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CIFE Working Paper
Number 26

February, 1994

Stanford University

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Abstract

This paper presents a conceptual framework for an agent-based computational model of organizational change in response to information technology. The framework emphasizes how meso-level features of an organization constrain micro-level adaptations to technology, and how micro-level responses reshape meso-level features. It is based on ideas of micro-level structuration in response to technology, and borrows the concept of access structures from the Garbage Can model for representation. The computational model potentially enables organizations to predict, through simulation, the impact of various information technologies on organizational behavior and to evaluate their effects on organizational performance.

1. INTRODUCTION

Much research has focused on the development of computer environments which support collaborative work. Although collaboration technologies are developed for data sharing and communication among participants, their impact on social and task performance of organizations remains unclear. This uncertainty makes it hard for firms to decide which technology to adopt for their specific organization and task domains.

Extant organization theory allows aggregate predictions about the impact of technology on organizational performance, but is not effective in providing specific guidelines for technology evaluation. There is a strong need for a framework in which the impact of collaboration technology on organizational change can be predicted and its effect on organizational performance can be evaluated.

There are two important objectives in developing such a framework: (1) To develop a conceptual framework to address the emergent changes in organizational structure and performance in response to the introduction of new information technologies; and (2) To develop a methodology to validate the conceptual framework to produce realistic predictions. This paper presents a conceptual framework for an agent-based computational model of organizational change in response to the introduction of a new information technology into an organization and discusses the potential use of synthetic experiments for future testing. The framework focuses on how meso-level features of an organization constrain micro-level adaptations to technology, and how micro-level responses reshape meso-level features. It is an attempt to operationalize existing theories of organizational action and change, and to extend them by modeling micro-level organizational processes. Introduction of new information technology is viewed as a disturbance to a partial organizational equilibrium which results in an emergent organizational change through the interaction between organizational participants or "agents" and the technologies available to them for decision support and communication. The framework is based on ideas of micro-level structuration in response to technology and borrows the concept of access structures from the Garbage Can model [Cohen et al. 72] for representation.

The conceptual framework and potentially the computational model attempt to answer the following research question:

What is the relationship between a newly introduced information technology, organization's structural potential, initial organizational structures in use, and emergent structures in use?

The insights gained in answering this question can enable the definition of configurations of information technology, organizational structural potential, and initial structures in use that result in enhanced organizational performance.

The paper first reviews the relevant literature on organizational theory, and computer modeling of organizations. This

This work was supported in part by the National Science Foundation, Division of Information, Robotics and Intelligent Systems, Grant Number IRI-9725441 and by Seed Research Grants from the Center for Integrated Facility Engineering, Stanford University.

review is followed by the introduction of the framework and the model for organizational change in response to technology. Finally, a section on design of simulation, and synthetic experiments as well as hypotheses generation describe the transformation of the potential computer simulation model into a tool for organizational analysis.

2. BACKGROUND

2.1 ORGANIZATION THEORY:

Organizational Action and Change. March [88] provides six perspectives on organizational action described in literature. Four of these perspectives; namely, rule following, problem solving, learning and conflict perspectives are relevant to the repertoire of actions available to the agents in our conceptual framework. Lounamaa and March [87] developed a computational model of adaptation in organizations which implies that organizations should not measure performance at too fine a grain size, and should make significant, but infrequent adaptations while avoiding too many simultaneous adaptations in noisy environments. The adaptation processes of agents in our conceptual framework borrow ideas from this work, and the computational model will attempt to test them. In their review of organizational learning, Levitt and March report "competency traps" into which organizations can fall by being early adopters of technology [Levitt and March 88]. The framework in this paper attempts to replicate the competency trap phenomenon by having actors whose short term performance suffers and long term performance improves while learning to use new technologies.

Research on the Technology-Structure Relation. There are three theoretical approaches, based on different models of causality, that explain the role of information technologies in organizational change [Markus & Robey 88]. (1) The technological imperative; (2) The organizational imperative; and (3) The emergent perspective. The former two view either technology or the choices of managers [Galbraith 77, Daft & MacIntosh 81, Daft & Lengel 86] as the only cause of organizational change in response to technology; respectively. The emergent perspective, however; attributes outcomes to an 'unpredictable' interaction between technology and organizational agents focusing on the dynamic interplay between agents, context, and technology. It requires detailed understanding of dynamic organizational processes in addition to the features of the organization, technologies, and intentions of agents.

Sproull and Goodman [90] emphasize three requirements that emergent technology-structure models should satisfy: (1) These models need to capture the dynamic relationship between technology and social structure. (2) They should develop fine-grained descriptions of different configurations of the same technology rather than aggregate descriptions, and should examine the differential effects on process and outcomes. (3) Models should take into consideration that different levels of the organization display different structural properties, and predictions, e.g., at the organizational level may not hold for the work-unit level. Although most organization theorists to date address organizational design issues at a level of aggregation that abstracts most of the content from tasks, agents and decision-making processes, recent research employing computers to simulate organizational behavior and analyze organizational structures has demonstrated that a computational modeling approach allows us to model organizational processes at very specific and detailed levels [Cohen et al. 72, Masuch & LaPotin 89, Carley et al. 92, Cohen 92, Christiansen 93]. The framework presented in this paper adopts an emergent perspective of organizational change in response to technology, representing and reasoning about both structure, and agent intentions and preferences.

