Complexity Thinking & Leadership:

How Nonlinear Models of Human Organizing

Dynamics Can Inform Management Practice

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Abstract

The growing field of complexity leadership argues that leadership emerges from within interactions. The specific nature of the interaction dynamics that enable organizing to emerge provides a context for leadership. Three dimensions of this complexity context are identified and described. A convergent context exists as solutions to pressing problems are sought; choosing direction and promoting efficiency become important when resources are constrained. A generative context for leadership is present when new knowledge or other resources in the environment are more plentiful; in this case, encouraging new ideas and innovations becomes a focus of leadership attention. Finally, the unifying context exists when organizational decomposition, time, space and bureaucracy complicate organizing efforts as they scale up; internal and external boundaries, the flow of knowledge and other resources across them, and the creation of a shared mission and values to hold the organization together demand the attention of leadership in this context. Propositions are developed about the nature and implications of these dimensions at three levels of analysis.

Keywords: complexity leadership, complex systems, multi-level leadership, systems theory, context for leadership

Complexity Thinking & Leadership: How Nonlinear Models of Human Organizing Dynamics Can Inform Management Practice

Complexity leadership theory (Lichtenstein et al., 2006; Marion & Uhl-Bien, 2001; Uhl-Bien, Marion, & McKelvey, 2007) answers the call for an integrative approach to leadership research that includes context (Antonakis, Cianciolo, & Sternberg, 2004) and explores meso-level mechanisms (Osborn, Hunt, & Jauch, 2002). It assumes that leadership occurs within a complex system of human agents interacting with one another (Marion, 1999; Thietart & Forgues, 1995) and that leadership emerges from these interactions and is not imposed upon them from the outside. This paper furthers this approach by framing organizations and leadership using one the conceptual tools from complexity science, namely dynamical systems theory (Guastello, 1998, 2002, 2007). It argues that different complexity dynamics require different types of leadership.

To fully understand the above assertion and the argument that follows, it is useful to consider the epistemological status of complexity science and of dynamical systems in particular, as they relate to human organizations. Few would disagree with the statement that when complexity ideas are imported from the natural sciences and applied to human organizations *as metaphor,* they have been useful for researchers and practitioners as they pursue traditional approaches to management (Thietart & Forgues, 1995). For example, a framework that considers organizations as complex adaptive systems has provided useful insights about the nonlinear impacts of leadership activities (Marion & Uhl-Bien, 2001). However, the question of whether complexity ideas can be applied directly in the study of organizations and of leadership is less settled.

The question remains open partly because there have been formidable challenges in the development of a complexity theory of human organizing. Because humans are learning and remembering beings, the original natural science models of agent interaction and of collective dynamics can only be applied to human organizations using models that greatly simplify human interaction, essentially treating people like interacting particles. This does not mean that a complexity science of organizations is not possible, only that new techniques, and in some cases, new mathematics, must be developed to address the inherent informational complexity of human experience. That being said, even these simplified models have applied complexity science concepts directly to human interaction, not just as metaphor, but also as science (Guastello, 2002; Hazy, 2008c). Few would argue that game theory studies or microeconomics are not science, for example, only because they use simplified models.

Although there have been direct applications of predictive models, the field has yet to reach its full potential. This is due primarily to two interacting uncertainties. First, there are many aspects to complexity science that have grown up in different traditions—the two approaches that form the basis of the present theory, dynamical systems analysis and complex adaptive systems thinking, are only two of these—and these techniques are not easily integrated even in the natural sciences. As a consequence, no integrated complexity-inspired theory of organizations has emerged. Rather, various tools and techniques have been applied to different phenomena in an ad hoc, technique-oriented approach (Hazy, Millhiser, & Solow, 2007; Siggelkow & Rivkin, 2005). With a few notable exceptions such as work by Guastello (2002) and Hazy (2008c), theory driven scientific inquiry has been lacking. Second, theoretical constructs and their inter-relationships remain poorly defined or difficult to measure. This difficulty has led to conceptual papers that cannot easily be pursued empirically (Thietart & Forgues, 1995; Marion & Uhl-Bien, 2001). Finally, conceptual insights can be inferred from case studies inspired by complexity ideas (Plowman et al, 2007; Meyers, Gaba, & Colwell, 2005), for example, but the practical and predictive implementations of their results remain illusive.

