COMPUTATIONAL ORGANIZATION THEORY: A NEW PERSPECTIVE

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Introduction

The discipline of Computational Organization Theory (COT) focuses on theorizing about, describing, understanding, and predicting the behavior of organizations and the process of organizing using formal approaches (computational, mathematical and logical models). This research includes the development, testing and analysis of computational models, and the development and testing of computational techniques particularly suited to organizational analysis. These computational abstractions are incorporated into organizational practice through tools, procedures, measures and knowledge.

The notion of organizations as conceived in this burgeoning field spans groups, teams, societies, corporations, industries, and governments (see for example Carley and Prietula, 1994; Prietula, Carley and Gasser, 1998; Gilbert and Doran, 1994). The two generic types of organizations considered are the human and the artificial. Human organizations continually acquire, manipulate, and produce information (and possibly other material goods) through the joint, interlocked activities of people and agents and information technologies. Artificial organizations are comprised of multiple distributed artificial agents (such as webbots, robots, or simulated avatars) which exhibit collective organizational properties (such as the need to act collectively, an assignment of tasks, the distribution of knowledge and ability across agents, and constraints on the connections and communication among agents). Researchers use computational analysis to develop a better understanding of fundamental principles for organizing multiple adaptive information processing agents and of the nature of organizations as computational and adaptive entities. Research in this area provides insight into the design of computational and human systems.

The field of COT has witnessed four decades of research. One of the earliest works is Cyert and March's (1963) "The Behavioral Theory of the Firm" in which a simple information processing model of an organization is used to address issues of design and performance. During the past decade an explosion of interest has occurred in the use of computational, mathematical and logical models (formalization techniques) for theory development and testing in the organizational and social sciences (Carley, 1995). The role of formal techniques in general, and computational analysis in particular, in the development of organizational and social theory is expanding for a number of reasons. There is growing recognition that social and organizational processes are complex, dynamic, adaptive, and non-linear, that organizational and social behavior emerges from interactions within and between ecologies of entities (people, groups, technologies, agents, etc.), and that relationships among these entities are critical constraints on individual and organizational action. Researchers have recognized that organizations are inherently computational since they have a need to scan and observe their environment, store facts and programs, communicate among members and with their environment, and transform information by human or automated decision making (Burton and Obel 1996).

COT has a fundamentally interdisciplinary intellectual history with contributions from social network theory, distributed artificial intelligence and the organizational information processing tradition. Within COT, researchers draw heavily on work in the information/resource processing tradition (Simon, 1947; March and Simon, 1958; Thompson, 1967; Galbraith, 1973; Cyert and March, 1963; Pfeffer and Salancik, 1978) and social information processing (Salancik and Pfeffer, 1978), as modified by recent work in cognitive science (Carley and Newell, 1994), institutionalism (Powell and DiMaggio, 1991), population ecology (Hannan and Freeman, 1977; 1989), and the contemporary contingency theory (Baligh, Burton and Obel, 1990). Within social network and communication/coordination theory, there has been important work done on measures of organizational design and communication (Wasserman and Faust, 1994; Malone 1986), cognitive social structures (Krackhardt, 1987), network effects on performance, influence and power (Wasserman and Galaskiewicz, 1994; Kaufer and Carley, 1993; Granovetter, 1985; Burt, 1992), and research on inter-organizational networks (Baum and Oliver, 1991; Stuart and Podolny, 1996). Within the area of distributed artificial intelligence researchers draw on findings regarding representation, (Durfee, Lesser and Corkill, 1987; Lesser and Corkill, 1988), teams (Decker, 1995; 1996), coordination (Durfee and Montgomery, 1991), and strategy (Gasser and Majchrzak, 1994).

Computational organizational theorists subscribe to a neo-information processing view of organizational behavior. The basic principles of this perspective are as follows.

Bounded rationality: Organizational agents are boundedly rational both in terms of capabilities and knowledge. Capabilities depend on agents' cognitive, computational and/or physical architecture. Knowledge depends on agents' ability to learn and their intellectual history. An agents position in an organization influences what information is accessible and what knowledge is available. Thus, an agent's knowledge of how to do specific tasks, of how its specific organization operates, and indeed of how organizations operate in general, is a function of what positions the agent has held. The neo-information view goes beyond the traditional boundedly rational argument by explicating the precise nature of the bounds and the mechanisms underlying the dissemination, acquisition, storage, and processing of information. The greater the precision in specifying the bounds on the agent (such as through a model of cognition and a model of the organization's structure) and the relevant mechanisms, the greater the predictive ability of the model and the broader the range of possible predictions.