Nass and Mason [90] emphasize that organization literature does not provide any specified set of attributes or dimensions that vary across technologies and that are causes or consequences of organizational phenomena. Most research to date has focused on looking at case studies of how specific technologies affected specific tasks within specific organizational settings. After Nass and Mason [90], we operationalize in our model technology, task, and organizations along dimensions that we can use to make realistic generalizations and comparisons for a wide range of technologies, tasks, and organizational settings.

Structuration theories are getting increased attention in organizational and group communication and information systems research [e.g., Poole & DeSanctis 1990, 1992, Poole & McPhee 1983, Orlikowski & Robey 1991 in Poole & DeSanctis [92]]. Structuration is "the production and reproduction of a social system through members' use of rules and resources in interaction" [Weick 90]. This definition describes structure as both the medium and the outcome of social interaction. For example, organizational actors work with a technology constrained by existing structures, but in turn create new structures as a result of their interaction with the technology. The same technology may lead to different organizational structures and interactions depending on the initial structural configuration in which it was embedded [Barley 90]. Poole & DeSanctis [92] apply adaptive structuration theory to the use of group decision support systems (GDSS). They refer to two key concepts - the "structural potential" and "structures in use". *Structural potential* in the context of a structuration process refers to the array of structures available to the system through technology or formal group and task characteristics. *Structures in use,* on the other hand, refer to the specific structures that are appropriated by the group. Thus, structures in use are a subset of the structural potential for an organization. Structuration processes follow two interaction dynamics: (1) Continuous subtle changes either stabilizing or changing existing structures; and (2) Junctures at which major shifts in structure occur. The model in this research attempts to reflect the former of these dynamic processes.

According to Pfeffer and Leblebici [77] match between technology and structure is through control, and any information system that provides better means of organizational control should relax the other aspects of the organization set up for control. Huber [90] provides a set of hypotheses on the effect of information technology; specifically, decision support tools on organizations. Some of these hypotheses predict, *inter alia,* changes in participation in decision making, size and heterogeneity of decision units, an increase in the centralization of decision making, and a change in the number of organizational levels involved in authorization of decisions. These hypotheses take a technological perspective. We attempt to test hypotheses like these from an emergent perspective, describing other organizational phenomena with which they co-exist.

Contradictory findings are reported from studies on the information technology-organizational structure relationship (e.g., deskilling vs upgrading of skills, centralization vs decentralization) [Attewel and Rule 88]. Among the reasons cited for these contradictory findings by [Crowston et al. 88] are: (1) "Limited views of causality" [Markus and Robey in Crowston et al, 88]; information technology is not necessarily the direct cause or result of organizational structure, but rather it is embedded into organizational structures enabling change along with many other mediating organizational factors.; (2) "Scattered results" focusing on one aspect of structure that is effected by IT with no theory predicting multiple effects of IT on an organization; and (3) "Blunt measures" of technology and structure extracting content from many organizational variables and treating them as binary variables. Sproull and Kiesler [91] report both planned and emergent changes in structure and performance resulting from its introduction and emphasize the lack of systematic research on changing organizational structures through electronic communication

In order to explain the contradictory results reported in the literature, and to generate consistent theories applicable to a range of situations, we need models that describe individual action, decision-making, and learning within organizations. These models should reflect which contextual variables (i.e.,technology dimensions, organization structure, organizational communication networks, organizational performance) significantly affect the key processes and how. Our framework attempts to address this need.

2.2. COMPUTER BASED MODELING OF ORGANIZATIONS:

Computer simulation models have long been applied by sociologists to study both fundamental issues in, and applications of, organization science [Burton and Obel 93]. The pioneering work by Cyert and March [63] on the behavioral theory of the firm addressed the question, "How do business organizations really make decisions?" Their computational models generated economically relevant and accurate predictions of business behavior and bridged between classical microeconomics and organization theory, viewing the firm as a decision-making system, peopled by boundedly rational actors with multiple, conflicting goals and adaptive aspiration levels, attention rules and search strategies.

The Garbage Can model [Cohen et al. 72] characterizes decision-making in "organized anarchies" by problematic preferences, unclear technology, and fluid participation. The Garbage Can computer program successfully demonstrated how a simple, quasi-random model of loosely coupled decision-making could yield both realistic predictions of behavior as well as deep theoretical insights. Together with Cyert and March's decision-making paradigm of the firm [59], the Garbage Can's modeling methodology has provided a point of departure for our current research.

Although early simulation models employed procedural programming languages with limited descriptive power, recent progress in artificial intelligence (AI), object-oriented programming, distributed AI, and agent-oriented programming has provided a rich set of tools for computer-based social and organizational modeling. Masuch and LaPotin's DoubleAISS is one of the first computational models that applies AI and object-oriented tools to study organizational decision making, based on the interplay of actors, skills, actions, issues and structure [Masuch and LaPotin 89]. They found that decision-making in organized structures can also become disorderly, but in different ways than in an organized anarchy.

Carley and her colleagues' extended Soar to examine the three-way relationship between individual's skills, job, requirements, and schemes for coordinating individuals within the organization. Their model, called Plural-Soar, is a multi-agent artificial organization which incorporates individual cognitive capabilities in an organization with various information flows. The application of Soar in this organizational context provided a cognitively motivated theory of micro-organizational behavior. It thus was a source of important insights for our research on modeling organizational change based on agents' micro-level actions.

