Representation and Adaptation of Organization Coordination Knowledge for Autonomous Agent Systems

Trent Jaeger and Atul Prakash
The University of Michigan
Department of Electrical Engineering and Computer Science
Software Systems Research Laboratory
University of Michigan, Ann Arbor
E-mails: {jaegert|aprakash}@eecs.umich.edu

Abstract

We present a framework that represents and adapts the organization coordination knowledge of autonomous agent systems. Organization coordination knowledge represents long-term knowledge about problem solving relationships between agents. As problem solving conditions change, organization coordination knowledge must be adapted to maintain system performance. Our framework includes: (1) an organization model that represents organization coordination knowledge; (2) a model that represents adaptation knowledge; and (3) an adaptation mechanism that uses AI techniques to find an organization model whose predicted performance satisfies a performance goal.

1 Introduction

We present a framework that represents and adapts the organization coordination knowledge of autonomous agent systems to reduce coordination costs during problem solving. In autonomous agent systems, agents coordinate their actions to solve problems. To solve problems efficiently, an agent must be able to find the agents it needs to coordinate its actions with quickly. If agents organize themselves, such that any agent is relatively close to the agents it needs to coordinate with most often, coordination costs should be reasonable. An agent's knowledge about its organizational relationships is called *organization coordination knowledge* [2].

Researchers have shown that, in systems with a high level of uncertainty, predefining organizational responsibilities in advance is too inflexible [1]. Many autonomous agent systems being proposed today expect to perform in environments with significant uncertainty, so our framework must also be able to adapt its organization coordination knowledge as conditions change.

Our goal is to define a framework that can represent organization coordination knowledge for a system with a large number of agents and evolve this knowledge as problem solving conditions change. Toward this end, we propose an organization coordination framework that consists of: (1) an organization model that enables agents that often need to coordinate their actions to aggregate into hierarchical teams; (2) an adaptation knowledge model that represents knowledge about how to modify the organization model; and (3) an adaptation mechanism that uses AI techniques and adaptation knowledge to find an organization model whose predicted performance satisfies a performance goal.

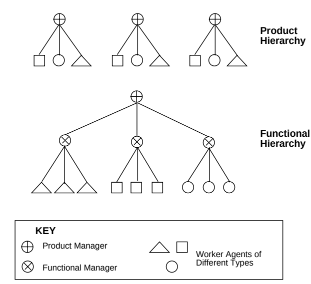

Figure 1: Organization Structure Types

In the following sections, we provide definitions of: (1) the organization model; (2) the adaptation problem; (3) the adaptation knowledge model; and (4) the adaptation mechanism.

2 Organization Model

Malone and Smith [5] evaluate the impact of organization structure on problem solving effectiveness. They evaluate the performance of a set of organization structures, including product and functional hierarchies shown in Figure 1 (taken from [5]). They conclude that the best organization structure depends on the market (i.e., problem solving) conditions. Therefore, we define an organization model that enables the agents to aggregate into a combination of organization structures We call these aggregations *teams*.

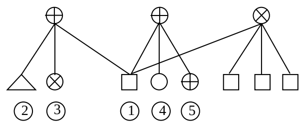

Figure 2: An example organization (team links shown)

- **Definition 1**: An *agent*, $a \in V$, is a tuple $a = (C, T, F, P_a)$ where: (1) C is a set of communication links to other agents; (2) T is the set of team links to other agents; (3) F is a function that computes the agent's cost to perform a job; and (4) P_a is a set of agent performance parameters.

- **Definition 2**: A *worker agent*, $w \in V$, is an agent with requirements R that the agent can fulfill.

- **Definition 3**: A *product manager agent*, $pm \in V$, is an agent with A, a set of agents that belong to its product team and R a requirements set that the manager's team fulfills.

- **Definition 4**: A *functional manager agent*, $fm \in V$, is an agent with A, a set of agents that belong to a functional team and R a requirements set that the manager's team fulfills.

- **Definition 5**: A *team link*, $t \in E_t$, is a tuple $t = (a_1, a_2, P_t)$ where: (1) a_1 is a manager agent; (2) a_2 is a team member agent in a_1's team; and (3) P_t is a set of team link performance parameters.

- **Definition 6**: A *communication link*, $c \in E_c$, is a tuple $t = (a_1, a_2, \$, P_c)$ where: (1) a_1 is the sender agent; (2) a_2 is the receiver agent; (3) \$ is a message cost of sending a message using c; and (4) P_c is a set of communication link performance parameters.

- **Definition 7**: An *organization*, o, is a tuple $o = (G_t, G_c, P_o)$ where: (1) G_t is a directed graph $G_t = (V, E_t)$ where: V is the set of agents and E_t is the set of team links between agents; (2) G_c is an directed graph $G_c = (V, E_c)$ where E_c is the set of communication links between agents; and (3) P_o is a set of organization performance parameters.

