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Organizations as complex adaptive systems: Implications of Complexity Theory for leadership research

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Abstract

This article contrasts the assumptions of General Systems Theory, the framework for much prior leadership research, with those of Complexity Theory, to further develop the latter's implications for the definition of leadership and the leadership process. We propose that leadership in a Complex Adaptive System (CAS) may affect the organization indirectly, through the mediating variables of organizational identity and social movements. A rudimentary model of leadership in a CAS is presented. We then outline two non-linear methodologies, dynamic systems simulation and artificial neural networks, as appropriate to enable development and testing of a model leadership under the assumptions of Complexity Theory.

Keywords: Organizational leadership; Complexity Theory; Dynamic systems simulation models; Artificial neural networks; Organizational identity

While many organizational issues linger from the previous century—most notably, how to prevent managerialism (Berle & Means, 1968), i.e., the manipulation of corporations by management—many issues have changed. Indeed, the very notion of organization has evolved, from a bureaucracy with clear boundaries and internal areas of authority to a new form, which has fluid and flexible external and internal boundaries (Ilinitch, D'Aveni, & Lewin, 1996). Although leadership has long been an area of interest and is a mature field (Bass, 1990; Hunt & Dodge, 2001), new models of leadership continue to develop, including a model of leadership for the new form organization, in which leadership relies less upon managerial authority (Schneider, 2002), and a new set of ideas that transcends the physical, biological, and social sciences, referred to as Complexity Theory, has entered the realm of leadership research (for example, Marion, 1999; Marion & Uhl-Bien, 2001; Mathews, White, & Long, 1999; Wheatley, 1994).

Although Complexity Theory has indeed entered the leadership lexicon, its linkage with leadership theory is nascent, indicating that further development of the linkage and its implications are in order. Some researchers have been provocative and not necessarily inappropriate in tying the sense of order under Complexity Theory to spirituality and improvement of the human condition, but are vague regarding inferences for leadership. We find that the assumptions of Complexity Theory remain murky despite much description of the theory, which hinders the

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development of its implications for leadership. Further, it is difficult to ascertain how Complexity Theory-based models of leadership could be developed and tested.

The article contributes to the linkage of Complexity Theory (CT) and leadership by suggesting how leadership within a Complex Adaptive System (CAS), one type of dynamic system under CT, might influence or shape the CAS. It attempts to fill a critical step in developing linkage of the existing literature on Complexity Theory and leadership with the ambitious objective of development and testing of a CT-based leadership model. This effort is aligned with the broader quest to move from generalizations about dynamic systems to tools and processes for understanding these systems (Sterman, 2000).

The paper starts with a review of General Systems Theory (GST) and the properties of Open Systems, as these properties are the foundation for much existing organizational and leadership research and are thus a relevant frame of reference. It then reviews Complexity Theory and explicates its assumptions regarding properties of Complex Adaptive Systems. After comparing the two sets of properties, we develop the implications of organizations as Complex Adaptive Systems for the definition of leadership and the leadership process.

Based on the properties of CAS and the insight of leadership as a tag in evoking change within dynamic organizational systems (Holland, 1995; Marion, 1999; Marion, 2002; Marion & Uhl-Bien, 2001), the paper presents a rudimentary CT-based model of leadership. We propose that organizational identity and social movements serve as mediating variables between leadership and organizational emergence. Leadership might come to affect other variables as well, in the iterative interactions of variables which characterize dynamic systems. We then describe two non-linear methodologies, dynamic systems simulation and artificial neural networks, as appropriate methods to enable further model development and testing.

This research contributes by clarifying the properties of Complex Adaptive Systems vis-à-vis Open Systems, explicating the definition and process of leadership within a CAS, and developing a rudimentary CT-based model of leadership within the framework of non-linear research methodology. Our dual intentions are to promote the development of a CT-based model of leadership and to assist in the eventual development of Complexity Theory's implications for leadership practice, as implications for practice tend to emerge from theory-based research.

1. An examination of General Systems Theory

According to General Systems Theorists, some systems phenomena were thought to be "… of almost universal significance for all disciplines" (Boulding, 1956, p. 200). These phenomena include populations–or aggregations of individuals in inter-dependent relationships–and the interaction of these individuals with their environment, governed by the principle of equilibrium or homeostasis. Systems were categorized into a hierarchy of nine levels based upon their complexity. Those at the Open System or greater levels of complexity (levels four and above) were thought to be regulated by the principle of self-maintenance, achieved through energy flows across permeable system boundaries. Social organizations were considered to be complex, exceeded only by transcendental systems not yet imagined (Boulding, 1956).

Katz and Kahn (1978) captured GST's application to organization theory in describing its emphasis on relationships, structure, and inter-dependence, and delineated 10 characteristics of Open Systems (See Table 1). As organization and leadership theories are innately linked (Osborn, Hunt, & Jauch, 2002), their contribution is also relevant to leadership theory. In particular, Katz and Kahn contributed by explaining how open systems tend toward both equilibrium or homeostasis and growth by importing energy for homeostasis, but tend to import more than is necessary. Accordingly, GST implies an openness of social systems, but also implies system boundaries and stable patterns of relationships within the boundaries.

Some other characteristics of Open Systems include synergism, i.e., that the whole can only be explained as a totality and is not just the sum of its parts; an emphasis on hierarchical relationships within the system; and a tendency toward multiple goals or purposes, particularly given the characteristic of differentiation (Kast & Rosenweig, 1972). There was great elaboration of the concepts of differentiation and integration (for example, Mintzberg, 1979). Findings emerged for highly complex global firms, such as greater complexity results in greater inter-dependence between headquarters and subsidiaries (Bartlett & Ghoshal, 1990).