Researchers in distributed artificial intelligence (DAI) have addressed organization structuring and coordination issues for developing effective and efficient multi-agent and distributed computer systems [Fox 81, Bond and Gasser 88, Gasser and Huhns 89, Durfee et al 89]. Gasser analyzed the social concepts of knowledge and action from a distributed artificial intelligence point of view [Gasser 91]. Although the goal of research in DAI is to develop "optimal" architectures and mechanisms for distributed artificial systems, the computational model of intelligent agents and agent-oriented programming language have provided a rich source of concepts and methodologies for us to model interacting agents.

2.3. Our Previous Research

In our research on the Virtual Design Team (VDT), we have taken the first step toward developing analysis tools for providing detailed performance predictions for various project organization structures [Cohen 92, Levitt et al. 92, Christiansen 93, Jin et al. 94]. VDT is concerned with the organizational performance of design teams performing complex but relatively routine tasks, and attempts to explicate the interplay among team performance, communication tools used by the team, and the team's organizational structure. VDT takes an information processing approach to modeling organizations. It describes tasks based on engineering principles, and models capability, preference and capacity of agents in terms of behavioral parameters. Based on the organizational structure and communication tools used by the team, VDT can predict project duration, cost and task process and communication quality. Our experience with VDT has led us to a better understanding of how to model tasks and communication technologies, and how to model task processing and agent interaction based on an information processing perspective. The current research builds a richer task processing and communication model than VDT to investigate the organization change caused by three-way interplay between agents, tasks, and technology.

Our previous research on i-AGENTS adopts an agent-oriented approach for distributed problem solving in complex design and planning environments by multi-agent teams [Jin and Levitt 94]. i-AGENTS is composed of a number of high level concepts: tasks, agents, organization structure and communication. A task is described in detail by task action, task object and task constraints; an agent is modeled as consisting of cognitive attributes including goals, beliefs, commitments, and expertise; and role-based organizational structure is adopted for describing organizations. i-AGENTS merges organization theory and distributed artificial intelligence and provides a flexible and rich framework for modeling organizational agents which we will use as a starting point for implementing agent actions in the current research.

In summary, computer-based simulation has proven to be a powerful approach for organization modeling. Although many computational models have been developed, none of them addresses organizational change in the context of the introduction of new information technology . Our experience with computational organization modeling both motivates and underpins the current research and provides us with the resources and capability to develop a computational model

3. OVERVIEW OF THE MODEL

Our model views an organization as a collection of interacting agents who apply a set of "technologies" (i.e., material / information / communication technology or knowledge) to a set of relatively certain tasks that have at least pooled interdependence. The purpose is to model organizational change as it is constrained by the organization's "structural potential" and facilitated by micro-level agent actions.

The introduction of a new technology modifies the structural potential of the organization by imposing new structural limitations on the organizational agents, and/or by relaxing others. The modification of the organization's structural potential results in the disruption of equilibrium. The next quasi-equilibrium state—at which a relatively stable set of "structures in use" are established—is dependent on the attributes of the technology and the existing "structural potential" in which it is embedded. The time it takes to reach this equilibrium state, if this is ever possible, and the stages through which the organization transforms itself, are also dependent on the initial "structures in use" at the time of the technology introduction.

Our model for studying organizational change in response to technology consists of four main conceptual components (Fig. 1):

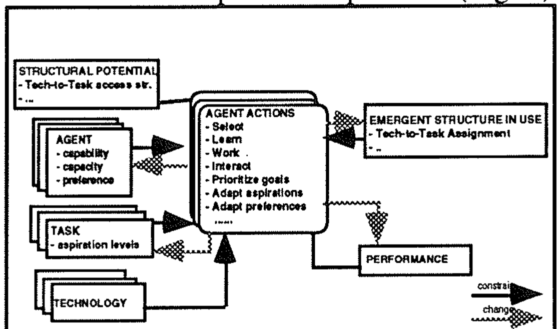

FIGURE 1 - CONCEPTUAL FRAMEWORK

(1) Agents; (2) Tasks; (3) Technology; and (4) "Structural Potential".

Agents have capabilities that are based on their training and experience. They have capacities depending on their time and resource constraints. Most importantly, agents have preferences that change over time based on their experience with the environment, and their own agent attributes.

Organizational **tasks** in this model are considered in terms of their skill requirements, applicable information technologies, interdependencies with each other, and the aspiration levels associated with task goals.

Information Technologies are described in terms of agent skill requirements for use, impact on organizational tasks for which they are applicable, and impact on capabilities and capacities of agents who can use them.

Finally, the **structural potential** concept is used to describe the possible interaction between technology, task, and agents depending on their individual attributes and the organization's formalization, centralization, and specialization policies.

Agent actions involve micro-level processes that are based on the capabilities, capacity, and preferences of an agent, as well as the structural potential of the organization.