Information ubiquity: Large quantities of information in many different forms are widely distributed across multiple agents within and among organizations. The information may not necessarily be correct, timely, relevant or accurate, but it is ubiquitous. The ubiquity of information means that with respect to performance the issue is not the presence of information but the distribution of information.

Task orientation: Organizations and the agents within them are continually engaged in performing tasks which require communicating, analyzing, adapting or otherwise processing organizational information using various technologies and to search out new information and new solutions. These tasks may change frequently. These tasks specify a set of goals; however the goals may not be articulable. Also, these tasks may not be the tasks that the organization's management thinks are being done.

Distributional constraints: Organizational performance is a function of what information is shared by whom and when and of the process of searching for and combining that information. An organization's culture is the distribution of the knowledge and processes across the agents within the organization. This distribution affects the extent and character of socially shared cognition, team mental models, group information processing, and concurrent information analysis.

Uncertainty: Uncertainty about task outcomes, environmental conditions, and about many other aspects of organizational life influences organizational activity. Distributed computational models such as distributed search or distributed constraint satisfaction make the distribution of information itself a source of uncertainty: different distributions can cause critical uncertainty-reducing information to be unavailable because of the associated search, communication, processing or coordination costs.

Organizational intelligence: Organizational intelligence resides in the distribution of knowledge and procedures within and among agents and in the linkages among agents. Organizations redesign themselves and their vision of their environments so that they can better search for and process information on the basis of the available information. Such redesign is part of organizational learning and adaptation processes. Redesign can alter an organization's intelligence but may or may not improve organizational performance.

Irrevocable change (path dependence): As agents and organizations learn, their intelligence is irrevocably restructured. This evolution means that the order in which things are learned and what is learned — the particular history — can have dramatic consequences both for the form of the organization and for its performance.

Necessity of communication: In order to function as a corporate unit, agents within an organization need to communicate. Agents can explicitly communicate by sending and receiving messages or implicitly by perceiving the actions of others. Both formal and informal communication affect the flow of information and, therefore, the organization's culture, intelligence, and performance.

Modeling

The drawing or use of a map, assembling a piece of furniture from written instructions, or playing a musical instrument requires creating and using models. What do these activities have in common? They all use one thing to represent another: the map represents geography, the assembly instructions represent the relations of mechanical parts to one another, and musical notation represents sounds of specified pitch and duration. The map, the instructions, and the music are models (Waisel, Wallace and

Willemain, 1998). In addition to being an everyday activity, modeling is the *sine qua non* of science: virtually all scientific activities require some form of modeling, since a scientific theory is a kind of representational system (Nersessian, 1992).

Models are both integral and integrating components of theory building in COT. No matter what their disciplinary home, researchers in this area assume that meaningful and predictive models of organizations can be built. Computational organizational theorists use formal models to (1) describe organizational phenomena observed in the world, structure real or hypothetical experiences as described or postulated by individuals or group, and (2) formalize and integrated theoretical principles from science that are relevant to coordinated activity.

Methodological Approaches

Advances in Computational Organization Theory have been made by employing a variety of methodologies. To illustrate this variety, five of the most significant approaches to theory building will be discussed: (1) general intellective simulation models, (2) distributed artificial intelligence and multi-agent models, (3) organizational engineering models, (4) social network models, and 5) mathematical and/or logic based models.

Organizational theorists are most familiar with the general intellective simulation models. These models often represent the organization or various processes as a set of non-linear equations and/or a set of interacting agents. In these models the focus is on explaining and theorizing about a particular aspect of organizational behavior. Consequently the models often abstract many of the factors in actual organizations, laying bare only the entities and relations essential to the theory. Models embody theory about how the team, group, or organization will behave. Given these models a series of virtual experiments are run to test the effect of a change in a particular process, action, policy, etc. These models are used to illustrate the theory's story about how the organization will behave under various conditions. These models enable cumulative theory building as multiple researchers re-build, augment, and develop variations of earlier models.

