Organizational Model for Cooperative and Sustaining Robotic Ecologies

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Introduction

The use of robots to explore space has many advantages over using humans for the same task. However, a shortcoming of exploration using robotic entities has been the lack of ability to create sustainable teams with enough flexibility to perform numerous tasks, provide a high-level of versatility, and work as a cooperative team to satisfy mission critical goals. The ability for a robotic colony to create and sustain itself, in the long-term, in a planetary or space environment, will require the flexibility to reorganize and reform itself to meet and overcome continuous, unforeseen challenges.

Our research deals with the development of an organizational model and implementation that allows a robotic team to continuously pursue mission goals. While working through tasks to accomplish the goal(s), the team will examine its current operational state and decide whether goal satisfaction can occur by utilizing the current organization or if a more efficient organization, consisting of available resources, exists to accomplish the goal. In the example case of robotic malfunction, where a robot team member can no longer fulfill its stated duty, the team will reorganize to reassign the fallen member's tasks.

In the event goal(s) have changed significantly enough to warrant action, the robotic team will have the option of invoking a mixed-initiative plan where other agents can enter the scenario to create new plans and goals, provide goal relaxation, or terminate the current group assignment. Other agents included in the scenario may be human, intelligent agents or robotic.

Robotic Team Formation

The model for a population of robots to form an organization is a simplified version of a human organizational model. The continuous and circular process of team organization and reorganization is defined by a sequence of general steps:

1. *The mission goal must be defined from an intelligent robotic agent or human source.*
2. *The goal is used to generate plans to satisfy all requirements.*
3. *The plans are used to dynamically create Work Breakdown Structures (WBS) and decomposition structures to develop the definition of roles, organizational rules, relationships and tasks.*
4. *The available member's skills and capabilities are inventoried and cataloged.*
5. *The roles are matched to actors based on optimal allocation of capabilities to roles.*
6. *The group is set into action.*

To create an effective and efficient organization, it is critical for robotic agents to coordinate activities collectively. A large body of research has been conducted in the area of teamwork [1] [3] and group planning [3] that defines a base from which to model cooperative robotic teams. The organization must have the flexibility to allow robots to change roles if capable. A generic model for dynamic role assignment [4] in a team setting has been developed to allow versatility. To assign roles to individual robots, they must possess the intrinsic computational and physical traits required to performed specific tasks. A robot's traits and attributes define the capabilities inherent in their design, form and function. Use of constraints is necessary to assign available resources to specific roles for completion of the overall group goal [5].

Organizational Design Model

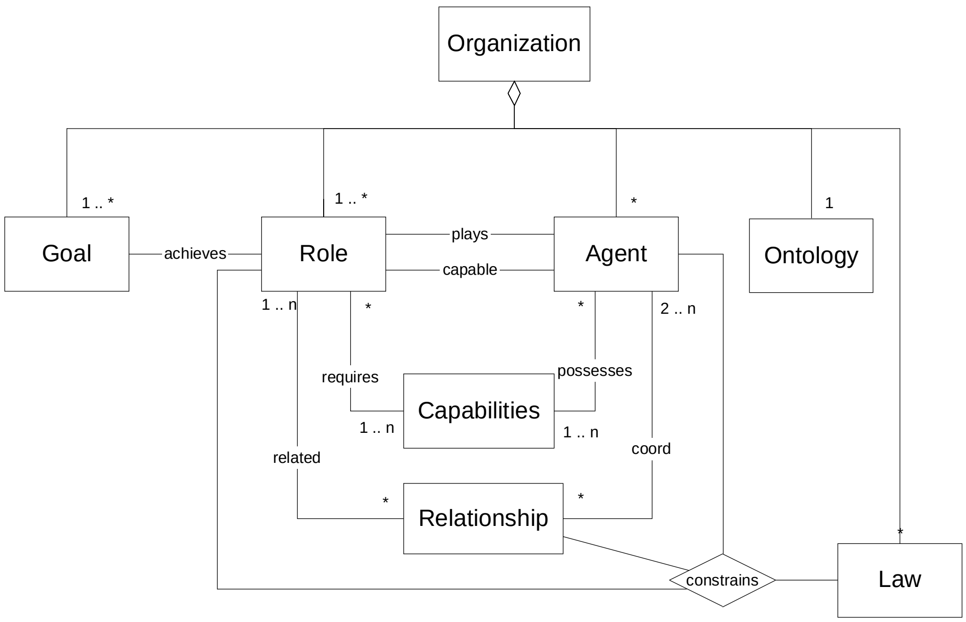

Figure 1: Organization

To field an organized, cooperative team of robots, we have developed an organizational model to define the characteristics and constraints for a well-founded, adaptable and versatile team organization. The organization (O) components consist of goals (G), roles (R), capabilities (C), rules or laws (L), relationships (P), ontology (ON), and a set of agents (A).