The present analysis makes contributions in each of these areas. Regarding the concern that a comprehensive complexity-oriented theory is lacking, the three distinct complexity contexts described herein provide an integrated theoretical perspective wherein researchers and managers can learn to recognize the current dynamical state of their organization. Using this information they can then determine what must be done to enable or to constrain more appropriate dynamics and to monitor progress as feedback to further action. In the end, complexity thinking may provide an entirely new paradigm in organization science, one that includes a predictive theory of individual, organizational and societal events and outcomes (Kuhn, 1970). With respect to the dearth of constructs and variables, the propositions offered herein are a attempt at defining these—as well as the relevant relationships among them—for the purpose of driving empirical research.

To advance my argument I begin with a discussion of key complexity and dynamical systems concepts that will be used in later sections. This is followed by an overview of complexity leadership theory (Uhl-Bien, Marion & McKelvey, 2007; Uhl-Bien & Marion, in press). Next, practical leadership challenges are identified and placed into distinct categories as classified by their underlying complexity dynamics. These complexity contexts—i) one that supports collective convergence toward a common set of objectives, even if they are tacit, ii) one that is generative of new ideas and options, and iii) one that is unifying for the collective in the face of conflicting and possibly incompatible alternative directions—are then described.

COMPLEXITY & THE DYNAMICAL SYSTEMS PERSPECTIVE

The term “complexity” is used in many ways. In common usage, “complexity” is often used in a sense that is roughly equivalent to “complicated.” The phrases “the design of a microcomputer is complicated” and “the design of a microcomputer is complex” are roughly interchangeable in this common usage. In this article these terms are not the same. Here, complexity “refers to a high degree of systemic interdependence, which among other things, leads to nonlinearity, emergent order creation, and other surprising dynamics" (Hazy, Goldstein, & Lichtenstein, 2007, p.4).

One difference is that complicated systems such as microcomputers, electronic systems, automobiles, etc. are often specially designed, or they develop spontaneously, to avoid high degrees of systemic interdependencies and thus to improve quality and reliability. In complex systems, such dynamics are unavoidable and actually define their unique character. Complicated systems can be decomposed into component parts whereas complex systems cannot be decomposed without the loss of their essential character (Cilliers, 1998). This means that complex systems have properties that are not easily inferred from an understanding of the components alone. The interactions among them must also be considered. System properties that arise from complexity are called "emergent" and the process whereby they are expressed as system characteristics is called "emergence" (Goldstein, 2007). In practical terms, this means that most if not all simplifying strategies that are developed and implemented within organizations may generate unforeseen consequences in the longer term, whether for good or for naught.

Complex adaptive systems

A subset of complex systems includes those that are also adaptive as they incorporate and use information about their environment (Holland, 1975). Many systems are complex—fluid flows, atmospheric patterns, chemical reactions, etc.—but relatively few are also adaptive. In addition to being complex, complex adaptive systems (CAS) learn from experience or at least change along side or in response to the changes in the environment. A CAS, by virtue of its hold on its interdependent component parts, maintains itself as a system (Buckley, 1968).

As used in complexity research today, however, the idea of a CAS often follows Holland's (1975) more restrictive definition that refers to a system of interdependent, heterogeneous, semi-autonomous agents. These agents can change individually and in relation to one another, and it is through combinations of these changes along with concurrent fitness tests in the environment, that the CAS adapts and changes, often over several generations.

For the present analysis, it is assumed that organizations can be represented as complex adaptive systems with individuals, or more generally “decision making units” acting as interdependent, semi-autonomous agents. Further, it is assumed that not only do individual agents learn, but information about the environment can be incorporated into the structure of the system of agents (Hazy, 2008c). This latter process is called *structural learning* while the former is *agent learning*. Allen (2001) showed how knowledge about the environment can be incorporated into the system as structural learning. What he called *structural attractors* can be observed in social systems as emergent and persistent internal structures—often with physical artifacts like warehouses or cities—that are continually reinforced by the on-going functioning of the system. The social structure of a “city” becomes an ever better place to trade goods simply because it brings in more goods for trading and so on. The present analysis assumes that the collective as a whole can learn through changes to its structure just as its individual agents can learn. In other words, it assumes that organizations can be understood as complex adaptive systems.