Many researchers are building organizational models using multi-agent techniques. Multi-agent techniques have grown out of the work in distributed artificial intelligence. Distributed artificial intelligence intended to perform highly specific but stylized tasks such as soccer, navigation or surveillance (Bond and Gasser, 1988; Gasser and Huhns 1989; Cohen, 1986). A strength of this approach is the focus on representation and knowledge. For example attention is often focused on how to represent the task and knowledge about how to do the task via the agent. Another strength of this approach is a focus on decision making as search. Models are often developed to address issues of communication, coordination, planning, or problem solving, often with the intent of using these models as the "brains" in artificial agents. These models can explain many organizational phenomena and test the adequacy and efficiency of various definitions or representation schemes. Today, much of this work goes under the rubric of multi-agent modeling. Work in this area is beginning to focus on the role of emotions, the development of team mental models, and coordination of large numbers of agents. From an organizational theory perspective two issues stand out. First, how scaleable are these models and representation schemes? That is, do the results from systems of two to five agents performing a highly stylized task generalize to larger more complex organizations? Second, when are these cognitively simple agents adequate or valid representations of human behavior?

Organizational engineering models, often referred to as emulation models, are characterized by the extensive detail with which they represent the formal sides of organizations or tasks (organizational chart, workflow, communication paths, and re-work routines) and the attention to the specific features of particular organization. These models generally focus on predicting overall organizational or group response rather than the actions and behaviors of individual agents. These models are sufficiently detailed that they can be used to analyze potential policy changes and address "what-if", questions for the particular organization for which the model has been tuned (see, for example, Levitt, et al 1994, and Gasser and Majchrzak, 1994). Model adequacy is often demonstrated by determining whether the parameters can be adjusted so that one or more important team or organizational behaviors is described at least at a qualitative level. Importantly, simply having managers work with the research team to elicit the data on the organization needed to model it often leads the manager to gain important insights into organizational problems. As such, these models are a valuable decision aid. The same is true of system models.

Social network models are characterized by representations of teams, groups, organizations and markets in terms of the relationships among individuals or organizations. These models emphasize the structural or relational aspect of the organization and demonstrate when and how they can affect individual or organizational behaviors. Current work in this field is focusing on developing models of network adaptation, evolution and change and on developing a better understanding of how agent knowledge affects and is affected by an agent's position in the network. Network models have successfully been used to examine issues such as power and performance, information diffusion, innovation, and turnover. The adequacy of these models is determined using techniques from non-parametric statistics.

Logic models are characterized by representations of organizations and organizational processes using the techniques and formalisms of formal logic. Such models enable researchers to focus on the generative aspects of organizational form given a specific grammar (see Leblebici 1998) and to test the consistency of extant verbal theories. These models tend to be among the most limited in their realism and the least likely to capture dynamic aspects of organizational behavior. However, these models are the only ones from which complete proofs and an exhaustive understanding of behavior can be generated. These models provide, independent of a specific machine implementation, a way of assessing the internal validity of extant theories and generating proofs about organizing behavior.

This brief review of these methodological approaches just begins to describe the vast array of modeling techniques and tools that have been used to examine organizations. These and other approaches address a variety of questions about organizations ranging from questions of design, to questions of learning, to questions of culture. As work continues in this field researchers are beginning to employ models which contain intellective and emulative elements. These models, for example, draw on the work in cognitive science and contribute to the work on multi-agent systems, use network representations and measures, and use logic in developing formalizations.

Application Areas

Computational organizational theorists often address issues of organizational design, organizational learning, and organizational adaptation. Consider the design question. Organizations, through their design, are expected to be able to overcome the cognitive, physical, temporal, and institutional limitations of individual agency. Research has shown that there is no single organizational design that yields the optimal performance under all conditions yet it has shown that for a particular task and under particular conditions, there is a set of optimal designs. Organizational performance itself is dynamic, even under the same design (Cohen, 1986). Thus, the determination of which organizational design is best depends on a plethora of factors which interact in complex non-linear ways to effect performance. Such factors include the task(s) being performed; intelligence, cognitive capabilities, skills, or training; available resources; quality and quantity of information; volatility of the environment; legal or political constraints on organizational design; the type of outcome desired (e.g., efficiency, effectiveness, accuracy, or minimal costs). The organization's design is considered to be capable of being intentionally changed in order to improve it's performance. Consequently, computational models focused on design should be an invaluable decision aid to managers who are interested in comparing and contrasting different types of organizations. Researchers are thus providing guidelines for when to use which design, and developing computational tools for enabling managers to do "just-in-time" design.

