ADAPTIVE TEAM-BASED MULTI-AGENT ORGANIZATIONAL MODEL: A CASE IN RESCUE SYSTEMS

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ABSTRACT

In this paper, we addressed the problem of modelling complex cooperative multi-agent organizations. Proposed team-based model is inspired from the Schwaninger's model of intelligent human organizations. Considering time and agents' identity features is the main important factor in the mentioned model. In our considered problem domain, rescue systems, rapid task handling is a main requirement. Proposed model supports it through fast initial team formation, greedy capability-based coalition formation, and using the nearest neighbours' resources. Adaptation via reorganization makes the model appropriate for dynamic environments.

KEYWORDS

Team-Based Organization Model, Adaptive Multi-Agent System, Capability-Based Task Allocation

1. INTRODUCTION

Our everyday lives and specially our social transactions require various types of coordination that incorporate decision making process within a dynamic uncertain environment under multiple constraints. Cooperation between members is an important coordination task which aims to maximize the overall utility. Multi-agent systems (MASs) have been widely used to model and probe the complex behaviours in such cooperative systems.

In a MAS, agents' cooperation plays a significant role in helping system reach its pre-determined goals. The main feature of MASs is that their intelligent agents may coordinate and cooperate with each other so as to perform optimally the tasks that they cannot perform individually.

Using organization theory, behaviour of individual agents can be described by the roles they adopt and behaviour of MAS may be predicted as the result of their overall actions.

Organizational models defined for MASs are mainly adopted from analogue models in human communities [1]. The intelligent nature of agents and purposefulness of entire system, result in high similarities between behaviours of agents in these organizations and human agents present in real communities. In addition, as in human organizations, the best model to design an agent organization depends directly on its operating environment, tasks to be performed, properties and goals.

Mintzberg showed in [2] that adaptive organizations have a better prospect of good operation compared with static organizations; a prospect that led into many researches on adaptive MASs. Efficiency and effectiveness of adaptive MAS are the most challenging issues in this area. In more detail, using a proper organization model to form a MAS, cause the organization members to adapt themselves effectively to changing environment parameters. Such an organizational

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model should be able to improve the efficiency of the system, decrease agents' interactions, and reduce their computational effort.

In real world, we may face emergency systems which need very fast task handling. This rapidity is the main effectiveness requirement of the system. Rescue in emergency situations is an example of such systems, where cooperative humans tend to use their maximum capabilities to rapidly perform the tasks. In other words, they may prefer to act out of their role-specific responsibilities in occasional situations.

In this paper, a team-based multi-agent organizational model is proposed based on the Schwaninger's model of intelligent human organizations [3]. It provides an integrative framework to rapid task handling. [1]

In remainder of the paper, section 2 discusses some background theory and existing related works. Then, section 3 introduces the proposed organizational model. Section 4 shows some experimental results, and section 5 concludes and gives some suggestions to future works.

2. THEORY AND RELATED WORKS

As mentioned in [4], [5], [6], a task is an activity that should be performed by one or more agents to achieve a goal or make a certain affect on the environment. The tasks may be primitive or decomposable. In this paper we assume that the tasks need not to be decomposed and should be accomplished by a team of cooperative agents. Each task requires a set of capabilities and resources to be performed completely. A team of agents, which their aggregated capabilities and resources satisfy the task's needs, may be a candidate for performing it.

A MAS organization is a group of distributed agents, following a common goal. The interactions between the agents, the relationships between the agent roles, and their coordination style make the organizational design. Thus as one or more of these aspects change, the reorganization occurs. We assume that occurring new tasks and entering or exiting any agents to/from the environment, trigger the reorganization.

Several organizational Structures for modelling MASs are introduced in literature [5], [7], [8]. In addition, a variety of adaptation methods for different organizations have been proposed yet [6], [9-16]. All of these methods attempt to enhance the system effectiveness using adaptation. These methods can be classified as following:

1. Organization Reconfiguration, in which Organizational Structure is inalterable, but features of agents participating in the structure changes with time.