$$O = \{G, R, C, L, P, ON, A\}$$

The organizational structure, shown in Figure 1, is generally static. The organizational state, on the other hand, defines the relationships that exist within the current organizational structure, at a certain point in time. A state describes the roles each robot currently plays and which robots are actively cooperating to accomplish a specific task. These relationships are often dynamic in nature. Thus we can define an organization as a tuple consisting of its *structure* and its *state*.

$$O = \langle O_{struct}, O_{state} \rangle$$

Where: $O_{struct} = \langle G, R, L, P, ON, C, achieves, related, requires \rangle$

$O_{state} = \langle A, plays, coord, capable, possesses \rangle$

$plays: A, R \rightarrow Boolean$

$coord: A, P \rightarrow Boolean$

$capable: A, R \rightarrow Boolean$

$possesses: A, C \rightarrow Boolean$

$achieves: R, G \rightarrow Boolean$

$related: R, P \rightarrow Boolean$

$requires: R, C \rightarrow Boolean$

Organization

While most people have an intuitive idea of what an organization is, when asked to define it explicitly, there are large numbers of "correct" answers. From early organizational research, organizations have typically been defined as including the concepts of a set of agents who play roles within a structure that defines the relationships between the various roles [8]. Instead of defining the term organization specifically, Carley and Gasser have come up with a general characterization of organizations [9], which describes them as (1) large scale problem solving technologies, (2) consisting of multiple agents, (3) engaged in multiple tasks, (4) goal directed, (5) able to affect and be affected by their environment, (6) have knowledge, culture, history, and capabilities distinct from any single agent, and (7) have a legal standing distinct from that of individual agents.

Goals

Goals are used to identify the critical aspects of system requirements. Therefore, an analyst should specify goals as abstractly as possible without losing the essence of the requirement. This abstraction can be performed by removing detailed information when specifying goals. For example, to "Detect invalid sonar pings" is a goal. How to detect invalid pings is a requirement that may change with time or between various operating systems and is not a goal.

Role

A role describes an entity that performs some function within the system. In Multiagent Systems Engineering (MaSE), each role is responsible for achieving, or helping to achieve, specific system goals or sub-goals [7]. MaSE roles are analogous to roles played by actors in a play or by members of a typical company structure. The company (which corresponds to system) has roles such as "president", "vice-president", and "mail clerk" that have specific responsibilities, rights and relationships defined in order to meet the overall company goal.

Agent

Agents are basically equivalent to autonomous robots in this instance. Agents coordinate with each other via conversations and act proactively to accomplish individual and system-wide goals.

Ontology

The word ontology was taken from philosophy where it represents the study of the nature of being. Much debate exists on the exact definition of ontology when used for knowledge engineering or artificial intelligence. The most common definitions state that an ontology is a specification of a conceptualization or that an ontology is the shared understanding of some domain of interest. This research uses the latter definition, specifically, that ontologies define classes, functions, object constants, and axioms to constrain meaning of some type of world view of a given domain. [10]

Capabilities

Capabilities are the abilities that reside within a particular agent (robot). For robots, there are two levels of capabilities; computational and physical. The computational capabilities are defined by the level of intelligence built into the robot. The physical capabilities are defined by the range of sensors and effectors included as part of the robot's design.

Relationships

Relationships are dynamically allocated, cohesive links that exist from role-to-role, agent-to-agent, and robot-to-robot during the active organization lifespan. The relationships may be based on communication, delegation, cooperation, or other factors.

Organizational Laws/Rules

We introduce the notion of *laws* into the organization, which operationalize norms, sanctions/rewards, and their relationship. Laws should also conform to organizational values. Laws are constraints on actions and thus the law (a, s) prohibits the action *a* from being taken when state *s* holds [6]

Reorganization

The definition of reorganization is simply a function that maps one organization into a new organization.

$$Reorganization : O \rightarrow O$$

At this point, however, we do not want to consider the full gamut of reorganizations. In fact, we are only currently interested in reorganizations that involve the *state* of the organization. Thus we will define two distinct types or reorganization: *state reorganization*, which only allows the modification of the organization state, and *structure reorganization*, which allows modification of the organization structure.

