Computational and Mathematical Organization Theory: Perspective and Directions

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Abstract

Computational and mathematical organization theory is an inter-disciplinary scientific area whose research members focus on developing and testing organizational theory using formal models. The community shares a theoretical view of organizations as collections of processes and intelligent adaptive agents that are task oriented, socially situated, technologically bound, and continuously changing. Behavior within the organization is seen to affect and be affected by the organization's position in the external environment. The community also shares a methodological orientation toward the use of formal models for developing and testing theory. These models are both computational (e.g., simulation, emulation, expert systems, computer-assisted numerical analysis) and mathematical (e.g., formal logic, matrix algebra, network analysis, discrete and continuous equations). Much of the research in this area falls into four areas: organizational design, organizational learning, organizations and information technology, and organizational evolution and change. Historically, much of the work in this area has been focused on the issue how should organizations be designed. The work in this subarea is cumulative and tied to other subfields within organization theory more generally. The second most developed area is organizational learning. This research, however, is more tied to the work in psychology, cognitive science, and artificial intelligence than to general organization theory. Currently there is increased activity in the subareas of organizations and information technology and organizational evolution and change. Advances in these areas maybe made possible by combining network analysis techniques with an information processing approach to organizations. Formal approaches are particularly valuable to all of these areas given the complex adaptive nature of the organizational agents and the complex dynamic nature of the environment faced by these agents and the organizations.

Computational and Mathematical Organization Theory: Perspective and Directions

1 Introduction

Computational and mathematical approaches to the study of organizations have played an influential, though often overlooked, role in the development of organizational theory. Essentially, as an organizational phenomena became sufficiently well understood that it could be represented and analyzed formally the study of that phenomena and the associated organizational theory and formal models divided off from mainstream organizational theory and became its own, generally applied, subfield. Examples include the transformation of scientific management into operations research, the movement of organizational behavioral analysis of human response into the subfields of ergonomics and human factors, and the transformation of task analysis and experts into expert systems. Even if we discount these large scale applications, we still find that formal models have played an important and critical role in the field of organizations. Computational and mathematical models helped to define issues in organizational formalism (Hage, 1965), bounded rationality (Cyert and March, 1963), organizational process (Dutton and Starbuck, 1971), group decision making (DeGroot, 1970; Padgett, 1980), consensus formation (DeGroot, 1974; Marschak, 1955), resource allocation (Arrow and Radner, 1979), organizational structure (Cohen, March and Olsen , 1972), and so forth. By illustrating a key point these models tended to crystallize issues and spawned empirical studies to test the proposed processes.

The majority of research in the area of computational and mathematical organization theory has been done and is being done in four substantive areas. These areas are organizational design, organizational learning, organizations and information technology, and organizational evolution and change. Crossing these substantive areas are various distinct methodological approaches including general organizational modeling, distributed artificial intelligence, organizational engineering, social networks and logic. Before discussing these substantive areas in more detail let us first consider some of the features of the various methodological approaches.

General organizational models are characterized by their focus on general principles and processes. Such models are Weberian in the sense that they are often developed to compare and contrast features of “ideal type” agents, organizations, or networks of organizations. Complex features of agents, tasks, and organizations are often abstracted away. Illustrative models include those by Cohen March and Olsen (1972), Patrick (1974), Padgett (1980), Gode and Sunder (1993), Harrison and Carrol (1991), Carley (1992), and Glance and Huberman (1994a). These models, are limited in their realism as they use highly stylized models of agents, tasks, organizational designs, and so forth. These models serve as sufficiency explanations for many phenomena and can be used to test for the internal consistency of the claims of various verbal models. Dominant results using these models center on the relative tradeoffs of various design features. Mathematical models of this ilk typically are limited in the number of agents that they examine or in the complexity of the processes that they examine. Examinations are typically in terms of equilibrium behavior, or variation under changes in parameters. Computational models may include more agents or more complex processes. Historically it was possible to test computational models of organizations by doing a comprehensive analysis of the impact of all parameters. Current computational models are sufficiently complex that a complete sensitivity analysis across all parameters cannot be done; rather, researchers often use experimental designs and standard statistical techniques to examine limited aspects of the model. One of the important contributions of such models, other than providing sufficiency explanations, is that they can be used to demonstrate gaps in extant verbal theories and the consistency of the predictions made using such theories.