Organizational learning, adaptation and change is one of the areas where computational modeling holds forth the most promise. One reason for this is that computational techniques are ideally suited to the study of dynamical systems. Another reason is that within organizations multiple types of learning appear to co-exist and interact in complex ways. Organizational learning has been characterized in terms of the search for knowledge (Levinthal and March, 1981), constraint based optimization (Carley and Svoboda, 1996), and aggregation of individual learning (Carley, 1992). In organizational learning, one major challenge is to link multiple models of organizational learning together and to see how they inform each other. We need to understand how organizational networks evolve and how we can characterize an evolved organizational design as being statistically different from an initial design. Such issues of measurement are subjects of ongoing research.

The Future

Past research in Computational Organization Theory has focused on representations of natural or human organizations. This focus is changing gradually. Researchers are beginning to use mathematical and computational methods to study organizations which are composed of humans, artificial agents, or combinations of both human and artificial agents. There are several reasons for this change. Human organizations, and multi-agent systems in general, often show an intelligence and a set of capabilities that are distinct from the intelligence and capabilities of the agents within them. Multi-agent systems can exhibit organization, intentional adaptation, and can display non-random and repeated patterns and processes of action, communication, knowledge, and memory regardless of whether or not the agents are human. By improving our understanding of the behavior of artificial worlds in general, researchers will discover whether there are general principles of organizing that transcend the type of agent in the organization. Artificial or virtual organizations are appearing and being used to do certain tasks, such as scheduling, robotic control, and so on. One of the issues is how to structure interagent coordination and communications. Should organizations of humans and artificial agents be designed in the same way? Do artificial agents need to communicate the same type of information as do humans to be effective? Modeling the interactivity of humans and artificial agents should enable us to answer these questions.

It is expected that the development of reasonable computational models of technology may be one of the areas of highest payoff areas for management. To date, there have been some forays into trying to use computational models to understand the impact of technology on organizations (see, for example, Mezias and Glynn, forthcoming). One of the difficulties is that models adequate for expressing the potential impact of technology may well need to deal with learning, as organizational learning and search affect the organization's technological competence (Stuart and Podolny, 1996). The challenge for COT is to develop a theory of information technology and the associated tasks faced by humans and computers. One approach is to model the technologies ability to support different modes of interaction (Kaplan and Carley, 1998). Another approach is to model the technologies as artificial agents (Kaufer and Carley, 1993).

Advances may require researchers to develop a common way of representing organizations. Advancement of COT will almost assuredly require the formal theoretician to address how the micro actions of a collection of intelligent adaptive agents result in macro organizational response at both the intra- and inter- organizational level. Answering this question will require delineating processes of aggregation, generative functions for emergent behavior, and so forth. Advances in this area are likely to come from combining sophisticated models of cognition at the agent level with information processing based models of tasks and technology and with social network models of organizational design that relate agents, tasks, and resources.

COT will move theories of organizations beyond empirical description to predictive modeling. By focusing on the components (such as agent, structure, task, and resources), the networks of connections among these components (such as the communication structure or the resource access structure), and the processes by which they are altered (such as routines, learning, adaptation), a more dynamic and coherent view of the organization as an embedded, complex, adaptive system of human and automated agents with greater predictive ability will emerge (Carley and Prietula, 1994). Attending to these factors will necessarily increase the complexity and veridicality of the models, as well as increasing the difficulty in building and validating the models. However, the resulting models will be capable of addressing the concerns of both the theoretician and the practitioner, and yield greater predictive ability and practical guidance. COT thus has the potential to generate a better theoretical understanding of organizations, better tools for designing and re-engineering organizations in real-time, and better tools for teaching people how teams, groups, and organizations function.

References:

[1] Baligh, H.H., R.M.Burton and B.Obel (1990), "Devising Expert Systems in Organization Theory: The Organizational Consultant," In M. Masuch, ed., *Organization, Management, and Expert Systems*, Walter De Gruyer, Berlin.

[2] Baum, J. and C. Oliver, (1991) "Institutional Linkages and Organizational Mortality," *Administrative Science Quarterly,* 36(2), 187-218.