Any variation in organizational behavior or "structures in use" over time is triggered by the variations in agent capabilities, capacities, and preferences and/or by any variation in the "structural potential" of the organization. In this model, information technology is treated as a cause for variation in agent and task attributes. However, change in "structures in use" is not a direct causal effect of technology, but an emergent effect of the interaction among agents, tasks, and technologies. The change emerges as the aggregation of each individual agent's micro-level behavior in response to the task environment, based on the interaction of his/her agent attributes, and "structural potential" constraints. The agent micro-level actions that the model currently considers are: (1) Selection of a task to work on, and a technology to use; (2) Learning to use a technology; (3) Working on a task either using or not using a technology; (4) Communication with other agents, face-to-face, or mediated by information technology; and (5) Adaptation of agent preferences, and task aspirations.

Looking at organizations as systems of interacting agents we can observe the synergy of individual actions which result in an overall pattern of organizational interaction. Furthermore, since agents work on tasks that have at least pooled interdependence, the performance of each agent working on each task aggregates into an overall level of performance for the organization. Organizational change can be seen in both the overall patterns of interaction within the organization (i.e., "structures in use") and the overall products of that interaction (i.e., performance, task aspiration levels, agent attributes).

4. STRUCTURAL POTENTIAL

Our representation of the structural potential of a given organization extends the notion of access structures from the Garbage Can [Cohen et al. 72] and can be described in terms of the following access or interaction structures (Fig. 2):

(1) *Task structure*—"depends on" relationships (e.g., temporal, functional, information) between tasks;

(2) *Decision structure*—legal agent to task "has-access-to" mappings which may be based on the match between task requirements and agent skill, experience, and authority (e.g., unsegmented, specialized after [Cohen et al. 72]);

(3) *Control structure*—"report-to" relations between agents (e.g., hierarchy);

(4) *Agent-to-Technology access structure*—"has-access-to" mapping between agents and technologies to which they have access (e.g., unsegmented, hierarchical, specialized);

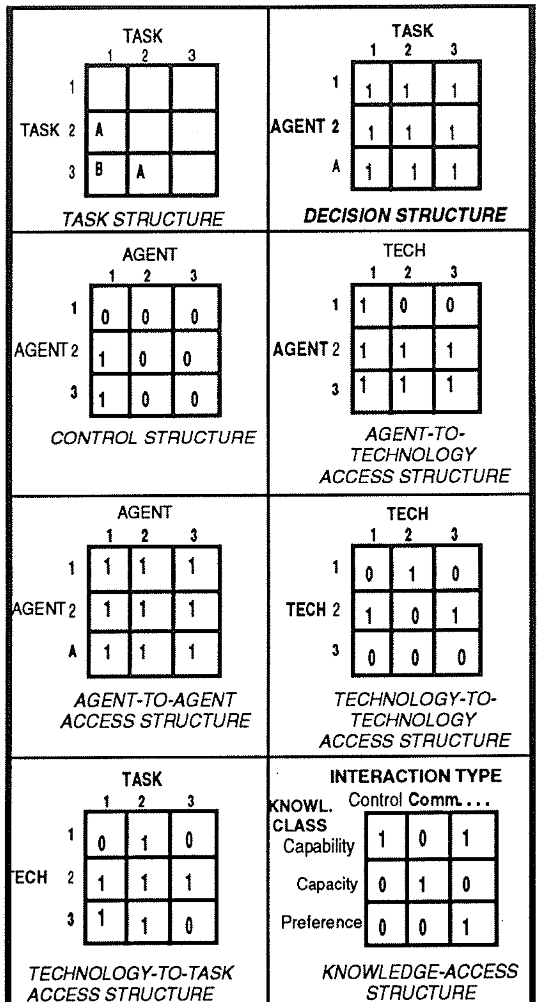

FIGURE 2 - STRUCTURAL POTENTIAL
The figure provides a set of possible sub-structures that are part of the structure potential of an organization consisting of 3 agents, three technologies, and 3 tasks. Structure Potential of an organization is defined by the legal interactions available between agents, tasks, and technologies.

(5) *Agent-to-Agent access structure*—legal agent to agent "can-communicate-with" mappings for (non)task-related communications (e.g., chain, all-channel, wheel, circle [Scott 92]);

(6) *Technology-to-Technology access structure*—"has-access-to" mapping among technologies based on the compatibility between them, and the existence of infrastructure to link them (e.g., distributed network, centralized network);
(7) *Technology-to-Task access structure*—"applicable-to" mapping between information technologies and tasks in which technologies can be utilized (e.g., unsegmented, specialized);
(8) *Knowledge access structure*—"accessible-through" mapping between the classes of knowledge (e.g., interaction partner's capacity, capability, preferences, competency etc.) an agent may have access to about others and the type of interactions (e.g., communication, control) through which an agent may gain access to this information

These structures collectively constitute the structural potential of an organization and constrain the range of possible actions for agents in the organization. We assume that these ground rules are fixed and taken for granted by most agents, although, in reality, they may be violated by a few agents infrequently. In the current model, we treat structural potential as an independent variable and assume that agents are not allowed to make policy changes that will modify the structural potential of the organization.

The structural potential describes only the availability of access, or the interaction possibilities between system entities as binary variables. To reflect the fitness of these feasible interactions, we define a set of fitness tables which describe the quality of the match between interacting entities on a scale from 1 to 10 with increasing fitness. For example, the interactions seen in the technology-to-technology fitness structure, the agent-to-technology access structure, and the technology-to-task access structure are modeled in terms of the quality of the match between the related interacting variables. Values in interaction attribute tables are dynamic for those interactions where learning or organizational adaptation may improve the fitness of the interaction.