Despite its influence, concern was expressed about GST and its application to management. Some found the analogy of organizations as organisms to be troublesome (Kast & Rosenweig, 1972). GST reinforces the Darwinian notion of

Table 1
Comparison of properties of open and complex systems

Properties of open systems		Properties of complex systems	
(1) Importation of energy	Energy is imported from the environment.	(1) Importation of energy	Energy is imported from the environment.
(2) Throughput	Inputs are converted through the use of energy.	(2) Throughput	Inputs are converted through the use of energy.
(3) Output	Produced output is exported into the environment.	(3) Output	Produced output is exported into the environment.
(4) Cyclicality	System events are structured by cycles.	(4) Chaos	CAS are poised systems that function at the edge of chaos for optimal buffering and adaptability.
(5) Negative entropy	The transformation cycle is a cycle of entropy, leading to disorganization or death. To survive, negative entropy is acquired by storing energy from the environment.	(5) Emergence	Some activity occurs that is not induced by the environment, but instead, results from the interdependence of system components.
(6) Information input, negative feedback, and the coding process	Inputs consist of information and signals about the environment and system functioning, as well as materials that are transformed. Negative feedback allows for necessary correction. Information must be coded appropriately to be meaningful.	(6) Information input, negative feedback, and the coding process	The interactions of system agents or elements with one another are need-based, bottom–up, and emergent, and are associated with the presence of catalysts and feedback mechanisms.
(7) Steady-state and dynamic homeostasis	The basic principle is the preservation of the character of the system. In countering entropy, systems move toward growth and expansion, as they tend to import more energy than is necessary.	(7) Adaptation	The basic principles are preservation and adaptation of the character of the system.
(8) Differentiation	There is movement toward greater differentiation, specialization, and elaboration.	(8) Differentiation	N (the number of sub-units) blends with the intra-system variables K and P and the inter-system variable C to achieve a poised system.
(9) Integration and coordination	Greater integration and coordination are necessary to counter the tendency toward greater differentiation.	(9) Integration and coordination	The intra-system variables K and P blend with N and the inter-system variable C to achieve a poised system.
(10) Equifinality	The same final state can be reached from differing conditions and a variety of paths.	(10) Path Dependence	Unique final states may be reached due to sensitivity to initial conditions.

Adapted from Katz and Kahn (1978).

survival as largely a chance event based upon mutation (Glassman, 1973), seen in early Population Ecology, which has been criticized for viewing organizational evolution as a Darwinian process (White, Marin, Brazeal, & Friedman, 1997). GST has also been associated with the Parsonian school of sociology, whose emphasis on order and system maintenance and view of conflict as dysfunctional fail to explain how social change comes about (Peery, 1972), and with contingency theory, which similarly presents organizations as reacting to their environments and never initiating change (Lawrence, 1981; Marion, 1999).

In summary, GST has had a large influence on leadership research, characterized by a view of systems thinking as an appropriate framework (e.g., Hunt's (1991) theory of leadership, based on Jaques' (1976) general theory of bureaucratic organizations), a focus on contingency thinking (e.g., Fiedler's (1967) Contingency Model), and a confounding of leadership with management (Schneider, 2002). Independent of the influence of CT, leadership research started to expand its repertoire to reflect changing organizational practices, with research on emergent, team, and shared leadership (e.g., Denison, Hart, & Kahn, 1996; Manz & Sims, 1987; Pearce & Conger, 2003).

2. An examination of Complexity Theory

Complexity Theory is a broad-based movement that contains new tenets about a type of system, referred to as Complex Adaptive Systems (CAS). Although its ideas have deep historical roots (Marion, 1999; Simon, 1996), the movement gained ground in the 1980s with formation of the Santa Fe Institute (Pascale, 1999). To some, this "new science" is a paradigm shift from previous science (Wheatley, 1994). Others imply that it is a new paradigm by associating previous science with Modernism and CT with Post-Modernism (Baker, 1993; Funtowicz & Ravetz, 1994;

Lee, 1997) or Anti-Positivism (Marion, 2002). Yet others view it as an extension of previous science (Mathews et al., 1999). Is CT evolutionary or revolutionary?

We find that, in comparing CT to GST, the development of CT is more evolutionary than revolutionary, for it largely is based upon and does not refute much previous science. Just as GST is known for Open Systems, but did not assume that all systems are open (per Boulding, more elementary levels of systems are not open systems), CT focuses on Complex Adaptive Systems, but does not assume that all systems are complex, adaptive ones. Different system patterns have been noted; only some are chaotic, a characteristic of CAS, while many reach either a fixed point or state of cyclical equilibrium (see Dooley & Van de Ven, 1999). The famed "strange attractor" of complex adaptive systems is one of five types of attractors that may emerge in a system (Eoyang & Berkas, 1999). Thus, we conclude that CT does not negate the findings of GST, but does find them to be limited to certain types of systems.

However, CT's effect may be more revolutionary than evolutionary. A key assumption of CT is that some events, given our knowledge and technology, are unknowable until they occur, and may indeed be unknowable in advance (Eve, Horsfall, & Lee, 1997). This notion may be abhorrent to some researchers, whose training against novelty and toward reductionism leads to a continued search for new variables that might yet hold the promise of scientific prediction (Goldstein, 1999), and, according to GST, systems seek equilibrium, a notion that has a simple, seductive pull (Pascale, 1999). Thus, the more complex and unpredictable patterning of change under CT may be rejected based on emotional as well as intellectual reaction.

2.1. The building blocks of Complexity Theory

Previously, organizational complexity had been defined as the number of activities or sub-systems within an organization, with the dimensions of vertical or number of levels; horizontal or number of units, departments or divisions; and spatial, the number of geographic locations (Daft, 1992). This definition and the language used within it reflect the framework of GST, and are ill-equipped to accommodate CT. To remedy this situation, complexity theorists have developed new, idiosyncratic phrases and terminology, which, while well intended, may confuse more than they clarify. Accordingly, we employ this language here only to the degree that is necessary to aid explanation. We propose that there are three inter-related building blocks of CT—non-linear dynamics, chaos theory, and adaptation and evolution.