[3] Bond, A. and L. Gasser, eds. (1988), *Readings in Distributed Artificial Intelligence,* Kaufmann, San Mateo, California.

[4] Burt, R. (1992), *Structural Holes: The Social Structure of Competition*, Harvard University Press, Cambridge, Massachusetts..

[5] Burton, R.M. and B. Obel (1996), *Encylopedia of Operations Research and Management Science*, S.I. Gass and C.M. Harris, eds., Kluwer Academic Publishers, Norwich, Massachusetts.

[6] Carley, K.M. (1992), "Organizational Learning and Personnel Turnover," *Organization Science*, 3(1) 20-46.

[7] Carley, K. M. & D.M. Svoboda (1996), "Modeling Organizational Adaptation as a Simulated Annealing Process," *Sociological Methods and Research*, 25(1) 138-168.

[8] Carley, K.M. & L. Gasser (forthcoming), "Computational Organization Theory" in Gerhard Weiss ed., *Distributed Artificial Intelligence*. MIT Press, Cambridge, Massachusetts.

[9] Carley, K.M. & M.J. Prietula eds.(1994), *Computational Organization Theory,* Lawrence Erlbaum Associates, Hillsdale, New Jersey.

[10] Carley, K.M. & A. Newell (1994), The Nature of the Social Agent. *Journal of Mathematical Sociology* . 19(4), 221-262.

[11] Carley, K.M. and M.J. Prietula (1994), "ACTS Theory: Extending the Model of Bounded Rationality," in K. M. Carley and M. J. Prietula eds., *Computational Organization Theory*, Lawrence Erlbaum Associates, Hillsdale, New Jersey.

[12] Carley, K.M. (1995), "Computational and Mathematical Organization Theory: Perspective and Directions," *Computational and Mathematical Organization Theory,* 1(1), 39-56.

[13] Cohen, M.D. (1986), "Artificial Intelligence and the Dynamic Performance of Organizational Designs," on J.G. March and R. Weissinger-Baylon eds., *Ambiguity and Command: Organizational Perspectives on Military Decision Making,* Pitman, Marshfield, Massachusetts.

[14] Cyert, R. and J.G. March (1963), *A Behavioral Theory of the Firm,* Prentice-Hall, Englewood Cliffs, New Jersey.

[15] Decker, K. (1995), "A Framework for Modeling Task Environment," *Environment-Centered Analysis and Design of Coordination Mechanisms.* Ph.D. Dissertation, University of Massachusetts.

[16] Decker, K. (1996), "TAEMS: "A Framework for Environment Centered Analysis and Design of Coordination Mechanisms." In G.M.P. O'Hare and N.R. Jennings, eds., *Foundations of Distributed Artificial Intelligence*, John Wiley and Sons, New York.

[17] Durfee, E.H. and T.A. Montgomery (1991), "Coordination as Distributed Search in a Hierarchical Behavior Space," *IEEE Transactions on Systems, Man, and Cybernetics,* 21(6) , 1363-1378.

[18] Galbraith, J. (1973), *Designing Complex Organizations.* Addison-Wesley, Reading, Massachusetts.

[19] Gasser, L. and A. Majchrzak (1994), "ACTION Integrates Manufacturing Strategy, Design, and Planning," in P. Kidd and W. Karwowski, eds., *Ergonomics of Hybrid Automated Systems IV*, IOS Press, Netherlands.

[20] Gasser, L. and M.N. Huhns, eds. (1989), *Distributed Artificial Intelligence.* Vol. 2, Morgan Kaufmann, New York.

[21] Gilbert, N. and J. Doran, eds. (1994), *Simulating Societies: The Computer Simulation of Social Phenomena,* UCL Press, London.

[22] Granovetter, M. (1985), "Economic Action and Social Structure: The Problem of Embeddedness," *American Journal of Sociology*, 91, 481-510.

[23] Hannan, M.T. and J. Freeman (1989), *Organizational Ecology*, Harvard University Press, Cambridge, Massachusetts.

[24] Hannan, M.T. and J. (1977), "The Population Ecology of Organizations." *American Journal of Sociology,* 82, 929-64.

[25] Holland, J.H. (1975), *Adaptation in Natural and Artificial Systems,* University of Michigan Press, Ann Arbor, Michigan.