Currently, we only model the improvement in agent-to-technology interaction fitness that is achieved through an agent's learning of the technology by using it on a task. Other possible improvements, for example, in the fitness of the match between an agent and a task (through gaining experience by working on that task), or improvement in the quality of communication links in agent-to-agent communication matches (through gaining experience in communicating with a specific agent frequently), will be added to the model one at a time. The various forms of adaptation that are found to be critical to our model will be combined in the final model after testing and validation.

The fitness tables are set up initially for each simulation by comparing agents to tasks, technologies to tasks, and agents to technologies based on a set of technology, task, and agent attributes and are updated during simulation for those that are adaptive. The initialization is done before the simulation starts. "Information technology" is classified and evaluated in terms of how it changes various attributes of the (1) tasks it is supporting (e.g., reduce coordination load, change coordination mode, change task verification mode) and (2) the user agents (e.g., capacity, capability, preferences). The match between agents, tasks, and technologies is based on the skill and experience requirements of the tasks, the skill and experience of the agents, and the attributes of the technologies.. Agents' access to the fitness table attribute values of other agents (i.e., Who knows what about whom?) is defined in the knowledge-access structures. Those agents who have access to the fitness tables may use this information as a basis for their actions.

5. AGENT ACTIONS

In this section we will describe micro-level agent actions within an organizational context and how these aggregate into organizational change. The micro-level actions are governed by meso-level constraints (as defined by structural potential), task aspiration levels, and agents' capabilities, capacities, and preferences. These actions result in patterns of behavior that we call "structures in use", and in modifications to both task (i.e., aspiration levels) and agent attributes (e.g., capabilities). In turn, these behaviors add up to a local task performance, and an aggregate organizational performance.

These micro-level actions represent the behavior of agents as they interact with (1) tasks; (2) technologies; and (3) other agents. Agents search for and select tasks to work on given the constraints on decision structure and their preferences. They may avoid some tasks and prefer others if they have freedom to do so, as well as prioritize the tasks for which they are qualified. Once they decide to participate in a task they may adapt task aspiration levels based on current performance. Thus, the system employs mechanisms for self evaluation and evaluation by others. Agents work on tasks by spending energy and time. They allocate their time and attention based on constraints imposed by the structural potential, the task aspiration levels, their own capacities, capabilities and preferences.

Agents also interact with technologies. They search, select, and sometimes avoid certain technologies. Their access to technologies are constrained by the agent-to-technology access structure. Agents learn to use technologies. Learning a technology can be modeled by a change in agent capability and capacity over time through interaction with the technology, as in learning to use an automated design tool or a word-processor. This learning effect is reflected in the fitness structure between agents and technologies. Agents share work and coordinate using information processing technologies. Inaccessible agents may become accessible by the use of communication technologies. Task performances are assumed to improve in the long term, but may deteriorate in the short term due to learning curve effects when using a new information technology. Agents do not always improve as they interact with others, work on tasks, and use technologies. They may fail stochastically and avoid certain tasks, technologies and agents both rationally and superstitiously after a failure associated with them.

Agents interact with each other using vaious communication media (e.g., face-to-face, e-mail, video-conferencing). They engage in communications for three purposes: (1) Production—to get work done; (2) Innovation—to solve organizational problems and find new ways to accomplish organizational goals (e.g., policy change); and (3) Maintenance—for social support [Monge and Eisenberg 87]. They report to those agents with whom they are linked through control structures. They communicate with other agents to request or provide task-related information based on the interdependencies represented in the task structures, decision structures, and agent-to-agent access structures. They distribute tasks to agents constrained by task, decision, and control structures.

Although partially constrained by the structural potential in their task-related communications, agents will change their communication behavior, depending on their past experience with particular agents, and on changes in technology-task matches due to successful adoption of a new technology. Thus, agents learn to be selective in their communication behavior. Communication structures within an organization both provide a medium for the emergence of new power relations and are the outcome of existing power structures.

In summary, organizational change occurs by instantiating these agent processes with different values on structural constraints, task target aspirations, agent capabilities, and capacities, and agent preferences. New technology changes agent behavior by: (1) Changing the "structural potential" by definition at the time of new technology introduction; and (2) Changing agent capacity, capability, preferences, and competence through learning over time. This action in turn creates emergent "structures in use" and performance outcomes.

The model considers a set of control parameters that affect the micro-level behaviors of agents: (1) Motivation; (2) Memory span; (3) Frequency of adaptation; and (4) Learning mode. Currently, we consider the effect of the following types of motivation on micro-level processes: (1) Maximize self-utilization; (2) Maximize power; (3) Maximize personal competence; (4) Maximize interaction; (5) Maximize autonomy; and (6) Minimize resource-dependence. The motivation of the agent affects his/her choices, and behavior as simulated in micro-level processes. Memory span of the agents can also be varied to study its effect on organizational change. Considering the fact that some technologies make the memory span of an agent virtually infinite, this variable is deemed to be relevant.