Distributed artificial intelligence models can be characterized as symbol based models for performing highly specific, but stylized, tasks such as navigation or surveillance (Bond and Gasser, 1988; Gasser and Huhns 1989; Cohen, 1986). A strength of this approach is the focus on representation, for example a focus on how the agent’s knowledge, and the “shared” knowledge is represented. A second strength of this approach is a focus on search. Models are often developed to address issues of communication, coordination, planning, or problem solving. Within these models agents are treated as generic agents and there is an implicit assumption that the results are generalizable to any and all agents be they computers, software programs, or people. These models, are also limited in their reality but serve as sufficiency explanations for many phenomena and as tests of the adequacy of various definitions or representation schemes. Dominant results using these models center on the relative advantages of different representation schemes and search procedures, as well as the relative benefits of different types of strategic behavior such as planning. These models are typically analyzed by examining the flow of behavior. A major issue in interpreting the results of these models and the general organizational models is scalability. That is, do the results from these small organizations generalize to larger more complex organizations? One of the important contributions of such models is that they enable the researcher to think through how models of agents influence collective behavior.

Organizational engineering models are characterized by the extensive detail with which they represent organizations or tasks and the attention to the specific features of candidate organizations or industries. These models are often immense particularly compared to the general organizational models and they employ organizational details at many levels. They generally focus on work flows and overall organizational or group response rather than the actions and behavior of individual agents. These models can be used to develop policy implications and to do what-if planning to aid a specific organization. A variety of examples exist including VDT (Levitt et al, 1994; Jin and Levitt, 1994), TIDES (Reuter et al, 1994), HI-TOP (Majchrzak and Gasser, 1991; 1992a; 1992b; Gasser and Majchrzak, 1992), and ACTION (Gasser, et al. 1993; Gasser and Majchrzak, 1994; Majchrzak and Finley, 1995). These models are typically tuned so that they sufficiently capture the behavior of the organization they were designed to emulate. The adequacy of the model is often demonstrated by whether it can be sufficiently tuned to capture some important behavior at least at a qualitative level. Further analysis of these models can involve determining the extent to which the tuned model captures other behavior for which it was not tuned in the same organization, or the extent to which it captures the behavior of other organizations. One of the important contributions of such models is that the “mere” use of them by managers often leads to the managers gaining important insights into problems within the organization.

Social network models are characterized by representations of organizations and sets of organizations in terms of the relationships among individuals or organizations. Historically, more of the work in this area has used social network techniques for analyzing an extant situation. Currently, more work is focusing on developing models of network change or models of how the agent’s position in the network influences its behavior. Such models have successfully been used to examine issues such as power, information flow/diffusion/innovation, and turnover. Illustrative research includes the work by Burt (1973, 1980, 1992), DiMaggio (1986), Krackhardt (1994), Hummon (1995), and Granovetter (1973, 1974). The adequacy of these models is determined using statistical techniques, including non-parametric techniques and new network based statistical techniques. One of the important contributions of these models is that they emphasize the structural or relational aspect of the organization and demonstrate when and how it can affect individual and organizational behavior.

Logic models are characterized by representations of organizations and organizational processes using the techniques and formalisms of formal logic. Such models enable the researcher to focus on the generative aspects of organizational form given a specific grammar. Examples of such models include Masuch and Huang (1991), Huang and Masuch (1993), and Salancik and Leblebici (1988). These models tend to be among the most limited in their realism, of all the models discussed. One of the important contributions of these models is that they provide a forum for assessing the internal validity of extant theories.

This brief review of these methodological approaches belies the vast array of techniques and tools that have been used to examine organizations using formal models. These approaches have been used to address a variety of questions about organizations. These questions take many forms. However, as noted earlier, the majority of this work has historically, and is currently, focusing on four areas: organizational design, organizational learning, organizations and information technology, and organizational evolution and change.

2 Areas of Analysis

2.1 Organizational Design

The issue of organizational design is one of the dominant issues within the area of organizations. In large part this is due to the fact that organizations can alter their design and thereby adjust or adapt to the task environment (Baligh, Burton and Obel, 1987, 1990; Lawrence and Lorsch 1969; Woodward 1965). Another reason for the interest in design is that there is some evidence that by altering the organization's design we can alter its performance (Lawrence and Lorsch 1967; Burton and Obel 1984; Carley 1990,1991,1992; Malone 1987). Structural theorists have long argued that design is a performance determinant (Mackenzie 1978; Scott 1987; Krackhardt, 1994), as have information processing theorists (Galbraith 1973, 1977). Indeed, contingency theorists have suggested that not only does design impact performance but the right design is situationally specific (Lawrence and Lorsch 1967). However, across the literature there are numerous, and not necessarily compatible, characterizations of design. For example, design as: the formal structure and task decomposition structure (Burton and Obel 1984; Mintzburgh 1983); the degree of hierarchy (Mackenzie 1978); the informal network (Krackhardt and Stern, 1988); the process of coordination (Pfeffer 1978); the procedures for combining information or making decisions (Panning 1986; Radner 1987); and the information processing characteristics or cost (Carley 1990; Galbraith 1973, 1977; Malone 1987; March and Simon 1958).