[26] Kaplan, D. J. and K.M. Carley (1998), "An Approach to Modeling Communication Technology in Organizations." In M. Prietula, K. Carley and L. Gasser eds., *Simulating Organizations: Computational Models of Institutions and Groups*, AAAI Press/The MIT Press, Boston, Massachusetts.

[27] Kaufer, D.S. and K.M. Carley (1993), *Communication at a Distance: The Effect of Print on Socio-Cultural Organization and Change,* Lawrence Erlbaum Associates, Hillsdale, New Jersey.

[28] Krackhardt, D. (1987), "Cognitive Social Structures", *Social Networks*, 9, 109-134.

[29] Lesser, V.R., Durfee. E.D. and D. D.Corkill (1987), "Coherent Cooperations Among Communicating Problem Solvers", *IEEE Transactions on Computers,* C-36 1275-1291.

[30] Lesser, D.D. and D.D. Corkill (1988), "Functionally Accurate, Cooperative Distributed Systems", In A. H. Bond and L.Gasser, eds., *Readings in Distributed Artificial Intelligence*, Morgan Kaufmann, Inc., San Mateo, California.

[31] Levinthal, D. and J.G. March (1981), "A Model of Adaptive Organizational Search," *Journal of Economic Behavior and Organization,* 2, 307-333.

[32] Levitt, R.E., Cohen, G.P. , Kunz, J.C. Nass, C.I., Christiansen, T. and Y. Jin (1994), "The 'Virtual Design' Team: Simulating How Organization Structure and Information Processing Tools Affect Team Performance," In K.M. Carley and M.J. Prietula, eds., *Computational Organization Theory*, Lawrence Erlbaum Associates, Hillsdale, New Jersey.

[33] Malone, T.W. (1986), "Modeling Coordination in Organizations and Markets," *Management Science*, 33, 1317-1332.

[34] March, J. and H. Simon (1958), *Organizations*. Wiley, New York.

[35] Masuch, M. and P. LaPotin (1989), "Beyond Garbage Cans: An AI Model of Organizational Choice," *Administrative Science Quarterly*, 34, 38-67.

[36] Masuch, M. (1990) *Organization, Management and Expert Systems: Models of Automated Reasoning*, Walter de Gruyter, Berlin, New York.

[37] Mezias, S.J. and M.A. Glynn (forthcoming), "Using Computer Simulation to Understand the Management of Technology: Applications for Theory Development," *Technology Studies*.

[38] Nersessian, N.J., (1992) "How do Scientists Think? Capturing the Dynamics of Conceptual Change in Science", In R.N. Giere, ed., *Cognitive Models of Science*, Vol. XV, Minnesota Press, Minneapolis, Minnesota.

[39] Pfeffer, J. and G.R. Salancik, (1978), *The External Control of Organizations : a Resource Dependence Perspective*, Harper and Row, New York.

[40] Powell, W.W. and P.J. DiMaggio (1991), *The New Institutionalism in Organizational Analysis*, The University of Chicago Press, Chicago, Illinois.

[41] Prietula, M.J., Carley, K.M. and L. Gasser, eds., (1998), *Simulating Organizations: Computational Models of Institutions and Groups*," AAAI Press / The MIT Press, Menlo Park, Califronia.

[42] Salanick, G.R. and H. Leblebici (1998), "Variety and Form in Organizing Transactions: A Generative Grammar of Organization", *Research in the Sociology of Organizations*, 6:1-31.

[43] Simon, H. A. (1947). *Administrative Behavior*, Free Press, New York.

[44] Stuart, T.E. and J.M. Podolny (1996) "Local Search and the Evolution of Technological Capabilities" *Strategic Management Journal*, 17, 21-38.

[45] Thompson, J.D. (1967), *Organizations in Action*. McGraw-Hill, New York.

[46] Waisel, L., Wallace, W.A. and T. Willemain (1998), "Using Diagrammatic Reasoning in Mathematical Modeling: The Sketches of Expert Modelers," *Proceedings of the AAAI 1997 Fall Symposium on Reasoning with Diagrammatic Representations II*, AAAI Press, Menlo Park, California.

[47] Wasserman, S. and K., Faust (1994), *Social Network Analysis: Methods and Applications,* Cambridge University Press, New York, New York.

[48] Wasserman, S. and J. Galaskiewicz, eds. (1994), *Advances in Social Network Analysis: Research in the Social and Behavioral Sciences,* Sage, Thousand Oaks, California.