Dynamical systems and attractors

Human organizations often emphasize stability and outcomes and also flexibility and change. Importantly, for managers, outcomes are seen to be desirable, intentional objectives, not simply emergent patterns, and they operate assuming human agents can influence the dynamics as they develop. At the same time, change is expected to be responsive to the environment. In other words, it is important that potential outcomes—both intended and unintended—can be predicted in the context of uncertainty and variance, that changes in the environment can be recognized, and that predictions about both stability and change are considered when evaluating possible projects that are intended to influence the unfolding dynamics of the system.

Unfortunately, the mechanisms whereby desired outcomes result from highly interdependent actions in a complex and changing environment create an exceedingly difficult space for individual agents to navigate (Siggelkow & Rivkin, 2005). Important dual considerations become: i) determining desired outcomes in the face of change and ii) organizing disparate interdependent activities among interacting agents to predict and potentially influence the direction of the system as it moves toward desired outcomes while avoiding undesirable ones.

Dynamical Systems

Dynamical systems are highly interactive and nonlinear in their effects. In many ways they defy simplified analytical models that can clearly predict outcomes. In recent years, however, the development of a robust mathematics of dynamical systems has begun (Abraham & Shaw, 1992). According to an informal definition by Hirsch, Smale and Devaney (2004), “A dynamical system is a way of describing the passage of time for all points of a given space” (p.140). In this case, the “space” being considered does not have to be limited to the 3-dimensional physical space in which we live. Rather, it is an abstraction that represents the space of all possible states of an organization, or of a group or even an institutional field. The “states” refer to values for a set of variables such as employee engagement, sales growth or profitability[1]. Each variable represents a separate dimension in state space. Profitability might be one dimension, for example, while sales growth is another. Note that, for these purposes, the “time” being considered is physical time as measured on the clock and the calendar rather than more subjective conceptions of time in a narrative context as proposed by others (Boal & Schultz, 2007). Time does not cause change; it tracks how the dynamics unfold.

Integrating the micro with the macro

Because dynamical systems models are mathematically described as differential equations, they typically ignore the intricacies of the micro-dynamics occurring in the individual interactions of the CAS. Instead, they assume relationships among variables describing mesoscopic quantities—changing populations with differing characteristics—to identify emergent patterns and structures at the macro level. When a dynamic pattern that connotes stability of some kind is recognized—a constant growth rate, a predictable oscillation in inventory levels, or repeated monthly book closing routines—macro structure can be inferred. According to Haken (2006), when structure results only from internal rules—in other words, outside forces do not impose the structure in the way that a star-shaped cookie-cutter forces cookie dough into the shape of a "star"—these structures result from *self-organizing*. The monthly book close routines mentioned above are imposed by the calendar and would not be self-organized. However, a quasi-periodic "pendulum swing" in inventory levels that's arises from local decision rules would be a self-organized periodic attractor resulting from non-periodic market demand.

In systems where self-organizing processes are occurring, a useful metric to bridge the micro with the macro is the distance measured on a macro scale across which the observed micro-dynamics occurring locally are correlated across the population. To do this, one would measure the extent to which local patterns of interaction are replicated and can be observed broadly across the organization. An example might involve agents acting to maximize the profitability of a particular business unit of a multi-unit firm. The observed range along each of the other dimensions would be that dimension's correlation length for profitability.

Although a precise technical definition is beyond the scope of this article, *correlation length* is roughly the "distance" in state space over which correlation is observed across local decision and interaction rules among agents and the forces that impact them. This correlation implies that agent interaction dynamics are drawn to the same attractors (discussed in the next section). Although it's easier to visualize correlation length in physical terms—the number of miles across which dogs are howling at the moon—the quantity doesn't have to be across geographic distance. It can be calculated along any measureable dimension or combination of dimensions in state space. In effect, it is a rough measure that describes the observable macro-scale effects that are emerging from self-organizing dynamics at the micro-level.

Attractors

In an earlier section I described how structural attractors like warehouses, cities and organizational hierarchy, build upon themselves and attract the activities of the system. It turns out that this idea can be generalized and made mathematically precise. *Attractors* within a dynamical system are defined as subsets or *subspaces* of state space such that once the system's trajectory enters the subspace, it does not exit at any time in the future. Allowable states of the system become trapped within the *attractor* (Abraham & Staw, 1992; Hirsch, Smale & Devaney, 2004).