2.1.1. Non-linear dynamics

Knowledge regarding non-linear dynamics is based on the work of Prigogine (1996) and associates on dissipative structures in non-equilibrium thermodynamics; i.e., systems in states of extreme instability. Dissipative structures, characterized by high states of energy exchange with the environment, exhibit an inherent instability that leads them through multiple transitions, reached through a series of points, rather than a tendency toward equilibrium. At each point, the structure moves to a new and generally higher level of complexity that is qualitatively and quantitatively different from previous states (Baker, 1993; Mathews et al., 1999). Systems such as dissipative structures have an emergent quality that comes from the interaction of their elements, sub-systems or agents (Morel & Ramanujam, 1999), rather than from the system's interaction with its environment.

Dissipative structures may react disproportionately to an environmental change. A small exogenous event may trigger a change in the fundamental character of a system. (It may also trigger no change, a change that is proportionate to the event; or a change that is less than proportionate.) The phenomenon of large, disproportionate change is referred to as the "butterfly effect", i.e., the idea that a butterfly fluttering in Rio de Janiero can change the weather in Chicago (Kauffman, 1993). It was first noted by Lorenz in his study of weather systems and reflects the non-linearity of such systems (Wheatley, 1994) due to the great level of inter-relatedness of system parts (Anderson, 1999). Accordingly, properties of the system may emerge from its parts, rather than being imposed by the environment (Holland, 1998).

The butterfly effect illustrates that initial conditions form unique influences on a non-linear system (Kauffman, 1993; Sterman, 2000). The concept of path dependence, appearing in the social sciences in evolutionary economics (Nelson & Winter, 1982) and strategy (Barney, 1995) indicates the role of historical contingencies in influencing system states. Importantly, path dependence indicates that the GST characteristic of equifinality might not apply to non-linear systems, for their initial conditions might create paths that lead to unique states.

The self-induced transition of dissipative structures to a series of states casts doubt on the universality of the second law of thermodynamics and GST's related concepts of entropy and equilibrium, under which "… systems attain a state of equilibrium characterized by decreasing activity and entropy production" (Mathews et al., 1999, p. 442). The meta-assumption of linear relationships in GST-based research is also challenged, with evidence that dependent variables may change at rates that are not first-order coefficients of independent variables (Lee, 1997).

2.1.2. Chaos Theory

Chaos Theory emanates from a branch of economics. Although chaotic systems and complex systems are different, for complex ones are less mechanical and more stable and predictable, Chaos Theory does inform Complexity Theory, as both concern non-linearity (Marion, 1999). Chaos is critical to the process of adaptation and evolution, further described below. Not all systems have equal capacity to evolve; this capacity reflects the system's mix of chaos and anti-chaos, or order (Kauffman, 1995).

Five system patterns that emerge over time have been distinguished—fixed or static, periodic or cyclical, chaotic or strange, colored noise, and random (Morrison, 1991; in Dooley & Van de Ven, 1999). While the behavior of some systems may appear to be random, computer-generated depictions of the behavior over myriad intervals indicate that it is chaotic, not random. A random pattern is indeed no pattern. But, under chaos, a "basis of attraction" forms and brings about non-random behavior. A pattern emerges within the basin of attraction; it is referred to as a "strange attractor," which is the system's bounded preferences of microstates (Lee, 1997). Chaotic systems are predictable in pattern, as the strange attractor pattern emerges, but are not predictable in path or specific temporal trajectory. Random systems are predictable in neither, and periodic systems are predictable in both (Dooley & Van de Ven, 1999).

2.1.3. Adaptation and evolution

Despite other theories, including Larmark's teleological argument that acquired characteristics can become inherited traits (Marion, 1999), the Darwinian view that evolution is dependent upon the force of natural selection came to dominate. CT challenges these dominant beliefs by suggesting that, while selection does matter, species play a role in their evolution and adaptation to external changes. In the language of CT, CAS reflect an ability to adapt through the emergent characteristic of self-organization, which comes from the inter-dependency of their individuals or agents, a.k.a. sub-systems. This is similar to the emergence found by Prigogine in dissipative structures.

As mentioned, not all systems have equal capacity to evolve (Kauffman, 1995). Highly chaotic systems cannot maintain their behaviors, as small forces can result in systems disruption, i.e., the butterfly effect. They have too few stable or "frozen" components and tend to fail due to too little buffering and low adaptability and evolutability. Highly ordered systems are too rigid to coordinate new behaviors and likewise tend to fail. Many elements of highly ordered systems are frozen, so that virtually all forces yield, at most, only minor system changes, resulting in too much buffering and low adaptability and evolutability.

"Poised" systems, those at the edge of chaos, "… may have special relevance to evolution because they seem to have the optimal capacity for evolving" (Kauffman, 1991. p. 82). Their ability to evolve is high because adaptive buffering leads to a repertoire of responses, as seen in a strange attractor. Poised systems have the flexibility to evolve rapidly through the accumulation of useful variations (Kauffman, 1993), and the concept of self-organized criticality suggests that many systems can evolve to this poised state (Mathews et al., 1999).

Kauffman (1989a,b, 1991, 1993, 1995) theorizes that four variables in non-linear dynamic systems–N, K, P, and C–affect their degrees of chaos and anti-chaos/order and hence their ability to adapt and evolve. N is the system or organization's number of sub-units. K is the level of inter-relatedness or interaction of the sub-units, measured by the inputs to each N, which introduces non-linearity into the system (Morel & Ramanujam, 1999). P is the common schemata the sub-units share, a measure of internal homogeneity. While N, K, and P are intra-system variables, C is an inter-system variable; it is the level of inter-relatedness or interaction of N across systems and is another source of non-linearity. With optimal levels of chaos and anti-chaos/order, a system will then be poised, and hence, potentially adaptive and capable of evolution.