A question related to design that computational and mathematical approaches are particularly adept at is evaluating designs, particularly under adverse conditions. Contingency theorists have argued that general guidance and a simple theory of design cannot exist. In contrast, Scott (1987) argues that it is indeed important to search for underlying principles to guide the design of organizations. Researchers in computational and mathematical organization theory have me this challenge. Efforts at developing a theory of design have gone the route of creating expert systems that rely on highly situation specific knowledge (Burton and Obel, 1984; Baligh, Burton and Obel, 1987; 1990; 1994) or common or "best practices" (Gasser and Majchrzak 1994). Another approach has been the development of detailed organizational engineering models geared toward evaluating the design of a specific organization (Cohen, 1992). Still other studies moved beyond classical models of optimal allocation of resources and goods (Arrow and Radner, 1979; Gloves and Ledyard, 1977) and claims about structure (Galbraith, 1977; March and Simon, 1958; Staw, Sanderlands and Dutton, 1981; Weber, 1922) by utilizing static comparison techniques to look at the impact of differences in the allocation, communication, and command structures (Cohen, March and Olsen, 1972; Carley, 1990, 1991, 1992; Carley and Lin, 1995; Masuch and LaPotin, 1989).

This research, and the specific models build on each other. The bulk of this research takes an information processing approach. Cyert and March's (1963) "A Behavioral Theory of the Firm" signaled the beginning of the use of information processing based models for examining the effectiveness of organizational structure when the agents in the organization could make decisions and process information. The basic model looks at agents as boundedly rational, focuses on economic behavior, looks at a stylized form of a specific task, and examines a single organizational structure. Subsequent works, though they kept the focus on boundedly rational agents did not confine themselves to looking at economic behavior. Moreover, later works varied in whether they examined a specific task and if so which task.

Consider, for example, Cohen, March and Olsen's (1972) article "A Garbage Can Model of Organizational Choice." In this article, agents are very generic, characterized by their organizational position and their energy. Tasks are characterized only by the effort that would be put into them and the timing of their arrival. In contrast, Levitt, Cohen, Kunz, Nass, Christiansen and Jin's (1994) article " The 'Virtual Design' Team: Simulating How Organization Structure and Information Processing Tools Affect Team Performance" focuses on specific design tasks, and Carley's (1992) "Organizational Learning and Personnel Turnover" focused on a stylized classification and choice task. In both the Levitt et al model and the Carley model agents are boundedly rational and differ in their organizational position. A difference in these models is that the Levitt et al agents cannot learn; whereas, the Carley agents are adaptive.

These four models represent only the tip of the iceberg in this area. Other research using related models include the work of Bonini (1963), Cohen and Cyert (1965), Padgett (1980), Anderson and Fischer (1986), Masuch and LaPotin (1989), Carley (1986; 1992), Burton and Obel (1980), Verhagen and Masuch (1994). In particular, Cohen, March and Olsen's (1972) article "A Garbage Can Model of Organizational Choice" has been re-implemented numerous times and multiple extensions of it exist in the literature. Several of these extensions appear in March and Weissinger-Baylon's (1986) book "Ambiguity and Command: Organizational Perspectives on Military Decision Making."

This large body of research wherein the authors use computational or mathematical models to explore issues of organizational design using an information processing approach is highly cumulative. This cumulation, as we have seen occurs in part through an ongoing exploration of extant models and extensions of those models. Further, this cumulation is seen in the emergence of a consistent body of findings pursuant to design from divergent models. For example, this body of research conclusively demonstrates that there is no one best organizational design; rather, the effectiveness of an organizational design is highly contingent on various factors such as the task, the environment, and the training organizational members receive. Importantly, this work moves beyond this generic statement to a series of findings that specify how the various aspects of organizational design affect performance under specific conditions. These findings have moved the focus of interest from locating the best design to locating the relevant tradeoffs inherent in the use of different organizational designs.