Simple examples of this phenomenon in human organizations are difficult to justify in the mathematical details for reasons that are described later, but as an illustration, an attractor along the profitability dimension for a firm's dynamical system model might imply that the firm's sustainable profit margin is between 5% and 20% over time. Although early in its lifecycle an organization's performance might fluctuate into and out of this profitability range, once the business reaches a certain critical mass it is likely to remain in this range. This is because circumstances imply that managers and owners make trade-off decisions which effectively maintain the system in the attractor. In particular, excess profits are likely to lead to additional expenditures for business development to fuel future growth or to "feather their nests" in order to make their individual situation better, even as other firms are entering the market to compete for profits. These events would have the effect of reducing profit margins into the attractor range. On the other hand, lower profits would lead to decisions regarding cost-cutting actions to return the firm to acceptable profits so as to avoid the flight of capital to alternative investments. Only a change in the environment (as discussed later) would cause the attraction dynamics to change.

Thus, an attractor is a set of possible organizational states that in some sense "attracts" nearby configurations and draws them toward the attractor state. Even if the specific state of the system is not predictable, one can predict that the system will eventually enter and then remain within the boundaries around the attractor; the solutions are trapped within an *attractor cage.* Action and choices by individuals that occur in organizations whose dynamics are constrained within an attractor cage operate in a *convergent complexity context* where stability is the implicit and often explicit objective.

For dynamical systems, attractor cages can range from simple to complex depending upon the mathematics that describes them. The simplest, a fixed-point attractor, implies that the system moves to a single state; once it's there, it's stuck. This happens because all components converge. A firm heading toward dissolution is an example of this. Once it goes there, it does not change. In the shorter term, a sports team heading for a win would also represent a fixed-point attractor. Once the win is on the books, it is forever. The system is a little more complex when it "just goes around and around" such that the solution is stuck in a *periodic attractor*. The Securities and Exchange Commission's requirement that US public companies file quarterly financial reports never goes away. All across the country accounting departments "go round and round" every quarter, doing the same basic things, satisfying this periodic requirement.

Finally, when one or more of the components diverges (its value tends to infinity), the system can tend to a *complex attractor* when and if other components continue to converge. Of course, if all dimensions diverge there is no attractor at all and the system exhibits disorder[2]. An example of unbalanced divergence is the familiar audio feedback noise from an amplifier where the speaker feeds the microphone which drives the speaker to the microphone, and so on. Finding stable patterns that might imply complex attraction scenarios is a key challenge for management. Situations with divergence and thus where complex attractors might be present are discussed next.

Beyond convergence: Fluctuations and divergence within attractors

Up until this point, the present analysis has implicitly assumed that the dynamical systems under study are deterministic; in other words, there are no surprises. Once initial conditions are known, all future states of the system can be directly calculated. This is clearly a simplifying assumption. In organizational systems, surprises happen all the time. The invention of the microprocessor by Intel was serendipitous and unplanned; it was a surprise (Hazy, 2008a), and it fundamentally changed the operating environment both within the company and beyond it. Not only was this significant event not predictable or deterministic—i.e. it was an experiment at Intel, a "fluctuation" in the underlying stochastic dynamical system—it also introduced divergence and instability into the system[3] with dramatic long term effects. In the process of its divergence, the microprocessor "experiment" created new information about growth prospects along new dimensions: new technology and a brand new market space (Hazy, 2008a).

To understand the dynamics at work in these situations and the role of information, it is useful to apply Haken's (2006) synergetics model. Generalizing Ginzburg-Landau theory that described state changes in physical systems, Haken argued that internal fluctuations in systems—random events such as employee absences or unexpected inventions in business organizations—sometimes introduce a new and divergent component into a system's dynamics. Each divergent component has the potential to introduce new information because divergent components may bring to light previously unrecognized variables that suddenly become important. New information includes surprises that can sometimes be used to predict new emergent dynamics (Haken, 2006).

In the case of human systems, futurists sometimes call the observed information that reflects large scale forces in the environment "weak signals," "long waves," or "mega trends." As these forces create *adaptive tension* on the system, stressing it in the direction of change, new information—surprise—becomes available as events unfold. Sometimes, patterns in this new information can be recognized and used to predict future states of the system in its environment. Building on Haken (2006), opportunity potentials in the environment that shape the organization's changing structure are called *ordering forces*[4] and these can be modeled as *opportunity potential functions* (described later). When pressure from these forces influences agents, when those agents experiment to respond to these forces, and when information about the potential function is recognized by the agents through these experiments, the situation is experienced by the agents as *opportunity tension*. Under this tension, the agents recognize the possibilities and organize to address them.