2. Organization Restructuring, in which the structure changes with time.

[10] and [13] are among the latest works performed in this field. In [13] a Decentralized Structural Adaptation is proposed in which agents forge and dissolve relations based on their interactions with other agents. In this method, agents need to re-evaluate all their relations in each time step which results in decreasing efficiency regarding increasing computation. Furthermore, the possibility of entrance and exit of agents into/from environment has not been considered.

In [10], tasks are broken into sub-tasks and these sub-tasks are distributed among agents in lower levels of hierarchy to be performed by them. However, in many applications, tasks need not to be broken but to be performed by groups of agents. Furthermore, improving organization efficiency should be mentioned as one of the main goals.

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In the next section, we focus on collaboration that is achieved by adaptive team-based MAS organizations. We introduce a team-based organizational model which is able to change its structure upon occurring new tasks and with respect to entrance or exit of agents into/from environment, handling the occurred events effectively.

3. ORGANIZATIONAL MODEL

As mentioned in [2], [5], [17], most of proposed models for multi-agent organizations is driven from similar models in human communities. It is because of the MAS's ideal goal of having fully human-like intelligent agents. Such a MAS would be able to autonomous decision making towards reaching organizational goals.

From sociological point of view, since most people have a general idea of organization concept, there is no common definition for this word but in most literature, organization is known as an entity including agents doing some actions in a given structure to meet a set of goals. Thus, organization model is a model that defines the structure, roles and interaction pattern of constituting agents, and the goal(s) of organization [2].

Schwaninger has presented in [3] a comprehensive organization model for intelligent human organizations. According to this model, an intelligent organization is one that is capable of changing to adapt with varying environment, mutual effect on the environment, and viability in the environment of its comprehending organizations. In this model, design, control and development are known as main components in systemic management that gradually need to be considered in the shade of attention to system identity structure. According to this, a framework including five aspects of activity, structure, behaviour, ethos identity vision, and time seems appropriate to model an organization.

In this research, adopting Schwaninger's proposed model, an organizational model is presented for cooperating MAS. Based on this model, in order to introduce a multi-agent organization we try to define structural model (that shows organization designing), activity model (that shows the entire functionality of organization) and behaviour model (that shows cooperation process of organization components).

3.2. Agent Model

It is supposed that the agents are homogeneous in potential capabilities, but different in the power to use each capability. This power is related to resources that agent have at the time. Besides, only two possible roles are assumed for agents: Supervision role, and Operation role. Table 1 shows the related properties of agents in proposed model.

Table 1. Main concepts of proposed agent model.

Notation	Definition	Discussion
A	Set of all agents	$a_1, a_2, \ldots, a_n \in A$ n: The total number of agents
C	Set of all recognizable agent Capabilities	$c_1, c_2, \ldots, c_k \in C$ K: the total number of capabilities
R	Set of all defined roles for agents	Here, R={Supervisor, Rescuer}
U	Set of all available spatial locations (as agent's position or task's occurrence target)	Here, the context is a M*N rectangular grid. So, U is a set of all tuples as <x,y> where $x \in [0, M]$, $y \in [0, N]$, and $x, y \in Z^+$. The context is divided to X*Y regions where X and Y are system parameters.

L	The interval which capabilities belong to	Here, L=[0,100]
$S_{a,\theta}$	Set of <capability, available level> tuples for agent a at time θ	$S_a \subset C \times L$ The time parameter shows that the agent capability level may varies with time.
f_a	Collaboration factor for agent a; the probability that a accepts cooperation in accomplishing a task	$0 \leq f_a \leq 1$ Here, as in rescue and relief applications, it is assumed to be 1.It means that all agents with sufficient capabilities will not refuse any kind of contribution.
$p_{a,\theta}$	The position of agent a at time θ	$p_a \in U$ The time parameter shows that agent is mobile, varying position over time.
v_a	The field of view of agent a	The radius which agent can sense around itself.
$r_{a,\theta}$	The role of agent a at time θ	$r_a \in R$ Here, agents can enact in different roles, due to their status in organization. The time parameter shows this variability.

