A Simulation Development Tool for Evaluating Coordination Strategies in Organizations

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Abstract

We are developing a prototype of a simulation development tool to aid administrators in the process of redesigning organizational structures. The purpose of the system is to help organization designers to more precisely model their hypothetical designs, and, by simulation, to predict key facets of the overall behavior of their proposed organizational structures. The tool will help them to evaluate the restructured organization's potential for improved efficiency, or spot potential weaknesses in the system during peak loads. With this tool, organizational models are built using a library of simulation components characterizing commonly used coordination structures and communications mechanisms. Our hypothesis is that the structuring of the design tool around a model construction library of coordination mechanisms will allow designers to readily compose existing and proposed organizational structures to effectively evaluate their options.

1. Introduction

When the circumstances in which an organization operates go through a change (e.g. the availability of new technology or a reduction in resources due to funding cuts), the organization itself may need to be altered so that it can continue to function efficiently. The process of designing new organizational structures that fulfill the basic missions of the organization and are at once efficient, reliable and versatile requires the designer to visualize the performance of a highly interdependent set of agents in likely future circumstances. He or she must be able to detect potential pitfalls, communications bottlenecks, and the critical capabilities that might fail in those circumstances. The organization design task bears many similarities to other design tasks, such as hardware design, where communications channels are used to coordinate processes. In these other domains, simulation has become a more or less routine way of coping with the large number of interdependencies and system responses possible when flexible communications and coordination strategies are used. With human organizations, the problem of evaluating potential designs is more difficult because these organizations are composed of inherently adaptive agents.

BBN, working with the Center for Coordination Science at MIT, is building a prototype of a system to help organization leaders' to define and evaluate new organizational structures before they are put into effect. The system is being constructed around a modeling vocabulary of organizational structures and a simulation tool for autonomous agents that can respond to communications within their organizational structures, following operating policies in a flexible, goal-driven fashion for a variety of situations. The existing modeling and simulation system we are building on provides the capability to simulate a large number of agents each persuing their own goals asynchronously. On top of this basic simulation framework, we are constructing a library of templates for common coordination strategies that users will be able to compose to represent their organizations. This library is built around a representational theory of organizational coordination structures based on work at MIT's Center for Coordination Science. Malone and his colleagues there have using AI representational techniques for the construction of organizational models which capture aspects of the organization's actual behavior, as discovered from extensive case studies (e.g.,Malone, 1987; 1988; Crowston, 1991).

2. Intentional Agent Simulations for Organizations

The system we are building is based on an existing simulation development tool that works with intentional models of the agents which compose organizations. That is, it directly models the actions of the agents as driven by their goals. This simulation environment, SIM-AGENT, is descended from an earlier system, SPROKET (Abrett et al. 1989), which was developed at BBN over a period of approximately three years, and applied in a number of government and industrial projects (Abrett, Burstein & Deutsch, 1989; Abrett et al, 1990; Abrett, 1991, Downes-Martin et al, 1992.). Its first major use was to represent and simulate organizational command and coordination policies guiding groups of agents in the SIMNET battlefield simulation environment. It has also been used to model the interactions between pilots and their planes, and air-traffic controllers. SIM-AGENT models the simultaneous activities of a number of agents, each pursuing its own set of goals, many of which may be guided by messages (directions, requests, etc.) received from other simulated agents.

SIM-AGENT uses a unique combination of classical AI knowledge representation techniques and object-oriented programming techniques. SFL is frame representation language derived from KREME (Abrett & Burstein, 1987) and similar to KL-ONE (Brachman & Schmolze, 1985) that uses the Common Lisp Object System (Bobrow et al, 1988), to incorporate simulation procedures efficiently. Goals, plans and procedures are modeled using an embedded description language called GPP which was based in large part on PRS (Georgeff & Lansky, 1986), and on (Schank & Abelson, 1977; Wilensky, 1982) It is a declarative language for enumerating the possible behaviors of agents in the simulated world. The SIM-AGENT simulator is essentially an interpreter for the GPP language.

This approach, because it provides for the explicit modeling of individual agent (or small group) behaviors should allow us to more realistically predict the capabilities and shortcomings of new organizational structures. The efficiency of the particular discrete-event simulation technology in SIM-AGENT makes it possible for us to model the variety of behavior found in complex organizations, and simulate concrete scenarios on a scale that is currently infeasible with numerical and stochastic models. The challenge is to demonstrate the predictive power of this technology by modeling real organizations, and to provide an environment that makes it possible for non-programmers both to build models and to evaluate them effectively.

To meet these challenges, a great deal of knowledge about how organizations function will have to be built into the modeling environment and simulation system. This information will have to be in a form that will both inform the simulator and allow the organizational designer to construct models using aggregate communications structures and object and job types that he can recognize. The 'Engineering handbook of coordination processes' being developed at the Center for Coordination Science is serving as a guide in the development of a library of the kinds of coordination structures that can be incorporated into these simulations. We will also supply templates for basic job categories, and simple representations of the objects that they will manipulate. By providing the organizational designer with interactive access to prepackaged coordination structures describing hierarchical, market-based and other basic group communication structures, we hope to make it easy to sketch out and simultaneously build executable models of quite complex organizations.

3. Coordination Theory: An approach to modeling organizations.

Our modeling and simulation of organizations is based, in part, on theoretical insights from the emerging interdisciplinary area called "coordination theory" (see Malone, 1988; Malone & Crowston, 1990, 1991). This approach uses concepts from cognitive science and other disciplines (such as computer science, artificial intelligence, economics, and organization theory) to analyze coordination in many different kinds of systems. In its broadest terms, coordination theory is the study of how sets of actors performing independent activities achieve collaborative goals. Organizational hierarchies, marketplaces, "hotline" telephone routing systems, computer communications networks and operating systems are all examples of coordination structures.