Resource Constraints and Multi-Stability

In a changing environment, an organization often experiences opportunity tension. Three questions arise for managers as they experiment with new and different approaches. Firstly, how do conditions develop in an organization such that ordering forces can be observed and recognized locally by agents as they solve problems? Secondly, how are these ordering forces identified and modeled as an opportunity potential function so that successful solutions can be implemented and reinforced? And lastly, how do individual actions and choices influence these forces?

A complex adaptive system consists of many semi-autonomous, heterogeneous agents interacting according to local rules (Holland, 1975). Even senior managers, including the CEO, are just agents in this scheme, albeit highly influential ones given their positions in the hierarchy (Hazy, 2008c). Within a local interaction regime, it is exceedingly difficult to perceive larger scale patterns, particularly when they are only weakly defined. When observed at all, they are often seen as anomalies which deserve follow up, but they are not easily recognized as significant patterns.

From the agent's perspective, the demands of maintaining organized stability in human systems can easily be allowed to dominate day-to-day activities and overwhelm attempts to recognize ill-formed patterns. However, if distractions can be set aside and the right experiments undertaken, weak-signals may be recognized. These may contain information about opportunity potential outside the firm. Under these conditions, discontinuous change across the organization can occur as agents gather and use the information and the firm absorbs it into its structure.

Discontinuous change

In dynamical systems, discontinuous change from one stable configuration to another is called *symmetry breaking* because one pattern is broken and replaced with another. When change is among possible future trajectories it is called *dynamic phase transition*. Haken (2006) builds on Ginsburg-Landau theory to describe the symmetry breaking process in general mathematical terms as applied to physical systems. These ideas were applied to organizations by Guastello (2002) who studied nonlinear behavior in human systems at critical points, a field that is called catastrophe theory (see below). The key idea is that changing the constraints on a system (and thereby implicitly changing the parameters in the mathematical equations) can cause its dynamical state to *bifurcate*. This means that the system branches into one of two or more distinct, qualitatively different structures each with its own "symmetry" characteristics. When a system switches from one symmetry state to another, for example when Intel changed trajectories from that of a memory company to that of a microprocessor firm (Hazy, 2008a), it reflected a dynamic phase transition. At or near the bifurcation point, these structures coexist and the system can seem to change back and forth, or be two things at once, depending upon the specific circumstances. A dynamic phase transition does not have to be sudden. Intel was both a memory and a microprocessor company for over ten years as it made the transition (Hazy, 2008a).

Although discontinuous change is not possible from many or even most states of the system, when it is possible, it can be described mathematically. In particular, bifurcation behavior can be shown in equation form using techniques developed in catastrophe theory. Further, in simple cases, a theorem of Thom (1989) implies that for a given number of control parameters (four or less) and a given number of variables (two or less), there exists a canonical equation that describes the systems' behavior at the singularity or bifurcation point. For example, a researcher might be interested in a single measure of performance, $f(Y)$, for a given state of the system in state space, *S*. For example, $f(Y)$ might represent forecasted free cash flow (FCF). Also, recall that a point, *Y*, in state space may be a vector that includes many variables: revenue, costs, number of employees, employee engagement, etc.

For simplicity, I limit this discussion to systems with one state variable and two control parameters although an analogous analysis is possible in other cases. Adopting Guastello's (2002) notation, the forces in the environment that act on the system and potentially cause it to respond are represented as a *potential function*, $f(Y)$, which can be described as follows:

$$f(Y) = Y^4 - k_1 Y^2 - k_2 Y \qquad (1)$$

How the behavior of the system "responds" to potential forces or how the system "changes" as *Y* changes is represented by its *response surface.* This is defined by the first derivative of the potential function. Defining new coefficients and normalizing to eliminate the coefficient of the cubic term for simplicity, this equation can be written as follows:

$$df(Y) / dY = Y^3 - bY - a \qquad (2)$$

Here, *b* is the *bifurcation parameter* which determines when the system can adopt multiple stable configurations, and *a* is the *asymmetry parameter* which describes which symmetry structures are possible. Both of these parameters are described later in more detail. The point of discontinuous change in system behavior, called a singularity, as described in (2), is shown as the point of the cusp in Figure 1 Panel A. This change dynamic is called a cusp catastrophe because the area of bifurcation on a plot of *a* versus *b* is in the shape of a cusp (see Figure 1 Panel B).