The effect of frequency of adaptation, as mentioned in Lounamaa and March [87], on organizational change and performance will also be investigated by simulating various time windows for adaptive behavior to occur. Finally, the effect of learning from self experience vs others' experiences on adaptation is to be investigated taking into consideration the knowledge access structure which determines the agents' access privileges to others' experience.

Another major issue in setting micro-level action control parameters is that of the distribution. The characteristics (i.e., homogeneous, random, grouped) of the population of agents in terms of these variables will affect the emergent "structures in use" as well as the performance outcome. For example, a homogeneous population motivated by maximization of power might be more unstable, than a population with more complementary motivational needs such as some with a need to maximize power, others with a need to maximize efficiency or self-utilization, as there will be less competition for similar tasks and technologies in the latter population.

6. STRUCTURES IN USE

"Structures in use" refer to one instance of the possible permutations that can be generated from legal task-agent-technology mappings provided by "structural potential". While imposed organizational change can be observed by looking at the "structural potential" of an organization, emergent organizational change can be observed by studying changes in "structures in use". The degrees of freedom provided by the "structural potential" constrain the variance in the "structures in use" over time. For example, in an organization with a one to one mapping between agents and tasks (i.e., decision structure) one would not see any variation in task distribution among agents based on their preferences about tasks, technologies, and other agents over time. However, given these constraints one would still observe some changes in the communication networks and power structures over time after the introduction of a new technology due to, e.g., the interaction of the decision structure with the technology and agent access structures.

Power structure is an emergent behavioral structure that is not specified in the structural potential but emerges over time based on the interaction between structures that are in use. For example, certain agents with special access to a technology that is central to those tasks critical for the survival of the organization gain power over those agents who do not. However, when the importance of these tasks changes, the power structure in the organization starts changing, along with it.

Communication structure of an organization is also an emergent behavior that our model will study. It is dependent on the task structure, control structure, decision structure, and the agent and technology access structures that are in use at a given time. However, agents still have a certain degree of freedom to decide with whom they communicate in different contexts depending on the purpose of communication, and on the availability of and the past experience with agents who may respond to this communication.

Figure 3 shows three sub-structures; namely, decision structure, technology-to-agent and technology-to-task access structures. Fitness tables are "objective" measures of the quality of interactions between system entities at a given time. Agents have partial access to these objective fitness measures. They interpret these objective measures in order to choose those alternative actions (e.g., tasks to work on, technologies to use) which will satisfy their motivational needs better. These commitments along with behaviors associated with them create two different "structures in use" at time t_1 and t_n (circles referring to specific interactions in use). Over time, gaining competence in a technology improves the match between the agent and the technology as seen at time t_n for agents 2 and 3 working on technology 2. These improvements in competencies increase the agent's probability of using that technology in the next time period as well as working on a task that requires the technology. Thus, as the organization approaches final quasi-equilibrium, the variance in the structures in use over time decreases compared to the initial introductory stages of the technology.

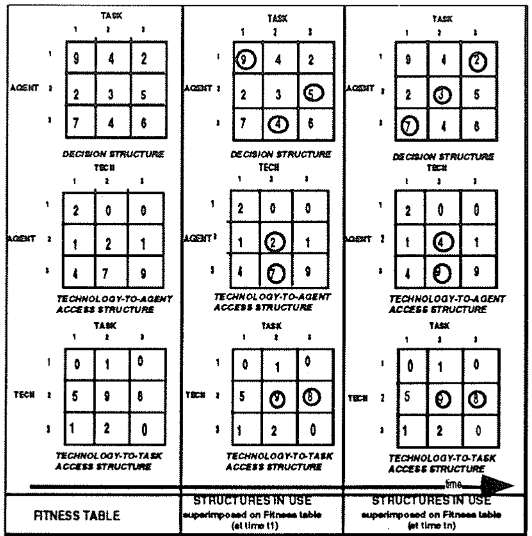

FIGURE 3 - Fitness Tables

Different combinations of structures that constitute structural potential result in different structures in use. All structures or constraints interact with each other as they get appropriated by the agents. The key is to provide agents with mechanisms to scan, attend, interpret, and adapt to the environment constrained by their preferences, but at the same time allow them to restructure their preferences.

7. PERFORMANCE

The current model considers two types of organizational performance: (1) Task performance; and (2) Social performance. Social performance is measured in terms of social and structural parameters that enable the critical evaluation of the "structures in use" whereas task performance is measured in terms of time, and resources spent on a task. Task performance and social performance is evaluated and compared to targets by agents in the light of their preferences during simulation in order to: (1) Adapt their behaviors to meet task aspiration levels; (2) Adapt aspiration levels; and (3) Change preferences.

Improvements in task performance may lag behind improvements in social performance. However, social performance improvements, e.g., in response to a new information technology, may result in "structures in use" with better fitness values, and may eventually lead to better task performance as the organization reaches a new quasi-equilibrium with the new technology. This improvement in social performance may be due to the networking of individuals who work on interdependent tasks using information technology, or to an improved emergent assignment of agents to tasks and technologies based on their fitness match, or to a total increase in the competency of agents interacting with technologies.

Depending on their preferences, agents will use different performance criteria (i.e., social vs task) and will adapt differently depending on their access to performance information at the sub-unit or organizational level. Thus adaptations of supervisors with a more global view on the sub-unit or organization will be different in scope and magnitude than the task performing agent's adaptations. This research will provide, as one of its deliverables, measures of social performance as an interpretation of the "structures in use" at a given time in the organization.