3. A comparison of the GST and CT frameworks: properties of open systems and complex adaptive systems

Table 1 contrasts the properties of Open Systems developed by Katz & Kahn (1978) under General Systems Theory with the properties of Complex Adaptive Systems we derive from the literature on Complex Systems. The comparison indicates some similarities and some notable differences. The first three properties–importation of energy, throughput, and output–are unchanged, and reflect that CAS are open systems that interact with their environment in a transformation process. However, there are marked differences in properties 4, 5, 7, and 10, and some differences in properties 6, 8, and 9.

Property 4 regards the nature of patterns that affect the system; while Open Systems may be cyclical, CAS are based upon the notion of chaos and are most adaptive when near the edge of chaos. Property 5 reflects the controversy regarding the second law of thermodynamics, seemingly refuted by Prigogine's research, which indicates that CAS evidence the property of emergence rather than entropy. Per property 7, CT focuses on system adaptation and evolution more so than maintenance and homeostasis. Last, CT suggests that CAS may experience unique or idiosyncratic paths, due to their sensitivity to initial conditions, indicating their property of path dependence rather than equifinality (property 10).

The three properties regarding structure and information processing are common but also different for open systems and CAS (6—information and feedback; 8—differentiation; 9—integration and coordination). In terms of information and feedback, CAS focus on emergence, the bottom–up interaction of system elements that facilitates order. Order arises from spontaneous interaction, referred to as autocatalytic interaction or autocatalysis, which begins on a local level. The cooperation of elements or agents in the system leads to their interaction and resonance. Autocatalysis comes from resonance, occurring when the behavior of elements or agents correlate due to their interactions and then catalyze (Osborn et al., 2002). Events catalyze through "tags" (Holland, 1995) or rallying points, symbols, actors or behaviors that provide filtering as well as cooperation. Emergence is aided by tags (Marion, 1999).

While differentiation (property 8) and integration (property 9) are properties of CAS as well as Open Systems, CT research suggests very different notions of these properties. In a CAS, variables K (inter-relatedness within a system), N (number of elements), C (inter-relatedness across systems), and P (common schemata shared by sub-units) are critical to the system's survival and adaptation. The model of leadership that we will develop shortly will elaborate on how leadership might indirectly affect these variables and their inter-dependencies.

4. What is leadership in a Complex Adaptive System?

Complexity Theory has promoted a re-examination of leadership, as much of the leadership lexicon developed under General Systems Theory. While it has been suggested that under CT, leadership may be crucial to the process of self-organization (Knowles, 2001) and leaders might serve as context setters and designers of learning experiences (Brown & Eisenhardt, 1997; Pascale, 1999), further examination is needed to evaluate how leadership in a CAS is similar to, but different from, leadership in an Open System.

In a classic definition based on the GST-Open Systems model of organization, Katz and Kahn (1978) offered that leadership is incremental influence over and above compliance with routine direction. We find that this definition, like some of the properties of Open Systems listed above, generates both similarities and differences in its application to Open Systems and CAS. Under CT, leadership remains about influence of others above routine compliance. What is different is the leadership process, for in CAS leadership is often non-reliant upon formal authority structures. Indeed, leadership is often independent of, and possibly even contrary to, the authority structure, as it may well influence the process of emergence or self-organization.

The difference in process implies that the leader is also qualitatively different. Under CT, leaders serve as tags and influence other persons and processes (Marion & Uhl-Bien, 2001). They frequently lead without authority and often do so in a temporary capacity. Leaders might consciously initiate their leadership role, or might accept the role that has been given at them. Leaders might be unaware of their role, as others might also be unaware, but nonetheless leaders might emerge. As tags are associated with action and outcomes, not necessarily with individuals or positions, one might co-function as leader, sharing the role in tandem. Thus, we prefer use of the term "leadership" to connote the often indirect, catalytic process within organizations–which might be performed by people in rotation or in tandem–to the term "leader," which might falsely signal that there are individual and positional factors that strictly distinguish leaders from others.

Further elaboration of the new CT-based conceptualization of organizational structure is necessary for an understanding of leadership within a CAS. Given that N is the number of system elements or units, and K is their level of inter-relatedness, it would seem per Daft (1992) that a large number of N, with $K=N-1$, yields a greater level of complexity than occurs with fewer N or fewer connections. But Complexity Theorist Gell-Mann (1994) indicates this is not the case, suggesting that a system is most complex when the relationships within it are difficult to describe either mathematically or verbally, i.e., no easily discernable pattern such as $K=N-1$ emerges. Gell-Mann distinguishes "effective complexity" measured by the length of the most concise description of the system from "crude complexity," or random responses. Using the example of a chimpanzee banging on a keyboard, it is proposed that the chimp's output has greater crude complexity but less effective complexity than a Shakespearean sonnet.

From Gell Mann's theorizing, we infer that a large, mechanistic bureaucracy has less effective complexity than a smaller, organic organization, suggesting that variables N (number of elements), K (inter-relatedness within a system), C (inter-relatedness across systems), and P (common schemata shared by sub-units) are indeed different from GST-based notions. While the principal design tool in a CAS is the manipulation of the interdependencies of these variables (Levinthal & Warglien, 1999; McKelvey, 1999), how might leadership influence the variables, given that they are different from current conventions and that direct attempts at influence, such as an unambiguous strategy, might disable rather than enable emergence and adaptation (Osborn et al., 2002)? We offer that leadership might affect the variables indirectly, through the mediating variables of organizational identity and social movements.