3.2. Task Model

Each task is assumed as a discrete event that may occur with a given statistical distribution all around the context area and in every point of time. For simplicity, in this work it is supposed that the spatial and temporal distribution of tasks' occurrence is random. Table 2 shows the main concepts of proposed task model.

Table 2. Main concepts of proposed task model.

Notation	**Definition**	**Discussion**
T	Set of all tasks	$t_1, t_2, \ldots, t_m \in T$ m: The total number of tasks
W_t	Set of <needed capability, min level> tuples for task t	$W_t \subset C \times L$
d_t	Deadline of task t	$d_t \in [0, \infty)$ Accomplishment of t after its deadline is worthless
p_t	The place of task t occurrence	$p_t \in U$

3.3. Structure Model

Organizational structure defines informational, controlling, communicational patterns (in Highest Abstraction Level), and features of task environment including distribution of tasks, resources, agents, and their capabilities [3], [11], [13].

According to this, our proposed organization in this research is a team-based organization whose initial structure forms once the system begins to work and reorganizes during the system operation, along with occurrence of reorganization triggers. System context is a two dimensional grid space in which a number of agents have been distributed following a statistical distribution pattern. In this paper we assumed for simplicity that the agents are distributed randomly around the physical environment, but their distribution can also be based on a given map in our implemented application.

Hence, agents have position attribute that means the proposed framework supports moving agents.

As mentioned earlier, in cooperative MAS agents tend to coordinate in the best way so as for system to reach its goals with most efficiency. In emergency applications such as rescue systems, the speed of task handling, the rate of task completion, and the usage of resources are the most important efficiency factors. In other words, the cooperative agents try to response to the largest number of tasks as fast as possible, trying minimum usage of resources.

On the other hand, in human organizations it is observed that in such situations agents while trying to use optimally their main skills and professions, in given cases they also use their non-professional resources to help system act more effectively. For example in an earthquake, if there is not any fire to extinguish, the fire-brigade agent could participate in civilians' rescue, if he has enough capability.

Based on this, in our proposed model, concept of role is restricted to key roles of Supervision and Operation. Instead, it is supposed that in the whole system a limited set of capabilities can be detected and each agent may possess each capability for a certain amount. Thus, appropriate agent or agents are selected to perform a task, based on the capabilities the task needs to be completed. Figure 1 shows the proposed structure model.

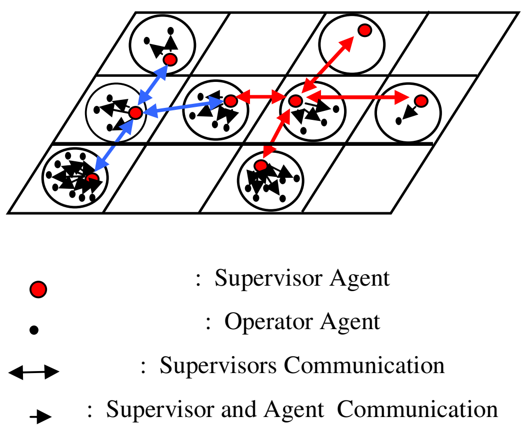

Figure 1. Organizational Structure

In proposed model, the initial teams form based on the establishment place of agent in the environment to minimize cost of initial team formation. In other words, the context is partitioned to some segments and all agents placed in each segment form the team related to that area. The number of segments is varying as one of the system parameters. For example, in Figure.1 the context is divided to 3 times 4 (equal 12) segments. 3 and 4 are the system variable parameters.

Since similar to the human organizations presence of a director seems useful in a cooperative organization [2], a supervisor is chosen to manage each team. The way a supervisor is chosen may be affected by capabilities of team members, agents' experiences, and other factors. In this research, the eldest agent among all team members is selected as the team manager. Thus, it avoids any cost to system for this task as well as the experience factor has been implicitly regarded for selection of supervisor. We bear in mind that the eldest agent is the most experienced one among his co-teams who would be a suitable case for management.

