# Computational Organization Theory

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# INTRODUCTION

As inexpensive and massive amounts of computing power have rapidly become more widely available, the operational aspects of computational-based organizational research has recently become a reality. Today, the concepts of Computational Organization Theory (COT) can be easily implemented and practiced by an ever-increasingly larger group of researchers. Some foresee such computer-science related "computational thinking" (Wing, 2006) as the future of all scholarly research, and COT is part of this broader trend.

COT invovles the theorizing about, describing, understanding, and predicting the behavior of organizations and the process of organizing, using quantitative-based and structured approaches (computational, mathematical and logical models). This invovles computational abstractions that are incorporated into organizational reserach and practice through COT tools, procedures, measures and knowledge.

The notion of an organization, as used here, spans the wide range of human-conceived collections of people, i.e., groups, teams, societies, corporations, industries, and governments (e.g., see *Carley and Prietula, 1994*; Prietula, Carley and Gasser, 1998; *Gilbert and Doran, 1994*). COT practitioners use computational models and analysis to develop a better understanding of fundamental principles for organizing and behaviors within an organization. Organizational members, i.e., people, are considered information-processing actors. They can interact with and adapt to their environment. They can learn, and they can communicate. While their behavior is certainly complex, this behavior and the underlying determinate of the behaviors can be reduced to basic mathematical equations and algorithms. With this formalization, researchers can develop complete computerized models of an organization which enables the use of computer simulation to create virtual worlds for non-obtrusive experimentation. After running these simulations the collective outcome of these virtual interactions and behaviors can be quantified and collected for extensive analysis. Typically, the results from these experiments are then incorporated into a formalized and thoughtful comparison against findings from controlled lab experiments and real-world empirical cases studies. The history of COT is rich with academic insight and current activity is proving fruitful to organization researchers and practitioners, alike; its future appears very bright.

# HISTORY

The field of COT has benefitted from several 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 organization design and performance. During the past decade an explosion of interest has occurred for theory development and testing in the organizational and social sciences (*Carley, 1995*). The use is expanding for a number of reasons: (a) there is growing recognition that social and organizational processes are complex, dynamic, adaptive, and nonlinear, and thus are hard to study in the real-world (b) researchers and practitioners have come to realize that organizational and social behavior emerges from interactions within and between ecologies of entities (people, groups, technologies, agents, etc.), which is hard to reproduce and control in the laboratory and real-world, and (c) we have come understand that the relationships among these entities are critical constraints on individual and organizational action, which is hard to control with direct human-based research. Researchers now recognize 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*).

# CURRENT STATE-OF-THE-ART

COT models extend from simple intellective principles of general decision-making behavior (Cohen et al., 1972; Carley, 1992) to representations of the decision processes and information flow within specific real-world organizations (Levitt et al., 1994; Zweben and Fox, 1994). Models may even operationalize specific management-decisions, -practices and -polices (Gasser and Majchrzak, 1992, 1994; Majchrzak and Gasser, 1991, 1992). These COT models enable the researcher to examine the potential impact of general management strategies (Gasser and Majchrzak, 1994; Carley and Svoboda, 1996), or enable the manager to examine the organizational implications of specific management decisions (Levitt et al., 1994).

Several multipurpose computational-models of organization have been developed including well-known models such as the Garbage Can Model, Plural-Soar, Team-Soar, DYCORP, and ORGAHEAD. In a review of the state of computational modeling (Ashworth and Carley, 2004, 2007), 29 specific organization theory computer simulations were found to have been introduced between 1989 and 2003; the authors also made a point that the richness of the models has also increased over those years. More recently, the CONSTRUCT model has been used extensively for theory generation and testing--notably in realms looking at the impact of communications occurring through diverse media. CONSTRUCT provides a vigorous model of organization that has its roots in symbolic interactionism (Blumer, 1969), structural interactionism (Stryker, 1980), and structural differentiation theory (Blau, 1970). These core-theories are combined into a computational theory called constructuralism (Carley, 1991) which is embodied in the CONSTRUCT model. The model recognizes that people interact within a dynamic social-based organizational network and are characteristically information-seeking agents. They interact to exchange information and purposefully may seek out others who have information that they do not yet hold. They are also being sought out by others seeking their information, or knowledge. This interaction dynamic is played out innumerable times in any organization. When this dynamic is coupled with the organization-membership changes (hiring and firing) in an organization, this emerging micro-interaction dynamic is manifested in complex organization-level dynamics and outcomes.

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 nonlinear 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 its 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 COT continues to provide invaluable knowledge and understandable promise. In most 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 within the field fo COT.

# THE FUTURE

The focus of COT is evolving. Past research has focused on representations of natural or human organizations. Increasingly, researchers using COT methods to study organizations which are also composed of artificial agents, or combinations of both human and artificial agents. Human organizations, and artificial systems in general, often show an intelligence and a set of capabilities that are distinct from the intelligence and capabilities of the membership within them. These 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 may 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 inter-agent 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.

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 reengineering organizations in real-time, and better tools for teaching people how teams, groups, and organizations function.

See **Organization, Organizational Behavior, Models, Complex Behavior.**

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