5. Leadership in a Complex Adaptive System: leadership as an indirect catalytic process

5.1. Leadership and organizational identity

Self-similarity is a critical characteristic of Complex Adaptive Systems; it means that a system exhibits invariance under a change of scale (Morel & Ramanujam, 1999). In a CAS, self-similarity is the basis for variable P, the common schemata shared by system sub-units. Self-similarity is evidenced in the physical world in fractals such as fern leaves and broccoli, which are geometric spaces in which the parts exhibit the quality of the entity's whole. We put forth that, in the organizational world, self-similarity is associated with organizational identity. Organizational identity encourages a degree of self-similarity: "Self-organization succeeds when the system supports the independent activity of its members by giving them, quite literally, a strong frame of reference" (Wheatley, 1994, p. 95).

According to social identity theory, social identification is a person's perception of oneness with or belongingness to some human aggregate, reflecting both psychological and social processes (Ashforth & Mael, 1989; Pratt, 1998). Organizational identification, a form of social identification, occurs when one's beliefs about an organization become self-referential or self-defining (Pratt, 1998). Organizational identity (as opposed to identification) is a shift toward the collective level of analysis. Initially defined as that which is central, distinctive and enduring about an organization (Albert & Whetten, 1985), the concept has been refined, to reflect members' shared beliefs regarding these characteristics (Dutton, Dukerich, & Harquail, 1994).

We propose that organizational identity (variable P) reflects path dependency and is also affected by and affects variables N (number of organizational sub-units), C (inter-relatedness across organizations), and K (inter-relatedness within the organization). An organization's identity manifests the identities, motivations and values of its founders (Bouchikhi & Kimberly, 2003), illustrating path dependency. Organizational identity is affected by other identities in the organization, such as those in its geographic divisions (Ashforth & Mael, 1989), so that variable N might also affect variable P. Due to members in boundary-spanning roles (Bartel, 2001), organizational identity is affected by the organization's image held by external stakeholders (Hatch and Schultz, 2002), suggesting how variable C influences identity. Last, the influence of variable K is illustrated by the effects of organizational context, including culture, on identity (Hatch and Schultz, 2002).

Organizational identity shapes the organization and its reactions by influencing the meaning of events and the set of actions that come to occur (Dutton & Dukerich, 1991; Gioia, 1998); it focuses attention on issues, influences resource allocation, and can be motivational (Stimpert, Gustafson, & Sarason, 1998). Given its critical role in sense-making and action-taking, it is suggested that an organization's identity can be the primary constraint on its adaptive capacity (Bouchikhi & Kimberly, 2003). Organizational identity has indeed been linked to organizational adaptability:

> Increasingly, an organization must reside in the heads and hearts of its members. Thus, in the absence of an externalized bureaucratic structure, it becomes more important to have an internalized cognitive structure of what the organization stands for and where it intends to go—in short, a clear sense of the organization's identity. A sense of identity serves as a rudder for navigating difficult waters. (Albert, Ashforth, & Dutton, 2000, p. 13)

An identity that is too rigid will discourage adaptation by encouraging narcissism and a lack of reflexivity (Hatch & Schultz, 2002), exemplifying a frozen system. An identity that is too malleable is also problematic; it may encourage an organization to become hyper-adaptive and allow image to replace substance (Hatch & Schultz, 2002), leading to a non-adaptive chaotic system. Some instability in organizational identity is adaptive, encouraging a poised system. Accordingly, organizational identity is better conceptualized as bringing about a sense of continuity while being fluid, instead of being enduring (Gioia, Schultz, & Corely, 2000). An effective identity encourages continuity as well as change (Brown & Eisenhardt, 1997) and creates the potential for balance between exploitation and exploration (March, 1991).

We suggest that three attributes of organizational identity are critical to *P*, and hence, critical to self-organization and adaptation. First is strength, the degree to which organizational identity is shared by members (Gioia & Thomas, 1996). As individuals' beliefs may or may not match the collective identity (Dutton, Dukerich, & Harquail, 1994), the strength of organizational identity varies. Second is the degree of singularity/pluralism, reflecting the confluence of stakeholder influences on organizational identity (Scott & Lane, 2000). Third is the degree of stability/instability (Gioia et al., 2000). A very strong identity, characterized by few influences (toward singularity) and a great a degree of stability will lead to a frozen non-adaptive system. A very weak identity, characterized by too many influences (pluralism) and too low a degree of stability, will lead to a chaotic non-adaptive system.

While organizational identity has a historical component, it can also be consciously influenced (Barker, 1998; Dutton & Dukerich, 1991; Gioia & Thomas, 1996). If leadership perceives that organizational identity is highly ordered and might contribute to the organization becoming non-adaptive, leadership might attempt to reduce the strength, singularity, and stability of organizational identity (variable *P*). These attributes of identity might be diminished by de-emphasizing symbols, myths, and stories regarding the organization's founders, to assuage path dependency. Leadership might also increase the number of organizational sub-units, to add new and varied sources of identity (increase variable *N*). Leadership might encourage more and stronger relationships with external organizations and constituencies (increase variable *C*), and reduce inter-organizational linkages (reduce variable *K*). If leadership instead perceives that organizational identity is highly chaotic and might contribute to the organization becoming non-adaptive, the contrary set of actions should occur.

Proposition 1a. *In the Complex Adaptive System framework of organizations, variable P, the common schemata shared by sub-units, appears in organizational identity.*

Proposition 1b. *Organizational identity (variable P) is affected by path dependency, organizational sub-units (variable N), intra-organizational linkages (variable C), and inter-organizational relationships (variable K).*

Proposition 1c. *The greater the strength, singularly, and stability of organizational identity, the greater will be variable P.*

Proposition 1d. *Greater values of P will promote a frozen non-adaptive organizational system, and lesser values of P will promote a chaotic non-adaptive system.*

Proposition 1e. *In a Complex Adaptive System, leadership might indirectly affect organization adaptability and evolutability through the mediating variable of organizational identity. To increase organizational adaptability and evolutability, leadership might affect a reduction in variable P by reducing path dependence, increasing variables N or C, or decreasing variable K; or might affect an increasing path dependence, decreasing variables N or C, or increasing variable K.*

5.2. Leadership and social movements

We propose that the study of social movements can inform understanding of leadership in a CAS. Social movements are sets of beliefs and actions for changing elements of a society. They are associated with networks of groups, based on a collective identity, that participate in collective action to bring about change (Rucht & Neidhardt, 2002). While early social movements tended to focus on class systems, recent ones are more diverse, exhibiting a plurality of ideas and values that is often not class-based (Johnson, Larana, & Gusfield, 1994) and tend to be pragmatic as well as ideological in searching for institutional reforms (Cohen, 1985).