Two levels of analysis have been used in these studies. The first level of analysis involves characterizing a process or organization in terms of the actors involved, the activities they perform, and the messages they exchange in the course of performing these activities (see Crowston, Malone, & Lin, 1987). This level of analysis identifies communication paths, task allocations, and bottlenecks, and under the effects of different task loads, staffing patterns, and communication costs. The second level of analysis involves representing the underlying goals, task partitionings, and interdependencies that give rise to the particular patterns of messages and activities identified at the first level. To the degree we are able to represent this "deep structure" of the situation, we may recognize or generate automatically new processes that could achieve the same goals.

4. A Hypothetical Example

Consider, as an example of the kind of situation in which the organizational simulator would be used, that a group of army installations are exploring the option of consolidating their vehicle maintenance facilities. In the past, each installation has supported an independent facility to perform routine maintenance and to respond to vehicle breakdowns by either sending out a repair crew or having the vehicle brought in to the local shop for repairs. Routine maintenance is initiated by regular requests from the maintenance shops at some installations and by the vehicle users at others.

The favored consolidation plan calls for the discontinuation of the maintenance facilities at each installation and the creation of a large, centralized shop at one of the sites. Broken-down vehicles would be driven or transported to the central facility for all problems. This facility would also keep track of all vehicles and initiate requests for routine maintenance. Proponents of the plan argue that it will allow for reductions in the overall size of the maintenance staff by reducing mechanics' slack time, allow the formation of a centralized parts warehouse which can hold a larger variety of parts than is available at each site now, and finally allow a consolidation of parts purchasing and other administrative functions.

A number of questions can be asked about this proposed change for which even partial answers would be valuable if they could be obtained before the change was implemented. Will the new plan work? Will the reduced cost of centralized maintenance offset the cost of transporting the vehicles to the central facility? Will the new system be more vulnerable to changing circumstances or less responsive to changing demands? What are the trade-offs to be considered in evaluating the proposed plan?

In order to begin to answer these questions while the plans are still on the drawing board, a simulation system could be used to model the existing organization, and the proposed consolidated facility. The designer might build a model consisting of several disjoint structures representing the existing maintenance organizations. Let's suppose that each facility now includes two to five mechanics and an administrator who handles functions including, tracking routine maintenance (for the shops which handle this), ordering parts and coordinating the mechanics. To model the global behavior of each shop, a simple CONTRACTED-SERVICE coordination strategy can be pulled from the coordination structures library, and then modified and specialized to provide details of the protocols for requesting the particular services provided (repairing vehicles, coordinating maintenance). In designing the organization at each maintenance site, a coordination structure for an ADMINISTRATOR WITH MULTIPLE (SIMILAR) PROCESSING AGENTS (another library element) can be composed with the contracted service model and adapted to provide the managerial protocols the administrator and the mechanics will use. The designer would then adapt a basic work model for the mechanics (the processing agents) by defining a list of the set of different activities they perform (repair, maintenance), and establishing the work time required for each task, and a name for its result. We will provide a variety of typical job categories that can serve as the basis for these elements. Next, the number of workers would be specified for each site, by duplicating the definition of a typical worker, as defined. Finally, this basic model can be duplicated for each site that is maintaining vehicles in the area to be covered by the new consolidated organization.

Each coordination structure applied in the model will have a template for the parameters that need to be specified to run the simulation. For example, each coordination structure pulled from the library will require the user to specify a set of communications policies (face-to-face contact, posting notices of tasks each workers queue, etc) that will be available to effect the coordination of activities, along the communications paths. For administrative agents, a choice of basic scheduling policies to be used by the administrator at each site will also be needed (i.e., assign jobs to the shortest worker queue). All other details of the communication mechanisms would be handled by default information in the library, unless further tailoring was desired.

After the basic shop models are constructed in the above fashion, other aspects of their operation can be elaborated: A warehouse model from the library can be configured so as to provide the parts ordering function for maintenance shops. A stochastic model of equipment failure might be adapted to simulate failures for each of the motor pools, at varying distances from the shops, to drive the overall simulation. Other procedures available in the simulation library, organized as potential goals for agents, include a calendar-based-reminding facility which could in this case provide behavior to the shop administrators to have them notify motor pools of routine maintenance requirements. (This is the same procedure/policy that would be used to model dentists offices that call their patients or payroll administrators that initiate the annual issuing of W-2 forms).

The second stage of development of an organizational model is tuning. The model will need to be run and adjusted until the current operation of the maintenance facilities is adequately mirrored. At this point, a new organizational design for the same function can be modeled and simulated in much the same manner that the current organization was handled.

Let us suppose that when the new organization is initially set up it has the policy of requiring vehicle users and repairers to communicate with each other through an intermediate level of administration. Such a layer allows more responsiveness to calls from the users and facilitates centralized control of the repair jobs. However, the simulation of the new organization shows an unacceptable level of over-all vehicle throughput. The designer now has several options, two of which are increasing the number of intermediaries or selecting a new coordination structure, such as one which allows direct communication between the users and the repairers. Each alternative will have costs and weaknesses which will show up in further simulation runs. This example is meant to give a flavor of the level of detail and complexity that we anticipate the simulation system will be able to model, and of the types of information that organizational designer will be able to obtain over the course of using the simulator to model a proposed change. For coping with very large organizations, one could produce a similar level of complexity by modeling groups or offices as the agents, instead of individual people. Thus, agent based simulation should, in principle, scale up to deal with arbitrarily large organizations, at least to the degree that it provides a more detailed model of what can happen than one would get by paper and pencil models alone.

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