Another type of finding has to do with representation. First, in order for information processing models of organizations to generate reasonable, concrete, and policy relevant implications the models need to include at some level of detail a model of the agent, a model of the task, and a model of the internal structure of the organization (including some information about the role or position of the agent in the organization). Models that ignore or minimize one of these three components tend to be less effective (Carley and Prietula, 1994). Second, many organizational features can be represented as matrices of relations. These relations may be among people or agents (e.g., Carley, 1992; Krackhardt, 1994), among resources or subtasks (e.g., Levitt et al., 1994), between resource/tasks and people/agents (e.g., Cohen, March and Olsen, 1972), between agents and skills (e.g., Levitt et al., 1994), between tasks and skills (e.g., Cohen, March and Olsen, 1972; Levitt et al., 1994), and so on. Representing organizations in terms of relations is important as it admits the construction of better measures, makes possible the use of existing techniques for analyzing networks, helps the researcher locate overlooked features, increases the systematicity with which parameters are examined, increases the ease of comparing models, and focuses the analysis on organizational or social characteristics rather than individual characteristics.

Let us return to the substantive findings. First, there exists a body of findings centering on how the structure and the communication techniques influence the rate of decision making and the ability of the organization to reach consensus. Much of the original research centered on how to structure the organizations so as to achieve optimal decisions (DeGroot, 1970; Shapley and Grofman, 1984; Pete, Pattipati, and Kleinman, 1993a), or to optimally allocate resources (Arrow and Radner, 1979) or to guarantee consensus (DeGroot, 1974; Marschak, 1955). Numerous field studies, however, have repeatedly demonstrated that within organizations optimality is rarely the goal and consensus is not necessary (e.g., March and Weissinger-Baylon, 1986). Further, studies of actual organizations actually demonstrate that organizations rarely have the time, access to information, or a static enough environment that it is possible to locate the optimal decision (March and Simon, 1958). Rather, organizational decision making occurs in a more distributed environment, that is fraught with problems and exceptions, and in which there may be some ability to learn from previous decisions but the feedback is often late, inconclusive, and biased. Currently, most computational and mathematical organizational theorists are moving beyond these early normative models and are focusing on making the best or a satisfactory decision rather than the optimal decision, and on making distributed rather than consensual decisions (Arthur, 1991; Carley 1992; Cohen, March and Olsen, 1972; Beroggi and Wallace, 1994; Davis and Smith, 1983; Masuch and LaPotin, 1976).

Indeed, there exists a body of findings about the conditions under which various designs work best given that the organization is acting in a more distributed, satisficing fashion. Many of these findings results from looking at issues of decision making (e.g., Marschak, 1955; DeGroot, 1970; 1974), communication (e.g., Levitt et al, 1994), cooperation (e.g., Cammarata, McArthur and Steeb 1983; Glance and Huberman, 1993), and coordination (e.g., Malone, 1987). Such findings are legion. Hierarchies arguably are non-egalitarian (ONeill, 1984), absorb ambiguity and uncertainty (March and Simon, 1958), enable specialization (Duncan, 1973), decrease competition and deception and admit better auditing (Williamson, 1975), reduce coordination costs (Malone, 1987). Increasing the level of hierarchy tends to decrease the efficiency/effectiveness/performance of the organization. Hierarchies and centralized structures tend to exhibit lower performance than democratic team or decentralized structures, on average, due to information loss, uncertainty absorption, and information distortion. Further, the greater the number of levels in the hierarchy the greater the level of information loss/distortion. However, hierarchical structures are more reliable; that is, their performance is less affected by environmental perturbations, information errors, etc. For simple tasks simple decentralized/team like structures perform better; whereas, for complex tasks more complex organizational forms such as hierarchies, networks, and matrices perform better. Organizations with fewer levels, lower span of control, and more democratic structures tend to learn faster and so perform better in the short run. More complex, hierarchical, centralized structures tend to respond slower but more accurately to the environment. Basically, on a number of dimensions, complex hierarchical structures appear more resilient and less dramatically affected by various “problems.” Teams or simple structures exhibit better performance, higher effectiveness, in the short run, or under good environmental conditions, etc., but suffer institutional senility as things go wrong. This finding is illustrated in Figure 1.