Social movements differ in the degree of radicalism of their positions and tactics (Carmin & Balser, 2002). Their success is based on the appeal of the movement's ideology and its capabilities to mobilize constituencies and resources and engage in political processes (McCarthy & Zald, 1977). Other factors affecting success are the ability to engage in social networks, the manner in which issues are framed (Crossley, 2003), and the weaknesses of those in opposition (Nathanson, 1999). Formal social movement organizations may influence this emergent process through the use of pressure (Den Hond & De Bakker, 2004).

Social movements develop locally and diffuse globally through the use of framing. Actors in a social movement are signifying agents actively engaged in the development of meaning for others in an interactivist manner, making these collective frames of meaning the result of a negotiated, shared process. A frame has greater resonance to the degree that it has credibility and is salient (Bedford & Snow, 2000). Per the mathematics of dynamic systems theory (Arrow, McGrath, & Berdahl, 2000), social movements may serve as catalysts in evoking global dynamics, referring to system-level rules that emerge from local dynamics, and contextual dynamics, the impact of global dynamics over time. For example, the health-related movement has led to both normative and regulatory changes regarding smoking (Nathanson, 1999).

The social movement that we have chosen to illustrate leadership in a CAS is that which promotes community gardens, which are gardens tended voluntarily by community members, often developed on abandoned plots of land. While government agencies serve as formal organizations promoting the movement, much of it takes place at a grassroots or local level, and local leadership is integral to its success (Smith & Kurtz, 2004; Twiss et al., 2003). For example, the Queen Anne Memorial Garden is named after the tireless, elderly African American woman who was president of the neighborhood association during its worst years (Glover, 2003). Eight members formed the core of the association. In part through their efforts, a critical mass of residents emerged to revitalize the crime-ridden neighborhood.

Community gardens bring about myriad benefits at different system levels, illustrating a defining characteristic of complex systems (Arrow et al., 2000). They encourage socialization and a sense of community, improve the neighborhood's appearance, and reduce crime (Glover, 2003). For members, the gardens facilitate development of a hobby and might elevate job skills, reduce household food expenditures, encourage exercise and healthy eating, and bring personal pride and collective identity. Yet, community gardens might sow the seeds of their own destruction, for the improvements they bring about might result in sale of the plots to developers, as the community becomes more desirable (Smith & Kurtz, 2004).

From the example, we see how social movements might have legitimacy in terms of the support of formal organizations, yet are highly dependent on the bottom–up process of emergence. Social movements are critically dependent on tags–leaders without authority but with great influence in their communities–for their diffusion. Leadership facilitates this diffusion by framing social movements as appealing and mobilizing resources on their behalf. However, unforeseen consequences may undermine the very existence of the organizations that promoted the social movement. Community gardens might render their plots to be attractive to developers, illustrating how change in a CAS is not equal to adaptation (Carley, 2000). Social movements bring about a range of consequences, demonstrating a defining aspect of Complexity Theory; not all consequences that might occur are predictable (Eve et al., 1997).

Social movements come to affect multiple system variables and their interactions across local, global, and contextual levels. In our example, the social movement affected a series of community organizations and their gardens, the local systems; their surrounding neighborhoods, the global systems; and members of the gardens. A social movement might be initially catalyzed within an organization, affecting variable K and might then catalyze the global system through variable C. The social movement might then affect other local organizations through variable C, and come to affect their various sub-units through variable K. Social movements might also come to affect variable P by influencing organizational identity, as the movement toward advocacy for the homeless affected the Port Authority of New York and New Jersey's identity during the 1980s (Dutton & Dukerich, 1991). Changes in variable P might then come to affect changes in variable N, as organizations align their sub-units with their newly changed identity.

Proposition 2a. *In the Complex Adaptive System framework of organizations, leadership might indirectly affect organization adaptability and evolutability through the mediating variable of social movements. Leadership might facilitate those social movements that are perceived as potentially increasing organizational adaptability and evolutability.*

Proposition 2b. *Social movements might generate unintended consequences for organizations, so that leadership facilitation of a social movement might reduce rather than increase organizational adaptability and evolutability.*

Proposition 2c. *Social movements potentially affect local, global and contextual dynamic levels; i.e., organizations, the broader systems to which they are linked, and the impact of global dynamics over time.*

Proposition 2d. *A social movement that is generated external to an organization will initially affect the organization through variable C, and then will affect variable K; while a social movement that is generated within an organization will initially affect variable K, and then will affect variable C.*

Proposition 2e. *After a social movement affects variables K and C, it might then affect variables P and N, given the tendency toward interactions of variables in a CAS.*

6. Leadership in a complex adaptive system: appropriate research methodology

Just as the development of Complexity Theory is bringing about new conceptualizations of organizational structure and leadership, it is also bringing about new non-linear and processual research methodologies that are necessary for further design and testing of a CT-based model. While non-linearity can seemingly be modeled using conventional statistical methods by adjusting the pattern recognition algorithm to be sensitive to specific non-linear relationships (Bettis & Prahalad, 1995), this method is insufficient, as variable interactions are not captured. Just as conventional statistics fail here, so too does human cognitive processing, as the need for intuitive solution of high-order non-linear differential equations exceeds our capabilities (Ilgen & Hulin, 2000a; Sterman, 2000). Complexity Theory requires new methodologies that capture the range of dynamic relationships that underpin its various theories.

