration, a coordinating agent selects a coordination strategy, decomposes and allocates tasks, reorganizes and communicates. Strategy selection is based on the current state of the environment and a set of organizational norms which prescribe the use of an appropriate coordination strategy in a certain situation. We consider a coordination strategy to be a combination of a task-decomposition strategy, an assignment strategy and a reorganization strategy. Strategy selection will enable an agent to switch between different coordination strategies during its lifetime. The next step in the coordination process is to create and update the task structure. Based on sensory input – which can both be observations by the agent itself or messages from other agents – the agent will decompose

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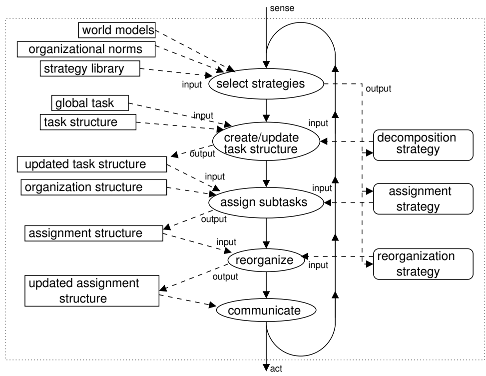


Figure 1: Coordination process description.

the global task into subtasks. Task decomposition results in a task structure that is similar to the goal trees in [4]. The decomposition strategy describes how the global task should be decomposed into subtasks.

In the task assignment sub-process, the leaves of the task structure are connected to the agents in the organization structure which results in an assignment structure. Figure 2 shows an example of how a task structure and an organization structure are combined into an assignment structure. How the agents are assigned to the tasks is determined by the assignment strategy that is used.

When assignment is completed, the agent has the opportunity to reorganize the assignment structure. The reorganization strategy describes when and how reorganization takes place. Since reorganization is applied to the assignment structure, both the task structure and the organization structure can be reorganized. Based on the updated assignment structure the agent communicates changes in the assignment structure to the agents affected by these changes.

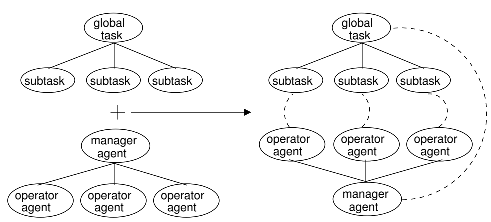


Figure 2: An example assignment structure.

In the next section we discuss an experiment in which we compare the performance of 3 different coordination strategies; *direct supervision*, *standardization* and *standardization with reorganization*, with different task-environment factors; completeness of information that is send to the coordinating agents and distribution of workload over the subtasks in the task-structure.

3. EXPERIMENT

The experiment is carried out using the RoboCupRescue simulator [3]. This is a simulation environment in which agents have to jointly perform a rescue operation after an earthquake has taken place in an urban environment. For the purpose of this experiment, the implemented M.A.S. will only perform the task of rescuing injured civilians. In the initial stage of the simulation, nothing is known about the amount of civilians, their location and health status. As the ambulances search the city, more information will become available. Another task-environment factor is the dynamics and uncertainty in health decline of injured civilians.

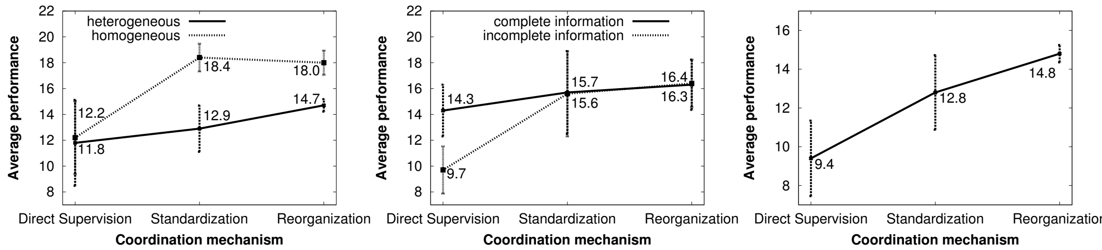
In our M.A.S., agents can have three different roles. An agent with an `AmbulanceRole` has an operational role and is capable of moving around, observing its surroundings, digging out civilians and transporting them to the nearest rescue. An agent with a `GlobalManagerRole` is capable of creating and assigning `SearchBlock`, `RescueCivilian` and `SearchAndRescueSector` tasks to ambulance agents. An ambulance manager will also monitor task progress and decide which task to perform next. The `LocalManagerRole` combines the operational capabilities of the `AmbulanceRole` and the management capabilities of the `GlobalManagerRole`. Initially, a `GlobalManagerRole` is assigned to one agent and nine agents are assigned to an `AmbulanceRole`. The latter are all able to perform the `LocalManagerRole`.