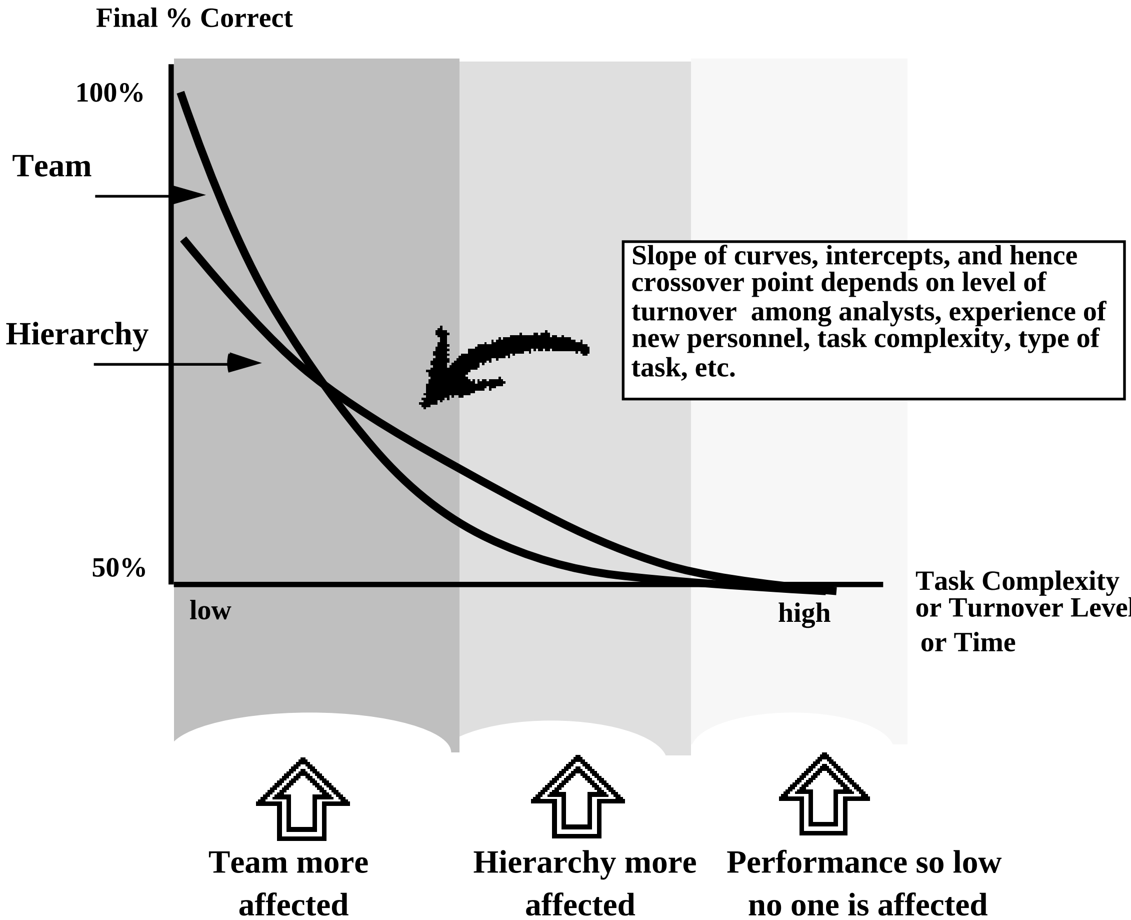

Figure 1. Stylized description of the relative performance of hierarchies and teams.

A variety of issues need to be addressed in this area. A particularly important issue here is linking together, and playing off against each other, different aspects of design such as the formal and informal structure of the organization. Such work, however, requires the development of theory and empirical results linking changes in one aspect of design to changes in another. A second issue is creating a more comprehensive approach to representing design. Currently, simply design taxonomies exist in the form of a limited set of stylized structures. However, if we are to link the results on such stylized structures to the behavior actual organizations it will be necessary to move beyond these simply taxonomies to a general understanding of the impact of design features. Here what is needed are a series of concrete measures of design that can consistently applied to actual organizations and can be easily incorporated into all models. Even as there is no one best design, there will be no one best measure (Lin, 1994). However, sets of measures have been and are being developed that can be used to capture various aspects of design. Many of these measures come out of work on networks. Such measures include Malone's measures of cost (1987); Krackhardt's (1994) measures of the graph properties of organizational structures, the various measures of centralization and power (Scott, 1991; Wasserman and Faust, 1994), and the various measures of hierarchy (Hummon, 1995).

Future progress on the impact of organizational design will benefit from an understanding of the link between organizational structure and organizational culture. Organizational culture and, indeed, culture in general is increasingly receiving attention in the literature (Ouchi and Wilkins, 1994). Part of this work stems from a view that culture is key to understanding the formation and maintenance of groups, and, within organizations, their productivity. A key computational piece in this area is that by Harrison and Carrol (1991) who examine cultural differences and their long term implications. Within computational organization theory more generally, culture is raising its head as researchers find that cognitive, structural, and task based constraints are not sufficient to explain organizational behavior. Rather, even with these factors specified there are still often multiple courses of action and multiple roles open to the agents in the organization. Culture, often in the form of setting individual agent "preferences" or "energy" comes into play as a critical determinant of action and role taking(Carley, Kjaer-Hansen, Prietula and Newell, 1992; Carley and Prietula, 1992, 1994; Cohen, March and Olsen, 1972; Masuch and LaPotin, 1989). Similarly, culture as distribution of knowledge or general action (Carley, 1991; Kaufer and Carley, 1993; Harrison and Carrol, 1991) also dictates the overall performance of the organization, its stability, and its ability to respond to the environment. Such factors also play a role in what and how the organization learns (Lant and Mezias, 1992).