The inter-team communications is limited only to each agent and its related team supervisor, and in intra-team aspect, only supervisors of adjacent teams can communicate. This limitation significantly reduces the communications and saves time and resources as well as supporting functionality in unreliable and unpredictable environments.

3.4. Behaviour Model

Behaviour model of proposed organization indicates the way system transforms from a state to another upon occurrence of a given trigger in the environment. As mentioned before, in this research occurrence of a new task event, entrance of a new agent to the system, and exit of the agent from the system form such triggers.

All components of a cooperative MAS should be controlled by a coordination mechanism. In the proposed model, it will occur through decentralized reorganization. In this way the organization behaviour upon receiving transformation triggers is as follows:

- A task occurs in a segment

In this case, for each capability required for performing the task, the total available potential is measured. In the case that the potential capability is sufficient, a minimal coalition (temporary sub-team) is chosen and designated for handling the task, and the remaining agents mark as free to be available to help in handling other tasks. Otherwise, by seeking help from 4-nearest adjacent teams, the appropriate coalition will form to perform the task.

Algorithm 1. A task t occurs in a segment

```
Task t waits until be perceived by an agent
If agent a perceives or be informed about t
        If a is a supervisor
                If t and a are in the same segment
                        a forms coalition to assign t
                Else
                        a Informs TheBestAdjacentSupervisor about t
        Else
                a informs its segment supervisor about t
```

- A new agent enters into a point at a given segment

In this case, the agent simply joins to team related to that segment. If there is no agent at the segment, a new team is formed and the new agent is marked as the supervisor of the one-member team, otherwise, the segment’s team supervisor detects the new member, sends his address to it, and saves its information for next communications.

Algorithm 2. A new agent a enters to a segment

```
Task t waits until be perceived by an agent
If agent a perceives or be informed about t
        If a is a supervisor
                If t and a are in the same segment
                        a forms coalition to assign t
                Else
                        a Informs TheBestAdjacentSupervisor about t
        Else
                a informs its segment supervisor about t
```

- An agent goes out of the system

In this case, the agent is simply deleted from the related team. If the related team has only one member, the team is destroyed, otherwise the agent's information is deleted from the supervisor's memory.

It should be mentioned that coalition formation algorithm used to select sub-teams from present teams and if needed, selection of accommodator agents taking from adjacent teams, seems to be very significant in organization efficiency. In this research, the simple greedy algorithm is used.

Algorithm 3. Supervisor s forms coalition to assign task t

```
s computes all available capabilities of free agents in its team
If enough to accomplish t
        s selects the best sub-team, greedily
        s assign t to selected sub-team
Else
        Until coalition is formed
                s asks help from adjacent segments
                s adds new team mates to the forming sub-team
```

3.5. Activity Model

As Schwaninger defines in [3], the activity model describes the overall intended operations of or actions taken by the organization. The emphasis of change is on revising principles, goals and rules that control and affect on the behaviour of the organization. Our proposed reorganization method, affects only on organizational structure.

Specification of the organizational goal is one of the most important aspects of activity model. The entire goal of a cooperative organization is maximizing the system's utility function. In our experiments, we defined the utility as the rate of completed tasks divided to the mean task accomplishment time.

$$\text{Utility} = \text{TaskCompletionRate} \,/\, \text{MeanTaskCompletionTime} \qquad (2)$$

The time dimension of Schwaninger's model is inherently purposed in all structure, behaviour, and activity models. It should be noted that the time scale is different in each of the three dimensions: Strategies can often be changed quickly, but structure can be transformed a bit slower and the behavioural variables react more slowly.

The fifth dimension of the model includes ethos, identity, and vision. It is the center of a paradigmatic change, which hardly affects the three domains: Structure, Behaviour and Activity. In this research, the agent's collaboration factor is defined as the only identity feature. Many other features can be identified in agents collaborating in a real time environment, which affect on their behaviours and worth to be considered when they want to coordinate. This aspect will be noted more carefully in future works.