As can also be seen in Figure 1 Panel A, as the settings for the control parameters vary, the shape of the response surface, in this example, the change in FCF, also changes. However, a small difference in the parameter settings can imply a sudden change in response at certain parametric settings. There is a range of parameter settings where the dynamics of the response can bifurcate into one of two distinct states. Because changes to certain constraints have this effect, the parameter, *b*, is called the *bifurcation parameter.* Bifurcation can be seen in Figure 1 Panel C.

| Insert Figure 1 about here |

In this example, other constraints on the system implicitly determine a second control parameter which determines which states of symmetry can ultimately be achieved by the system, or if two distinct symmetry states are even possible. This parameter, *a*, is called the *asymmetry parameter* (Guastello, 2002). It determines where on the response surface that the system will be and whether more than one symmetry type is possible and under what parametric conditions. When both the bifurcation and the asymmetry parameters are in their critical ranges, more than one state is possible. Under these limited conditions, a qualitative reordering of the organization is possible. Conditions where the system has multiple futures to choose from constitute a *generative complexity context*. Creating and responding to this context is a key challenge for management.

Shifting among attractors

When an organization is operating in a generative context, identifying a preferred state among multiple possible futures is another challenge for leadership. To find these futures, agents in the organization engage in experimentation to generate information about the intersection between the organization and the environment. Individuals in the organization can gather this information and use it as they attempt to recognize patterns and then infer the presence of opportunity potential in the environment. Choosing to follow these leads to a successful future (or not) is one area where individual decisions can influence system level outcomes.

The generative context exists when the control parameters of the dynamical system have crossed critical thresholds so that a dynamic phase transition—a discontinuous change of state—is possible. Earlier, we showed how these dynamics unfolded at Intel. The invention of the microprocessor entered Intel's dynamical system as an experiment, a fluctuation that included a divergent component in the form of the expanding technology and market opportunity. The potential function in the environment reflected the microprocessor's value to industry and interacted with the divergent component in Intel's experiment (their exceptional fabrication capability that doubled processing capacity annually according to Moore's law) making Intel's attractor cage more complex. The resulting dynamic phase transition took the firm in an entirely new direction.

The specifics of Intel's internal dynamics are described elsewhere (Burgelman, 1994; Hazy, 2008a), but what is important for this discussion is this: i) The invention of the microprocessor represented a dynamical fluctuation that was not extinguished; ii) higher margins from microprocessors enabled a new, higher value attractor cage—including a new set of market and financial objectives—to emerge; and iii) this newly formed attractor cage included divergent components. The presence of divergence implies that the system's trajectory was partially unpredictable because the initial conditions were not precisely known. Due to the divergence, small, imperceptible differences were amplified into very significant ones, a property of complex systems called sensitivity to initial conditions (SIC). The stable/multi-stable/stable transition that characterizes a dynamic phase transition follows the steps seen in Figure 2. As time passed the company moved to the new attractor. This occurred because the organization's dynamics were transformed by new ordering forces in the environment and was accomplished through the intentional actions of agents acting under the sway of these forces.

| Insert Figure 2 about here |

Organizational decomposition & differing contexts for leadership

When one considers how large organizations are necessarily decomposed into smaller components, often hierarchically (Simon, 1962), and further that in human organizations there is an undeniable influence from individual agency on the decomposition process, the complexity puzzle becomes even more intricate. These realities create the potentiality that individuals, and in particular highly influential individuals, will initiate efforts to change the design of the organization. Such changes in design may in fact be fitness enhancing at the system level if the prospects for the whole are enhanced by the effectiveness of its internal structure. Thus, if parts of the system can be insulated from (or opened to) some aspects of adaptive tension, or more directly, if constrains and thus the control parameters within components or divisions can be adjusted downward (or upward), then overall functioning might improve. Importantly, this also creates situations where very different complexity contexts for leadership might exist within the same organization at the same time, perhaps with different types of adaptive tension.