2.2 Organizational Learning

A second area of research within the field of computational and mathematical organization theory is organizational learning, and the related phenomena of training, innovation, and diffusion. Even as there were many different characterizations of design in the literature so to are there many different characterizations of learning. For example, organizational learning has been characterizes as process change (Lant, 1994), as the development of rules and procedures (Lant, 1994), as the holistic result of individual adaptation (Macy, 1990), as search (Levinthal and March, 1981; Durfee and Montgomery 1991), as planning (Corkill, 1979), and as negotiation (Davis and Smith, 1983). Using these and other characterizations researchers have examined factors affecting the convergence of organizational and individual decisions (Lant and Mezias, 1992), entrepreneurship (Lant and Mezias, 1990), the impact of training on learning and performance (Alluisi, 1991); the impact of learning on group action (Macy, 1990), and cooperation among individuals (Glance and Huberman 1993, 1994b), the impact of learning and professionalism on diffusion and consensus formation (Kaufer and Carley, 1993).

Models of organizational learning are of two types. The first type are single actor models in which the agent learns an organizational task, or the organization as agent learns to respond to the environment. The second type are multi-actor models in which the organization is modeled as a collection of adaptive agents. Further, the models vary in the way in which learning as a process is modeled. The specific learning models examined include classical learning theory models (Macy, 1990,1991), detailed artificial intelligence models (Tsuchiya, 1993; Masuch, 1990), cognitive models employing one step learning or chunking (Carley et al, 1992; Carley and Prietula, 1994; Papageorgiou, 1992), connectionist models (Gibson and Plaut, 1995), and genetic algorithms (Holland and Miller, 1991; Grefenstette, 1991; Crowston, 1994).

This work suggests that individual learning and the organizational training procedures may be the basic building blocks for understanding how individual actions produce and reproduce group outcomes. Indeed various models demonstrate that characteristics of the environment critically determines what type of learning or search procedure the organization should employ. It also demonstrates the criticality of feedback to organizational performance. When agents in the organization receive clear feedback the organization's performance improves not only over what would happen by chance, but the over the average performance of the individuals. Further, research in this area demonstrates that, for organizations, learning quickly is advantageous if the feedback is clear, accurate, and unambiguous; if there is no turnover; and if the environment is stable. Otherwise, rapid learning can lead to "mislearning" or false conclusions that are difficult to "unlearn" and which can cause the organization to make erroneous decisions. Further there is an interaction between turnover and learning (and type of training). Specifically, when the task or environment is complex the organization is less affected by turnover at executive or managerial levels than at staff levels. Whereas, in simple task environs the opposite is true.

In addition to these more general findings there are a number of interesting specific findings centering around the benefits and costs of shared mental models. Within organizations, there is less sharing of mental models and hence less of a team mental model when tasks or information is segregated and agents are working on specialized tasks. Cohen, March, and Olsen found that such information segregation (and so dearth of shared mental models) resulted in most problems (50-65%) being solved by resolution. Carley (1990) argued that a cost of information desegregation is that it effectively increases the information processing load per person (unless more personnel are hired). A consequence is that individuals, and hence organizations, learn more slowly. In general, the relationship between segregation or the lack of a shared mental model and desegregation or the existence of a shared mental model and overall organizational performance is only beginning to be understood. For example, organizations in which job overlap or job sharing occurs (multiple individuals are performing the same task and seeing the exact same information) tend to exhibit lower performance than organizations with less complete overlap. Stated another way, a little redundancy in the organizational members' mental models is a good thing, but too much redundancy may actually decrease the organization's accuracy. This suggests that not only are completely shared mental models not necessary to organizational performance, but that performance may actually degrade in the face of such consensus. Additional work on this proposition and the construction of these individual and shared mental models is necessary.