The methodological movement is referred to as the "third discipline" (Ilgen & Hulin, 2000a), to position it in terms of the first discipline of experimentation and the second of regression, per Cronbach (1975). The movement spans social science fields, emphasizes the study of process effects through a longitudinal approach, and includes a broad array of perspectives and methodologies, including simulation or computer modeling, field studies or naturalistic approaches such as comparative case studies, experimental simulations, and verbal theory (Arrow et al., 2000; Hunt & Ropo, 2003).

We highlight two third discipline methods–dynamic systems and artificial neural networks–that are appropriate to the study of leadership in a CAS and could serve to refine the CT-based model that has been developed. Dynamic systems simulation is not an empirical method in the traditional sense of analyzing data to test theory. Instead, based on a research question, researchers create a mathematical model within a virtual world that replicates critical aspects of the social world. From the researchers' verbal theory, their rudimentary mathematical representation of the theory, and the results of the computer simulation, and further informed by quantitative and qualitative empirical data, researchers are able to utilize simulation to develop advanced theory. The method of artificial neural networks is akin to traditional empirical methods in that it tests theory using data, but it can also inform and advance existing theory regarding non-linearity. We advance artificial neural networks as an appropriate, but to date under-represented, third discipline method.

6.1. Dynamic systems simulation

Complexity in a system occurs from the interaction of system variables over time. Major factors that influence complexity include positive or self-reinforcing feedback loops that generate growth and amplify deviations; negative or self-correcting feedback loops that counteract change; and single and double loop learning, the former in which existing mental models are maintained and the latter which involve the reframing of mental models. Other factors that also influence complexity include path dependence, as previously described; delays in outputs relative to inputs; aging of the system; and possible oscillation, amplification, and phase lags (Sterman, 2000). In summary, complexity is complex, meaning that it is difficult if not impossible for humans, given their cognitive processing limitations, to comprehend–albeit predict–phenomena under this condition.

Just as strange attractors–which distinguish complex systems from random ones–become apparent only with the assistance of computer technology tracking patterns over time, computer simulation might help us to gain understanding of the dynamics of emergence in a complex system, as changes reflecting the passage of time are often counterintuitive (Hanisch, 2000; Ilgen & Hulin, 2000a; Latane, 2000). Simulation is based on dynamic systems theory, a branch of mathematics. It differs from previous modeling methodology in its emphasis on emergent variables, interaction among variables at various system levels, and study of the evolution of the system over time. A virtual world is developed that reflects the researcher's assumptions regarding system variables, which begin as traditional verbal theory and are then quantified into algorithms. The virtual world attempts to reflect those aspects of the organization and its embedded social context that are relevant to the research question (Sterman, 2000).

Unlike traditional empirical testing, simulation creates rather than tests theory, so that the result of the simulation is the theory itself (Krackhardt, 2000). Simulation may serve to bridge verbal theory and empirical testing (Arrow et al., 2000). Dynamic hypotheses can be tested and model parameters can be subsequently fine-tuned, to adjust the fit between the simulation's prediction and empirical (both quantitative and qualitative) data. For example, theory regarding charismatic leadership has been developed by simulation; subsequent empirical testing supported the theory, finding that charismatic leadership is largely unpredictable in its incidence and outcomes (Jacobsen & House, 2001).

Simulation could be utilized to refine the verbal theory we have developed regarding the indirect process of leadership in affecting the *N*, *C*, *K*, and *P* variables over time and across system levels (see Propositions 1b, 1e, 2c, 2d, and 2e). CT suggests the criticality of leadership in networking and building relationships (Marion & Uhl-Bien, 2001; Osborn et al., 2002; Wheatley & Kellner-Rogers, 1996), as these activities engage non-linear processes (Regine & Lewin, 2000). Simulation could be employed to illustrate the relationship between networking with multiple internal and external stakeholders and leadership's efficacy in shaping organizational identity and social movements.

In addition, there is need for theory development regarding leadership microdynamics, the bottom–up process that leads to both coordinated and random behavior, and macrodynamics (Marion & Uhl-Bien, 2001), and the interactions between them. Leadership is a CAS involves a critical role for non-strategic leadership, or "leadership in the organization" (Boal & Hooijberg, 2000), for "...order, cohesion and viability may emerge from the middle and bottom" (Osborn et al., 2002, p. 823). Yet, there is also need for strategic leadership, or "leadership of the organization" (Boal & Hooijberg, 2000; Hunt, 1991). As simulation reveals the positive and negative feedback loops in the interactions between micro and macrodynamics (e.g., Saam, 1999), simulation holds promise to facilitate such theory building regarding leadership.

We note that while simulation is of assistance in understanding the dynamical effects of complexity, and we endorse its use, we agree that it is best utilized along with other third discipline methods–including comparative case studies such as those used by Jacobsen and House (2001)–and its virtual world should continuously be informed by the findings of other methods (Hunt & Ropo, 2003; Ilgen & Hulin, 2000b). Else, the virtual world risks becoming a "toy universe" which lacks characteristics that have influence on the behaviors being modeled (Munson & Hulin, 2000) or becoming a "black box" that defies comprehension (Kerr, 2000).

6.2. Artificial Neural Networks

Artificial neural networks (ANN) are pattern recognition algorithms with the capacity to uncover unique and complex patterns in data (Ripley, 1996). ANN map input variables to a specified set of outcome variables by modeling the set of embedded relationships in data. This is accomplished by continuous adjustment in error between observed and predicted values, as data are passed through advanced statistical functions (cf. Swingler, 1995).