In the case of coordination by direct supervision, the agent with the `GlobalManagerRole` divides the map into a grid of 400 small house blocks and for each, a `SearchBlock` task is generated. When a civilian is reported to be found, a `RescueCivilian` task for the civilian is generated. The priority of the `RescueCivilian` task is determined by the health status of the civilian. In the case of standardization of skills, the manager divides the map into 9 large sectors and a `SearchAndRescueSector` task is generated for each of these sectors. The ambulance agents are then free to decide for themselves how to search this sector and when to rescue civilians in their sector. Standardization of skills is extended with a reorganization strategy that triggers when (1) there is at least one agent that has not been assigned to a task and (2) there is at least one task that is still being executed by another agent. The change that follows when the trigger fires is that the ambulance agent that is already working on that task is ordered to switch to the `LocalManagerRole` and the other agent is assigned to be a subordinate agent of the newly appointed `LocalManagerRole`. Agents with a `LocalManagerRole` can assign a `LocalManagerRole` to their direct subordinate agents.

Completeness of information is operationalized by including or excluding civilians' health status in the status reports that are sent to the manager. Distribution of workload is operationalized by creating maps with 20 civilians each, where the civilians are either homogeneously or heterogeneously distributed over the map. Performance is measured by counting the civilians alive at the end of the simulation.

We have run simulations with each of the coordination mechanisms for both complete and incomplete information on heterogeneous and homogeneous maps. In order to obtain reliable results we have created 10 different maps (5 homogeneous and 5 heterogeneous).

Three-way independent ANOVA shows a significant interaction effect between coordination mechanism and workload distribution (figure 3(a)) on the performance of the organization, $F(2, 48) = 13.73$ and $p < 0.01$. Analysis also shows a significant interaction effect between coordination mechanism and completeness of information (figure 3(b)) on the performance of the M.A.S., $F(2, 48) = 14.81$ and $p < 0.01$. No other significant interaction effects were found. Furthermore the analysis shows main effects for coordination mech-



(a) coordination × workload (b) coordination × completeness (c) heterogeneous workload & completeness

Figure 3: Experiment results.

anism ($F(2, 48) = 45.78$ and $p < 0.01$), distribution of workload ($F(1, 48) = 59.19$ and $p < 0.01$) and completeness of information ($F(1, 48) = 14.80$ and $p < 0.01$) which indicates that all three conditions have an independent effect on the performance of the M.A.S.

4. DISCUSSION

When we look at the interaction between coordination mechanism and distribution of workload in figure 3(a) we see that reorganization performs different on homogeneous and heterogeneous maps. Initially, we had expected that the use of reorganization would fully compensate for the negative effect of heterogeneous workload. The difference can be explained by the fact that on a heterogeneous map, agents waste a lot of time searching sectors where no civilians are located. What we also see in figure 3(a) is that direct supervision performs significantly worse than the other two mechanisms. This is caused by the interaction effect of coordination mechanism and completeness of information in figure 3(b).

In figure 3(c) the performance of the organization is shown in the case of heterogeneous workload distribution and incomplete information. What we see here is not only that reorganization performs better than the two other coordination mechanisms, but the standard deviation is also smaller. This indicates that reorganization results in a more constant performance and a more robust organization. Figure 3(c) also indicates that incompleteness of information has a much stronger negative effect on the performance of direct supervision than the negative effect of heterogeneous workload distribution on standardization. This can be explained by the poor performance of the "first-search-then-rescue" strategy by the manager when using direct supervision with incomplete information. Applying a more sophisticated or aggressive (i.e. "rescue-first-then-search") strategy would probably yield more equal results for direct supervision and standardization.

5. CONCLUSIONS

In this paper we have described a M.A.S. where the agents have a mechanism for reorganization integrated into their coordination mechanism. In this coordination mechanism, strategies for task decomposition, task assignment and reorganization are selected from a strategy library and together these strategies determine the coordination style. In the current implementation the strategies are fixed during an agents lifecycle. In the future we intend to allow the agents to dynamically select the coordination strategies.

The experiment using the RoboCupRescue simulator has shown the effects of coordination style, distribution of workload and completeness of information on the performance of a M.A.S. engaged in a search and rescue task. More specifically, the experiment has shown that standardization of skills combined with reorganization resulted in better and more stable performance in an environment where workload was distributed heterogeneously and the manager received only incomplete information about the world.

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