Organizational learning is also intimately tied to the sharing or diffusion of information. As noted by Granovetter (1973; 1974), connections or ties among individuals determine what information is diffused and to whom. However, the strength of the ties among individuals may actually inhibit information diffusion. One reason for this is that in groups where the level of shared information is high, communication may tend to become ritualized and centered on repeating known information (Kaufer and Carley, 1993). In this case, the likelihood of new information diffusing can actually decrease as individuals within the organization work together and become more similar in what they know. Further, Burt (1992) suggests that individuals can learn to control their corporate environment, their own career within the organization, and the organization's ability to respond to event by controlling the pattern of ties within the organization. However, information technologies may influence the pattern of these ties (Freeman, 1984). Advances in the area of diffusion that are particularly relevant to organizations have been made by researchers using social network techniques. This work demonstrates that how integrated the individual is into the organization influence the likelihood that they will diffuse new information and adopt innovations (Burt, 1973, 1980; Kaufer and Carley, 1993).

There are two major issues in the computational and mathematical approach to organizational learning for which extensive research is needed. The first issue is linking models of individual learning to models of organizational learning. In part, this is a matter of linking cognitive models of agent behavior with structural and processual models of rule formation and role evolution. In part, this is a matter of coming to an agreement within the scientific community as to what is meant by the phrase organizational learning. And, in part, this is a matter of determining the extent to which individual learning, adaptation, or even intelligence is needed for effectiveness and adaptation at the organizational or market level (Gode and Sunder, 1993, 1994). The second issue concerns combining models of diffusion and learning with models of organizational structure. Few of the formal communication models used to think about diffusion simultaneously take into account the fact that multiple pieces of information or technology are simultaneously diffusing, that individuals are continuously learning about these multiple events and so their likelihood of adopting new information over time is continuously changing, that what information the individual has access to is affected by their position in the organization (both the formal and informal structure), and that this structure of relations is itself changing as information and technologies diffuse.

2.3 Organizations and Information Technology

Some might argue that one of the dominant forces for change in modern organizations is the addition of, or change in, information technology. Few formal models of organizations contain models of both the individuals in the organization and the information technology. There are two points here. First, many models of organizations as collections of agents models those agents as having capabilities beyond those which we know human beings to have. For example, such idealized agents may have perfect memories or they may not suffer stress effects when faced with time pressure. As such, one interpretation of these models is that the behavior they exhibit is the behavior of organizations of information technologies, or organizations of humans augmented by access to ideal information technologies. The second point is that there are now a few computational models that admit the possibility of studying the impact of new technologies, particularly information technologies.

This line of research follows from a long standing concern on the part of Organizational theorists have traditionally been concerned about the interplay among technology, communication, and organizational design (Thompson, 1962; Galbraith, 1977; Huber, 1990) particularly as it relates to organizational effectiveness. Computational and mathematical organizational theorists have taken these concerns and descriptions and converted them into models of information systems and technology within organizations (Bonini, 1963; Levitt et al, 1994; Mezias and Glynn, forthcoming). Such models can be used to do a “what if” analysis and so explore what happens if the technology breaks (Carley, 1991) or is altered (Levitt et al, 1994) or a new technology is introduced (Majchrzak and Finley, 1995). Using such “what if” studies, pre-intervention analyses can be done that have the potential to affect policy. In addition, information technology can be used to design organizations (Simon, 1973). Some of the best of these tools incorporate knowledge about organizations in terms of scientific findings (Baligh, Burton and Obel 1990, 1994) or best practices (Majchrzak and Gasser, 1992a; Gasser and Majchrzak, 1992; Zweben and Fox, 1994) into tools for thinking through the re-engineering of organizations. And, importantly, computational models of organizations can be used to evaluate and improve the design of information systems (Kumar, Ow and Prietula, 1993).

One of the issues here is how should information or tasks be distributed. Petri nets, for example, can be used to do task assignment for discreet event tasks (Levis, Moray, and Baosheng, 1994). However, much of the work in this area has focused on resource allocation and scheduling (Arrow and Radner, 1979; Zhou and Kleinman, 1993; Zweben and Fox, 1994). The work on scheduling has led to computational systems which are used in actual organizations to distribute tasks.

Another issue is how should information technologies be represented. One approach is to represent the technology as a bundle of characteristics. For example, email is asynchronous, fast, increases reach, etc. This is the approach taken in the Virtual Design Team (Cohen, 1992; Levitt et al, 1994). This approach allows the researcher to determine how particular bundles of characteristics affect the flow of information along extant communication channels and so the organization’s performance. An alternative approach is to represent the information technology as an artifical agent. In this case agents vary from each other in their information processing capabilities. For example, a book as an agent cannot choose its communication partners, its message remains fixed over time, it cannot learn, but it can be (through reproduction) involved in multiple simultaneous interactions. This is the approach taken by Kaufer and Carley (1993). This approach allows the researcher to determine how the information technologies affect the flow of information along extant communication channels and how the channels themselves change as new artificial agents are added to the communication networks (Carley, forthcoming). This latter point is particularly important when one is using network techniques for evaluating the results.