8. DESIGNING SIMULATION AND VALIDATION

The conceptual framework presented here is currently being implemented as agent-based computational simulation model. The model, once tested and validated, will be used to test existing theory and to generate new organizational theory on technological change. The testing and validation will be based on synthetic experiments in the short term and on longitudinal studies of real organizations implementing new technologies in the long run.

8.1 SIMULATION DESIGN

The independent variables for the simulation design are the organization's "structural potential" which consists of various sub-structures, and a set of micro-level agent action control parameters. The control variables in the model are the number of agents, the number of tasks, and the number of technologies reflecting organizational size and complexity. The dependent variables are performance (i.e., social and task performance) which will be recorded as a function of time during simulation, and the emergent "structures in use" similarly tracked over time.

We will not co-vary structural potential and agent action control parameters. One of the advantages of using a computational simulation model is that, in computer simulations, one can control for micro-level agent action control parameters which may be difficult if not impossible to control in natural experiments. The simulations will also enable us to measure the sensitivity of our model to various sub-structures listed under "structural potential". Based on such a sensitivity analysis the model can be simplified to include only those independent variables to which it is sensitive.

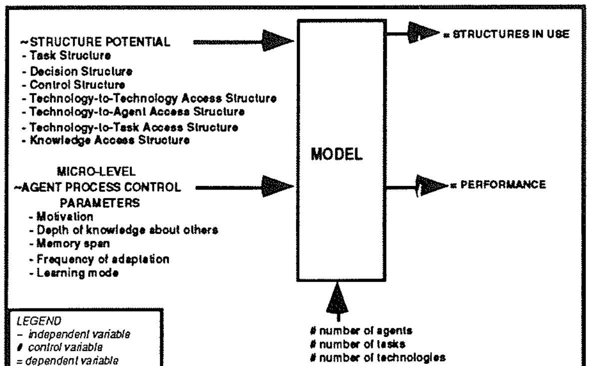

FIGURE 4 - RESEARCH DESIGN - MODEL DESCRIPTION

8.2 SYNTHETIC EXPERIMENT DESIGN

We plan to validate our computational model by running a set of synthetic experiments in a graduate computer integrated design class using student groups who work on engineering design projects using new computer-based collaboration tools. The independent variable in each experiment will be the "structural potential" with which the student group is provided. This will be achieved by providing groups with various rules for communication, task distribution, technology access, etc. We will specify different access structures for a given technology as well as one control case where no rules are established for access other than those imposed by the technology. As our dependent variable, we will collect data on structures in use, and social and task performance. The dependent variables—performance and the emergent "structures in use" will be tracked as a function of time during simulation as well as over the course of the experiments. We will obtain this data by reviewing the design logs that will be specified for various tasks, by interviewing group members, and by reviewing the video-tapes of the design sessions in which groups are involved..

8.3 HYPOTHESES GENERATION

This model will enable the testing of a wealth of existing hypotheses on technology-structure interaction and organizational change and learning. For example, we will test the hypotheses derived from the research of Huber [90] or Sproull and Kiesler [91] listed in the research review above; we will try to replicate the "competency traps" that ensnare early adopters of technology described by [Levitt and March, 88]; and we will try to reproduce the result that the best performance is achieved by making few, major structural changes at long intervals that was suggested by the simulation model of [Lounamaa and March, 87].

The computational model based on the framework presented in this paper can also be used to predict the impact of a given information technology in a given organizational context, gradually transforming the model into an organizational analysis tool through successive iterations of simulation, observation, and refinement.

9. SUMMARY

We have presented a framework to study the impact of new information technology on organizational structure and performance. Our framework views new technology as a disruption to the organizational quasi-equilibrium. This disruption starts a chain reaction among organizational agents who change their actions and the preferred structures in use, given a set of structural potential constraints, until a new quasi-equilibrium state is reached. We use an agent-based model of organizational action at the micro-level, and represent structural constraints on agent behavior based on theories of micro-level structuration. The conceptual framework presented here is currently being implemented as a computational simulation model building on and extending the i-Agents and VDT computational architectures.

10. REFERENCES

Attewel, P. and Rule, J. "Computing and Organizations: What We Know What We Don't Know," in *Computer-Supported Cooperative Work: A Book of Readings,* eds. Greif, I. pp.557-581, 1988

Barley, S.R., "The Alignment of Technology and Structure through Roles and Networks," in *Admin. Sci. Quart.* Vol.35, pp.61-103, 1990.

Bond, A. H., and Gasser, L., [Joint Editors], *Readings in Distributed Artificial Intelligence,* Morgan Kaufman, San Mateo, California, 1988.

Burton, R. M., and Obel, B., "On the Validity of Simulation Models in Organization Science", *Proceedings: The Next Quarter Century: Economics, Education, Management,* Carnegie-Mellon University, Pittsburgh, PA, September 1993.

Carley, K. M. C., Kjaer-Hansen, J., Newell, A., and Prietula, M., "Plural-Soar: A Prolegomenon to Artificial Agents and Organizational Behavior, " in *Artificial Intelligence in Organization and Management Theory* [Eds.] Masuch M. and Warglien M., North-Holland, Amsterdam, 1992, pp.87-118.