4. EXPERIMENTAL RESULTS

Our experiments consist of two parts. First we compare the proposed team-based model and the hierarchical one introduced in [10] against the rate of successful task handling. A second series of experiments show the effect of problem-size on system efficiency.

4.1. Task Distribution

Some unbalance may appear in agents' workload, when coordination and task allocation mechanisms work together. It means that some agents may be still working on their tasks while others are idle because of early-finishing their allocated tasks.

We compare the impact of workload distribution in team-based and hierarchical organizational models using RoboCupRescue simulator.

In [10], the performance of organization is measured under two conditions. In the first, civilians (tasks) are distributed randomly in the environment to show a homogeneous task distribution. In the second they are distributed as clusters to form a heterogeneous workload. We run some simulations on the Kobe map, creating 5 different homogeneous and 5 different heterogeneous task distributions, as Ghijsen et al. performed [10]. Each distribution contains 9 agents (ambulances to rescue civilians) and 20 tasks (civilians). Each simulation finishes after 300 time steps. Figure 2 shows the results. Direct Supervision, Standardization, and Adaptive hierarchy are three coordination methods which are introduced, implemented, and compared in [10]. More information about these methods exists in related reference.

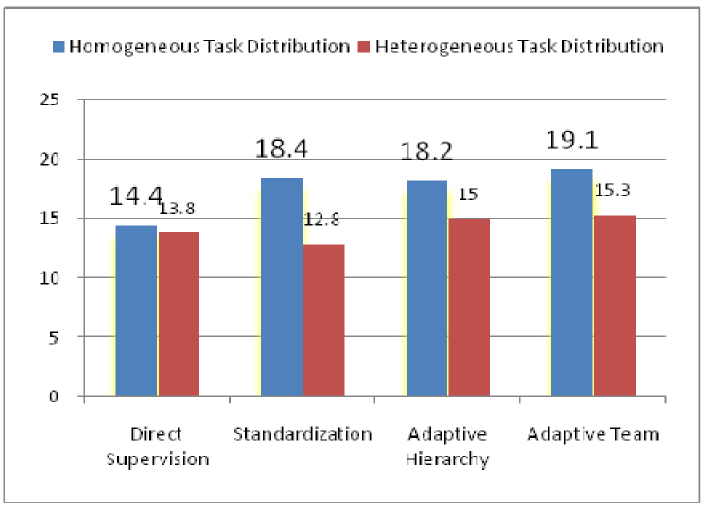

Figure 2. Average number of tasks successfully performed using four models (Performance)

As figure 2 shows, team-based method causes better performance than hierarchical ones. It is because of rapid initial team formation and proper load distribution between agents as teams. In homogeneous task distribution, this is done better because the tasks are almost uniformly distributed between agents. In heterogeneous distribution, the tasks are distributed as clusters and the agents near that clusters are mostly involved in task handling. So, the team-based model doesn't improve the performance as in homogeneous one.

4.2. Problem size

Scalability is an important quality factor for multi agent systems. In critical MAS, the system is expected to preserve its acceptable response time with growing problem size. In a rescue system, the main goal is rescuing the most civilians in the least time.

In hierarchical organizational models, the organizational tree is expanded horizontally and vertically while the size of MAS increases. The bigger tree makes the adaptation process more complicated and time-consuming. So, these models aren't suitable for large-scale critical MAS.

In proposed team-based model, the agents initially form some teams due to their location. These teams are potential candidates for performing tasks occurring in a limited area. A greedy coalition formation algorithm tries to find minimal coalitions, if the candidate team is't strong enough to complete the task. This strategy is intended to cause a better task accomplishment in a near-time-efficient and near-resource-efficient manner, better than hierarchical ones. In addition, it is intended that work load be distributed almost monotony between the agent groups and system runs with more scalability.