Our research in the reorganization area will focus on the definition of the *Reorganization* function and techniques for computing it efficiently and effectively in various forms.

Current Work

Our current research integrates the use of cooperative agent architectures applied to autonomous robots. The robots create cooperative teams to accomplish specific goals defined using the agentTool 2.0 Multiagent Systems Engineering (MaSE) development environment [7].

A flexible architecture has been developed that allows a team of autonomous robots to form an organization, upon being tasked with solving a specifically defined goal or set of goals. Our group has developed a flexible Java-based G*eneric Robotic Application Programming Extension* (GRAPE) that currently allows our organizational implementation access to Nomadic Technology and ActivMedia robots.

We have successfully integrated these technologies to create robotic teams that cooperatively solve missions. We are currently extending the system to allow for continuous operation through the ability to reorganize. The goal is to extend the current organization model implementation and use it to develop autonomous, cooperative teams that can effectively and efficiently operate over long run durations in complex task environments.

Current Research Goals

1. Integrate concepts of computational organization theory into teamwork theories and methods for developing teams of cooperative robots.
2. Use explicit organizational rules to define proper organizational function and to restrict/encourage certain organizational structures.
3. Extend general-purpose reorganizational algorithms to comply with organizational rules and to use those rules as heuristics to guide reorganization decisions.
4. Incorporate organizational design and knowledge into agent-oriented software methods for designing multiagent systems and apply to cooperative robotics.
5. Introduce organizational models and reasoning techniques into software development toolset to support organizational design and reorganizational knowledge insertion.

Further Research

- What are the effects of attrition and recovery on sustainable robotic teams using the models currently under development? What are the limits of attrition and recovery in reference to goal satisfaction, goal relaxation and effective reorganization strategies? What models can be employed to drive decision making in this domain?
- Developing capabilities for one robotic team member to repair/restore another failed team member from an inactive state to an active and organization-ready state. This problem is multi-layered. The failure can occur at computational or physical levels and the ability of a team member to “fix” another team member will depend upon the failure type. Initial interest exists in developing computational failure solutions.
- How can mixed-initiative programs employ human agents, as part of the organization, and what exactly can a human do while participating in a cooperative goal satisfaction strategy?
- Classification of computational and physical capabilities of agents and robots. How this classification can be used to define organizational model assignments dynamically in a reorganization cycle.

References

[1] Tambe, M. and Zhang, W., Towards Flexible Teamwork in Persistant Teams. Second International Conference on Multi-Agent Systems, 1996.
[2] Grosz, B. and Kraus, S. Collaborative Plans for Complex Group Action, Artificial Intelligence, vol. 86, no. 2, pp. 269-357, 1996.
[3] Cohen, P. and Levesque, H. Teamwork. Special Issue on Cognitive Science and Artificial Intelligence, 1991, pp. 487-512.
[4] Chaimowicz, L., Campos, M., Kumar, V. Dynamic Role Assignment for Cooperative Robots, ICRA 2002 (ICRA02), Washington, D.C., May 11 - 15, 2002.
[5] Turner, R. and Turner, E. A Two Level, Protocol-Based Approach to Controlling Autonomous Oceanographic Sampling Networks. IEEE Journal of Oceanic Engineering, vol. 26, no. 4, pp 654-666, October, 2001.
[6] Shoham, Y. and Tennenholtz, M. On Social Laws for Artificial Agent Societies: Off-Line Design. Artificial Intelligence 73(1995)231-252.
[7] DeLoach, S., Matson, E., and Li, Y. Applying Agent Oriented Software Engineering to Cooperative Robotics, Proceedings of the 15th International FLAIRS Conference(FLAIRS 2002). Pensacola, Florida. May 16-18, 2002.
[8] Cabri, G., Leonardi, L., and Zambonelli, F. Implementing Agent Auctions using MARS. Technical report MOSAICO/MO/98/001.
[9] Carley, K.M., and Gasser, L. Computational Organization Theory. In G. Weiss, ed. Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence. MIT Press, Cambridge, MA, 1999.
[10] DiLeo, J., Jacobs, T., DeLoach, S. Integrating Ontologies into Multiagent Systems Engineering, Fourth International Conference on Agent-Oriented Information Systems (AIOS-2002), 15-16 July, 2002, Bologna, Italy.