Christainsen, R. T., *Modeling Efficiency and Effectiveness of Coordination in Engineering Design Teams.* Ph.D Thesis, Stanford University, Sept.1993.

Cohen, M. D., March, J. G., and Olsen, J. P., "A Garbage Can Model of Organizational Choice," *Administrative Science Quarterly*, Vol. 17, No. 1, 1972, pp. 1-25.

Cohen, G. P., *The Virtual Design Team: An Information Processing Model of the Design Team Management,* Ph.D Thesis, Stanford University, December 1992.

Crowston, K, Malone, T. W, and Lin, F. "Cognitive Science and Organizational Design: A Case Study of Computer Conferencing," in *Computer-Supported Coorperative Work: A Book of Readings,* eds. Greif, I. pp.557-581, 1988.

Daft, R. L., and Lengel, R. H., "Organizational Information Requirements, Media Richness and Structural Design," *Management Science*, Vol. 32, No. 5, May, 1986, pp. 554-571.

Daft, R. L., and McIntosh, N. B., "A Tentative Exploration in the Amount and Equivocality of Information Processing in the Organizational Work Units", *Administrative Science Quarterly*, Vol. 26, No. 2, June 1981, pp. 207-224

Durfee, E. H., Lesser, V. R. and Corkill, D. D. "Trends in Cooperative Distributed Problem Solving ," in IEEE Transactions on Knowledge and Data Engineering, KDE-1 [1], 63-83, 1989.

Fox, M. S., "An Organizational View of Distributed Systems," in *Readings in Distributed Artificial Intelligence,* in *IEEE Transactions on Systems, Man, and Cybernetics*, Vol.11, No.1, pp.70-80, Jan.1981.

Galbraith, J.R., *Organization Design*, Addison-Wesley, Reading, Massachusetts, 1977.

Gasser, L., Social Conceptions of Knowledge and Action: DAI Foundations and Open Systems Semantics. *Artificial Intelligence Journal*, Volume 47, 1991, pp.107-138.

Huber, G. P., "A Theory of the Effects of Advanced Information Technologies on Organizational Design, Intelligence, and Decision Making," *Academy of Management Review*, Vol 15, No. 1, 1990, pp. 47-71.

Jin, Yan and Levitt R.E., "i-AGENTS: Modeling Organizational Problem Solving in Multiagent Teams", to appear in *International Journal of Intelligent Systems in Accounting, Finance and Managemen,* in special issue on "Mathematical and Computational Models of Organizations: Models and Characteristics of Agent Behavior", January 1994.

Jin, Y., Levitt, R.E., and Christiansen T., "The Virtual Design Team: A Computer Simulation Framework for Studying Organizational Aspects of Concurrent Design", to appear in *Proceedings of 1994 International Conference on Simulation in Engineering Education,* pp.93-98, January 1994,

Levitt, B, and March, J.G., "Organizational Learning," in *Ann. Rev. Sociol.* Vol.14, pp.319-340, 1988.

Levit, R. E., Cohen, P. G., Kunz, J. C., Nass, C. , Christiansen, T. and Jin, T., "The Virtual Design Team: Simulating How Organization Structure and Communication Tools Affect Team Performance," to be published in Carley, K.M, and Prietula M. J. [Eds.] *Computational Organization Theory.*

Lounamaa, P.H., and March, J.G., "Adaptive Coordination of a Learning Team," in *Management Science,* Vol.33, No.1, pp.107-123, January 1987.

March, J.G, "Footnotes to Organizational Change,", in *Decisions and Organizations,* eds., March, J.G., Basil Blackwell, New York, 1988.

Markus, M. L., and Robey, D., "Information Technology and Organizational Change: Causal Structure in Theory and Research," *Management Science*, Vol. 34, No. 5, May 1988, pp. 583-598.

Masuch, M., and LaPotin, P. *Beyond Garbage Cans: An AI Model of Organizational Choice.* Administrative Science Quarterly, 34,1989, pp.38-67

Monge, P. and Eizenberg, E.M., "Emergent Communication Networks," in Handbook of organizational communication Newbury Park, eds., Jablin, Putnam, Porter & Robert, CA, Sage Publications 1987.

Nass, C. and Mason, L., "On the Study of Technology and Task: A Variable-Based Approach," in *Organizations and Communication Technology,* (Eds.) Faulk, J. and Steinfield, C., Sage Publications, Beverly Hills, California, 1990, pp. 46-67.

Pfeffer, J. and Leblebici, H., "Information Technology and Organizational Structure", *Pacific Sociological Review,* Vol.20 No.2, 1977.

Poole, M.S., and DeSanctis, G., "Microlevel Structuration in Computer-Supported Group Decision Making," *Human Communication Research,* Vol.19, No.1, September 1992.

Scott, W. R., *Organizations: Rational, Natural, and Open Systems*, 3rd ed., Prentice Hall, NJ, 1992.

Sproull, L., and Goodman, S., "Technology and Organizations: Integration and Opportunities" in *Technology and Organizations* [Eds.] Goodman, S.;Sproull, L. and Associates, Jossey-Bass, 1990, pp.254-267.

Sproull, L., and Kiesler, S., *Connections* MIT Press, Cambridge, 1991.