The example organization in Figure 2 shows that worker agent 1 belongs to three teams: one functional team and two product teams. The agents that belong to worker agent 1's functional team all compete to fulfill a common requirement. An agent that needs that requirement fulfilled should contact the

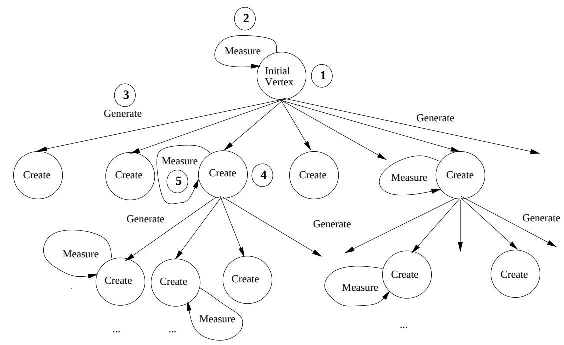

Figure 3: Adaptation search space

functional manager of this team. Worker agent 1 is a member of two product teams because it is involved in producing two products. Worker agent 1 collaborates with agents 2 and 3 to build one product and with agents 4 and 5 to build a second product. Agents within a product team are often interconnected by communication links as well. If an agent needs one of these products to fulfill a job, it can contact the appropriate product manager agent.

3 Adaptation Problem

First, we provide formal definitions for the remaining concepts of the adaptation problem:

- **Definition 8**: A *domain problem set*, D, is a set of tuples, $D = \{(d_1, f_1), (d_2, f_2), ..., (d_n, f_n)\}$ where d_i is a domain problem and f_i is the number of occurrences of that problem.

- **Definition 9**: A *performance goal*, G, for an organization model, o, is a set of goal elements, $G = \{ge_1, ge_2, ..., ge_n\}$. A *goal element*, ge_i, is a tuple, $ge_i = (o, parm, g)$, where: (1) o is the organization; (2) $parm$ is an organization performance parameter; and (3) g is the desired goal value of $parm$.

- **Definition 10**: An *operator*, op, is a tuple $op = (o_i, act, obj, val)$ where: (1) o_i is the *ith* organization in the search space; (2) act is the operator action of op; (3) obj is the object that op is applied to; and (4) val is a numerical indicator of the priority of op.

The *adaptation problem* is to choose a sequence of operators $OP = \{op_1, op_2, ..., op_n\}$ to adapt the organization coordination knowledge in the organization o to solve the domain problems in D in a way that satisfies the performance goal G. The adaptation problem is complex because: (1) operators interact by modifying the same organization objects and (2) the number of operators is large. Operators interact, so the solution space must be reevaluated after each operator application. Thus, the solution space forms a graph of organization specifications (see Figure 3). Operators can change a variety of combinations of communication and team links, and the number of possible operators is large.

4 Adaptation Knowledge Model

The organization model is adapted using operators. The adaptation knowledge model represents the knowledge to generate and select operators. The adaptation knowledge model represents rules that: (1) identify useful operators; (2) aggregate synergistic operators; (3) imply the generation of other operators; (4) prune less effective operators; and (5) evaluate the effectiveness of an operator. For example, an operator to create a team may imply the creation of communication links between the team's manager agent and the agents that the team members communicated with in the past.

Ishida, Gasser, and Yokoo [3] identify two categories of adaptation knowledge: (1) agent-agent relationships and (2) agent-organization relationships. *Agent-agent relationships* are agent and link performance parameters that enable an agent to suggest modifications to improve its performance. We define agent-agent relationships based on performance for messages sent or performance in a team. For example, if the ratio of an agent's performance within a team to the agent's performance outside the team is low, then an operator to leave the team is generated (formalization of Talukdar's concept of team synergy [6]). *Agent-organization relationships* are organization performance parameters from which the effect of an operator on the organization's performance is estimated. We define agent-organization relationships number of messages per problem, solution quality, and fault tolerance. Agent-agent relationships are used primarily for operator generation, aggregation, and implication while agent-organization relationships are used for pruning and evaluation.

5 Adaptation Mechanism

The adaptation mechanism uses the framework's adaptation knowledge to automatically modify the organization until its predicted performance meets a performance goal. We have specified the adaptation problem in such a way that it is isomorphic to the automatic workflow improvement problem [4], so we can apply a slightly modified version of the workflow improvement mechanism to this problem. The steps of the adaptation mechanism are listed below (numbers correspond to steps in Figure 3):

1. Define organization model o_1, the initial organization model.
2. Measure the performance of o_1 in solving problems from D, the domain problem set. Set a performance goal G based on the performance of o_1.
3. Until G is satisfied, no modifications remain, or the maximum number of modifications has been reached, adaptation knowledge generates operators, op_1 through op_n.
4. An op_i, $1 \leq i \leq n$, is selected based on agent-organization evaluation. A new organization model o_i is created by applying op_i.
5. Measure the performance of o_i and repeat starting at step 3.

6 Conclusions and Future Work

We present a framework that represents and adapts the organization coordination knowledge of an autonomous agent system. An organization model represents the organization coordination knowledge of an autonomous agent system using a hierarchy of collaborative and competitive teams and communication paths among the teams. The adaptation mechanism uses knowledge in the adaptation knowledge model to modify the organization model to meet a performance goal. In the future, extension of the organization model to also cache direct paths to agents would reduce broadcast costs. Also, the integration of this framework into a complete coordination mechanism should be investigated.

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