2.4 Organizational Evolution and Change

Within organization theory more generally there is a growing emphasis on change. Computational techniques make it feasible to examine organizations and groups in flux. Using these techniques the researcher can minutely scrutinize the processes by which individuals and organizations adapt, learn, react, respond, and evolve. Within the computational and mathematical arena there is a growing interest in organizational dynamics, organizational evolution, change, shifts, and so forth. Such analyses focus on the processes and impacts of shifts or changes in organizational designs and the evolution and alteration of organizations. Such changes in organizational design may occur through a variety of processes including evolutionary processes (Crowston, 1994; Hannan and Freeman, 1977), mimicry (DiMaggio and Powell, 1983), conscious re-engineering (Baligh, Burton and Obel, 1987; Gasser et al 1993), reactionary processes in response to the environmental events such as crises (Carley 1991), internal processual or demographic changes (Hanneman, Collins, and Mordit, 1992; Hanneman 1988), and learning processes (Lant and Mezias, 1990). Such studies have demonstrated that what evolves depend on the environment. Moreover, numerous studies using a variety of different models of adaptation show that hierarchies and cliques tend to emerge.

Computational and mathematical models are particularly suited for the study of organizational evolution and change (Cohen, 1986). These approaches allow the researcher to think through the impacts of complex strategies and locate unanticipated effects (Gode and Sunder, 1993), to focus on the processes by which organizations are designed and redesigned (Cohen, 1986), and to explore the impact of process on specific tasks (see for example Crecine's 1969 work on budgeting). This work brings to the fore a concern with how can organizational performance be assessed when organizations are continually being designed and redesigned or are evolving or naturally changing.

Using more dynamic models recent work is moving beyond strict structural design issues to looking at how design dynamics influence performance. Strategies for cooperating (Cammerata, McArthur and Steeb, 1983; Glance and Huberman, 1993), processes for achieving coordination when agents are distributed across multiple sights (Decker and Lesser, 1993; Durfee, 1988), planning processes (Corkill, 1979;Decker and Lesser, 1992), and procedures for general problem solving (Davis and Smith, 1983; Gasser and Toru, 1991) are all being examined. Issues that are important to which dynamic structural models need to be applied include the impact of organizational design and redesign on shared cognition, the development of individual mental models, and job distribution and redistribution in changing technological climates.

Additionally, this area is replete with methodological issues. For example, how should organizations be represented so that its evolution and redesign can be studied. Another methodological issue centers around determining whether the resultant organizational design is statistically different than the initial design. This is an issue with which researchers in the area of social networks have been wrestling (Wasserman, 1980; Doreian 1990; Snijders, 1990).

3 Summary

The area of computational and mathematical organization theory is a growing area within organizational science. Historically, much of the research has been focused in the area of organizational design. This work has looked at design both in terms of locating the optimal decision structure and in terms of the relative advantages of different designs. Work in this area has proceeded using both mathematical and computational models. Among the challenges in this area are locating common or shared formalisms across all the disciplines that approach this question, relating task features to organizational features, and relating issues of design to issues of culture.

Formal approaches are particularly valuable for examining organizational learning, the role of information technology, and organizational evolution. A variety of challenges raise their head. In organizational learning, one major challenge is to link models of individual learning to models of organizational learning and thereby see how they inform each other. In information technology a challenge is to develop and theory of and representation of information technology and the associated tasks faced by humans and computers. In terms of organizational evolution and change there are a number of methodological and theoretical questions that need to be understood. Two such questions that are particularly important is how do networks evolve and how can we tell statistically if the evolved form is different than the initial form.

Clearly there are other issues that researchers in this area will need to address. Advances may require developing a greater commonalty in the scheme for representing organizations used by researchers in the myriad of fields where scientists address questions of organizational performance. Further, advances will almost assuredly require the formal theoretician to address how the micro actions of the collection of intelligent adaptive agents in the organization result in macro organizational response. Such an answer will require delineating processes of aggregations, generative functions for emergent behavior, and so forth. And finally, advances in this area are likely to come from combining sophisticated models of cognition for modeling agents with information processing based models of tasks with social network models of organizational design.

Computational and mathematical organization theory has the potential to move theories of organizations beyond empirical description to generative formalizations. By focusing on process, agent adaptation, task, and change the research in this area can potentially provide a more dynamic and coherent view of the organization as an embedded, complex, adaptive systems. In doing so, the models will necessarily increase in their complexity and veridicality. Cumulative progress in this field will require additional research on how to represent, present, and analyze such models.

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