We performed the previous experiments in RoboCupRescue simulation environment. This is a good identified environment to develop and benchmark the multi-agent techniques. This simulator has some inconsistencies with our problem definition that encourage us to develop a more suitable simulation environment. Lack of control over the simulation environment, hardness of its manipulation, special communication infrastructures which restrict some types of communication, limiting the agent types to only three main agent types, and existence of some central agent types in contrast to our distributed decision making idea, are some of theses problems. Hence, we begin implementing a simulation environment, to test the proposed organizational model, in JADE. We implemented our team-based model along with a simple greedy team-formation algorithm introduced in previous sections, and performed several experiments in order to evaluate the scalability and effectiveness of it. It should be noted that the number of agents and total number of tasks vary as system parameters. We considered only some values from the infinite set of possible values for our experiments. Table 3 shows the summary of parameters and results. Results for the mean rate of successful task handling and mean time for handling each task are computed after 20 runs for each input set.

Table 3. Some experimental results.

Number of Agents	**Number of Tasks**	**Mean Rate of Successful Task Handling**	**Mean Time to Complete a Task (ms)**	**Utility**
10	5,10,20	0.95	9.8	0.097
20	10,20,40	1	8.5	0.118
50	25,50,75	0.8	10.1	0.079
75	50,75,100	0.75	13.2	0.057
100	50,100,150	0.73	12.7	0.057
150	75,150,200	0.77	11.8	0.065
200	100,200,250	0.8	14.7	0.054
250	100,200,250	0.69	14	0.049
300	100,200,250	0.87	12.74	0.068

We compare the hierarchical and team-based models against the rate of successful task handling. For small numbers of agents, the models are comparable and their effectiveness is in the same range. But for agents more than 50, the team-based model had much better results. The results show smooth changes in utility function when increasing the problem size. It shows that the proposed team-based model is scalable enough to be used in medium-scaled multi-agent environments.

Figure 2 shows the changes of utility function with increasing problem size. It seems that fast team formation, proper load distribution between agents, and team-based task handling cause the system to perform effectively.

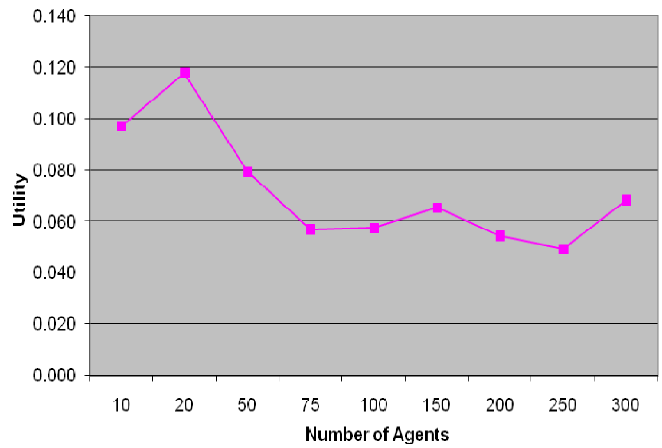

Figure 3. Utility of team-based model in different problem sizes

5. CONCLUSIONS AND FUTURE WORK

In this paper, we addressed the problem of decentralized adaptation with proposing a team-based organizational model. More specifically, we formulated a simplified organizational model based on schwaninger's model of intelligent organizations. The main reason for this selection was the importance of changeability for organizations acting in open, dynamic and uncertain environments. We coordinated the agents through reorganization via fast coalition formation, and developed a simple greedy task allocation method based on using the resources of the nearest teams.

Experiments show the better effectiveness of our team-based model against the hierarchical one. Adaptation via reorganization makes the model to be usable and scalable in dynamic environments. Fast initial team formation, greedy capability-based coalition formation, and using the nearest neighbours' resources, affect on utility improvements compared to the standard hierarchical organizational models.

Future work will initially involve proposing better coalition formation algorithms and testing the effect of task and environment varying factors on system efficiency. To do so, we are going to develop a more effective simulation environment to be able to support the open, dynamic, and uncertain environment's properties. Varying agent capabilities, different types of tasks, variable number of segments, changeable agents' sights, and controllable output information are some features to be added to developed tool as soon.

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