On the one hand, in some divisions and departments within a larger organization or in a start-up organization, the local bifurcation parameters can be adjusted downward by individual choices and decisions. For example, it is a common management practice to establish public commitments and firm timeframes for product delivery (Lynn & Reilly, 2002). This implicitly changes the bifurcation parameter. "Putting a stake in the ground" limits divergent possibilities and thus drives collective activity toward convergence. The practice of management-by-objectives (Drucker, 1954) can be thought of as a process to apply restrictive tension.

On the other hand, constraints can be relaxed in a workgroup or division as a way to implicitly increase its bifurcation parameter and apply opportunity tension. By relaxing constraints, the organization admits the potential for a multi-stable configuration and begins the process of experimentation. This often happens when a new business development team is charged to find a new "breakthrough" product as described by Lynn and Reilly (2002). By providing additional resources of certain types, reducing the distractions of day-to-day short-term routines, and limiting the politics of power relationships, the divergent components that emerge during experiments can be more fully explored and developed. Along the way, multiple future states—several product possibilities—can become evident. The challenges for individuals who are trying to hold the whole organization together in the face of both local convergence and local generative dynamics are key elements of leadership within a *unifying complexity context*.

THE COMPLEXITY LEADERSHIP PARADIGM

In 2001 Marion & Uhl-Bien called for leadership researchers to consider complexity ideas in their models. Since then, theoretical models have emerged that attempt to integrate complexity and leadership. What these approaches have in common is a re-conceptualization of leadership as a process that emerges from interactions among agents. The present study contributes a common theory of how leadership operates differently depending upon the complexity context.

Complexity Leadership Theory

Complexity leadership theory (CLT) as described by Uhl-Bien, Marion and McKelvey (2007) and further specified by Uhl-Bien & Marion (in press) takes a practical look at organizations and the limitations of traditional leadership theory. In their approach, leadership has three interdependent aspects: administrative, adaptive and enabling. *Administrative leadership* describes what individuals experience as management within a bureaucracy, not in the negative sense, but in the idealized sense (Marion & Uhl-Bien, 2007). This model assumes that in most organizations, policies, roles, tasks and hierarchy are often a "given." Actors operate within these structures and as such continually promote, maintain and sometimes change these social structures (Giddens, 1984). Formal leaders often assume many administrative leadership activities.

Because traditional research in leadership generally assumes the above context, complexity leadership focuses more directly on *adaptive leadership*, the process that brings about change. Adaptive leadership focuses on outcomes related to innovation. In particular, it refers to the interactions among agents that generate experiments and nurture successful ones to grow with new markets (Uhl-Bien & Marion, in press).

Finally, *enabling leadership* holds these processes together within an organization. This aspect of leadership works to balance administration and adaptation. How, for example does an organization continue in its current structure and also change in ways that allow it to adapt? The present analysis makes a contribution to the resolution to this conundrum.

***Leadership* and *effective leadership* defined**

In related work, complex systems leadership theory (Hazy, Goldstein & Lichtenstein, 2007) begins with a complex systems view of organizations. It seeks to understand how leadership is a necessary and constructive endogenous aspect of human social systems. In this sense, leadership is considered to be a system mechanism that promotes both bottom-up, self-organizing processes that result from experimentation and a top-down executive function that makes meaning (Gioia, & Chittipeddi, 1991).

For the present analysis, we follow Hazy, Goldstein and Lichtenstein who argue: *Leadership in complex systems* "takes place during interactions among agents when those interactions lead to changes in the way agents expect to relate to one another in the future" (p.7). Note that this definition is descriptive and does not make a judgment about the value or effectiveness of the mechanism; it only describes the mechanism or changing local rules of interaction among individuals. The authors acknowledge this and go on to say: "*Effective leadership* occurs when the changes observed in one or more agents (i.e., leadership) leads to increased fitness for that system in its environment" (p.7). Since fitness is defined only in relation to a particular system and some metric of survivability for that system, especially in terms of evolutionary selection, the "effectiveness" of leadership depends on the metric that is chosen. Thus effective leadership is only defined with respect to a particular system and a chosen metric; it is context dependent. As we discuss next, what constitutes effective leadership also depends upon the dynamics inherent in a complexity context. What was effective yesterday might be abysmal in a new ordering regime, and visa-a-versa, of course.