While artificial neural networks have been used to address problems in business disciplines such as marketing and finance (e.g., to predict stock prices), their use in management research remains sparse despite the suggestion for their potential efficacy in addressing thorny theoretical issues (Somers, 2001). We believe that the primary reasons that ANN are under-utilized in management are low awareness among management scholars and confusion about their use. While several have pointed out the pitfalls of over-reliance on linear thinking and methods in management research (cf. Bettis & Prahalad, 1995, Starbuck & Mezias, 1996), we find that in the management literature artificial neural networks have thus far been considered narrowly, as a tool to increase predictive accuracy over traditional linear methods, rather than as a method for more broadly exploring nonlinear relationships.

Linking ANN and qualitative research has been suggested (Somers, 1999, 2001), illustrating that ANN typifies third discipline research methodologies in being part of a multi-method approach to research. Our goal is not to offer guidance about how to use neural networks, which is beyond the scope of this article; there are several excellent books that serve this purpose (for example, Swingler, 1995). Rather, we consider how neural networks could be used to study CT and leadership and test some of the presented propositions.

The first set of propositions (1a, 1b, 1c, 1d, and 1e) suggests that leadership is affected by, and affects, the contextual factors in which it occurs. While this is hardly a new idea, CT suggests that at the edge of chaos, leadership (like the organization itself) becomes a phenomenon that is qualitatively different from leadership when the organization is at different states of being. A key question for researchers interested in exploring this notion is identifying poised organizations, those at the edge of chaos, from other organizations. While the concept is intriguing for discussion purposes, it also becomes necessary to move toward empirical testing.

Artificial neural networks are useful in this regard. Specifically, ANN could be used in a two-stage research strategy, to first identify poised organizations at the edge of chaos, and then conduct comparative analyses to determine how leadership is qualitatively different here from leadership in organizations not at the edge of chaos. By mapping the variables discussed in this article (P, K, N, and C) to a defined outcome variable, via sensitivity analysis ANN can be used to identify organizations that are on the edge of chaos. Sensitivity analysis is used to determine the effect of changes on input variables on an outcome variable of interest (Ripley, 1996); for example, some measure of organizational efficacy. Changes in one variable can have large changes in others, i.e., the famed butterfly effect. Such changes can be quantified and displayed visually with appropriate neural network software.

If a variety of organizations are included in the researcher's sample, the ranges of the predictor variables can be used to classify those organizations that are poised and at the edge of chaos and therefore are potentially adaptive. Qualitative analyses could and should then be used to study leadership processes in these poised organizations relative to other organizations that are not in the same state (e.g., are frozen). More to the point, researchers now have an empirical tool and an associated methodology to move beyond deriving theoretical propositions about how CT can be used to reinterpret leadership, to examining the plausibility of CT-based propositions.

7. Conclusion

This article advances Complexity Theory's nascent application to organizational leadership. We have clarified CT's assumptions by comparing them to the assumptions of General Systems Theory; examined the process of leadership in a CAS; illustrated how leadership might influence emergent self-organization through the mediating variables of organizational identity and social movements; and presented appropriate methods for further theory development and testing. We hope that our efforts help to overcome concerns that CT risks becoming a fad due to the backlash faced by developing paradigms (Sternman & Wittenberg, 1999) and the mysticism and obfuscation regarding it (Horgan, 1995).

It has been noted that Complexity Theory well captures the dramatic change occurring in social institutions (Cohen, 1999; Hunt & Ropo, 2003; Mathews et al., 1999). Yet, there is concern that CT should not be idealized, for emergent events might lead to destruction, as occurred in former Yugoslavia (Goldstein, 1999). We therefore mention that there is a potential "dark side" to the conceptualization of leadership that emerges from our model, just as there is a potential "dark side" to the new-form organization (Victor & Stephens, 1994). First, there is no assurance that the outcomes of emergence are desirable in terms of the organization's criterion of interest—which might be its mission, its role in society, or its fitness for evolution (Osborn et al., 2002). As has been demonstrated, unforeseen consequences are a defining characteristic of a CAS framework. Accordingly, we reiterate that leadership should encourage an organizational identity that reflects variation as well as self-similarity, for identity could then serve as a potentially countervailing force to destructive possibilities.

Second, we express concern about the process of self-organization or emergence. While experiments in the physical and biological sciences have some relevance for social systems, they fail to address the psychological effects of the emergence process. Do the involved persons remain individuals with unique identities, or might they tend to surrender themselves to the process? Might conflicts that surface negatively affect individuals and their relationships, should the process not be tempered by cooperation? Although emergence might tend to have positive effects on improving the human condition (Wheatley, 1994), we offer that concern about its potential harmful effects might lead to a movement parallel to the earlier human relations movement, which was concerned about the potential harmful effects of authority.

A limitation of the paper is that it has not developed implications for leadership practice. While the development of practical implications should be the ultimate goal of leadership research, at times focus must be placed solely on theory-building rather than on application, until the point when sufficient theory development has occurred (Montgomery, Wernefelt, & Balakrishnan, 1989). Notably, it has been suggested that the processual research approach we discuss might well become of interest to practitioners, as they have often experienced the shortcomings of linear approaches (Hinings, 1997). A second limitation is the model's emphasis on but two mediating variables, organizational identity and social movements. We focused on these variables as they well illustrate how leadership in a CAS might influence the bottom-process of emergence. We hope the model promotes future research regarding other mediating variables, and the process by which leadership in a CAS might act directly.

Our emphasis on Complexity Theory should not be interpreted as advocating the demise of leadership research conducted under the General Systems Theory framework. As organizations contain processes and sub-systems in various states (Dooley & Van de Ven, 1999), GST-based leadership theories remain applicable in multiple contexts, and many leaders will continue to gain insights from them. Approaches favoring a mix of models that explore a range of leader contexts best expand our understanding (Osborn et al, 2002). But within this mix, the relative value or usefulness of General Systems Theory-based models of leadership and Complexity Theory-based models cannot yet be assessed, as the former is currently extant and the latter is nascent. Accordingly, we hope that we have promoted the further development and testing of Complexity Theory-based models of leadership.

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