COMPLEXITY CONTEXTS FOR LEADERSHIP

Organizations exist within markets, institutional fields, and cultural norms. Each of these impacts not only the organization, but also its leadership. When an organization is represented as a stochastic dynamical system of interacting individuals in a complex adaptive system, the specific meaning of and variations in *complexity context* can be defined. In particular, there are constraints on the system such that changes in the environment (outside the boundary) put pressure on the system in various ways. These pressures create heterogeneous stress across the system that is called *adaptive tension* (Uhl-Bien et al., 2007). The specific nature of the adaptive tension determines the complexity context at work and the leadership approach that is appropriate.

Adaptive tension exists because there are significant differences in resource levels at various places in the organization as well as within the organization versus beyond its boundary. When adaptive tension arises due to limited resources outside the system, constrains to the system's internal dynamics are perceived and pressure to conserve resources builds inside the system. Beyond a certain threshold, as experimentation and fluctuations are seen as extraneous and costly, convergence toward an attractor dominates agents' actions and the system's dynamics. In contrast, when resources beyond the boundary are perceived to be plentiful constraints are relaxed in an effort to gain access to these new resources. Beyond a threshold, more experimentation is likely as information is gathered. With enough information and analysis, agents can potentially recognize the opportunity potential function that is driving the organization's emerging dynamics and take action to realize this potential.

Changing dynamics and complexity contexts occur in relation to bifurcation points. As the constraints vary from those pressuring for convergence to those enabling experimentation and learning—or the reverse—the leadership approach that is most appropriate also changes. Gersick (1989) described "punctuated change" in a work team, an example of a changing context. When the time remaining to complete a project dropped below a threshold value—the time constraint was tightened—in a sudden transition, the team that had been exploring options became more focused on completing the task. This is a sign of bifurcation and of convergence.

More generally, the *rate of experimentation* that occurs in an organization or group varies as adaptive tension changes and may include a bifurcation point. The level of adaptive tension at each location within an organization determines the complexity context in which leadership must occur. The above implies a proposition:

Proposition 1: *When constraints on an organization's resources and information are increased or relaxed—i.e. when adaptive tension is applied—there is a* ***positive nonlinear relationship*** *between the relative* ***level of resources*** *perceived to be available from the environment and the* ***rate of experimentation*** *in the organization. Under certain conditions there is a bifurcation point below which little or no experimentation occurs and above which it occurs and is encouraged. The bifurcation point reflects a change in the direction of flow in resources across the boundary.*

These conditions can be specified a priori, relating, for example, to group-level, organization-level, and environmental variables, and would apply as a general matter to all organizations and across organizational levels. In other words, one could predict whether experimentation would occur and at what threshold of adaptive tension it would begin. Below I describe in more detail all three types of adaptive tension and discuss how they define different complexity contexts for leadership.

Types of adaptive tension

Adaptive tension on the organization arises from differences in the relative availability of various resources and information both inside the organization and in the environment. Adaptive tension is experienced as constraints to choice and action. It arises as different levels of financial, physical, human, technology, information or energy resources are perceived to flow across various internal and external boundaries. The financial crisis of 2008, the glut of telecommunication investment capital in the 1990's, and a shortage of accountants, are all examples of how relative resource availability impacts organizations in ways that create adaptive tension.

Constraints on resources implicitly determine the control parameters that in turn guide the dynamics of the organization. Depending upon the values of the parameters, these changing resource constraints can qualitatively change an organization's internal dynamics from a convergent context to a generative one and back again. In doing so, the context in which leadership devolves likewise changes. The same organization might also experience both of these at the same time for different resources in different work groups or even in the same workgroup. Black and Boal (1994) showed how resources interact to produce varying, although equally efficacious, business strategies. Such complexity implies the need for a unifying context.

Restrictive tension implies a convergent context for leadership

In certain cases, adaptive tension results from a perceived decrease in physical and knowledge resources that are available to the organization from the environment. As an example, economic hardship like the 2008 and 2009 recession or recruiting difficulty might limit the options that are available to leaders and the organization. In tight capital and credit markets, organizations are forced to conserve resources and growth is limited to projects that can be sustained through their own internal funding mechanisms. This is a constraint that reduces the bifurcation parameter implicit in the firm's organizing dynamics such that a simpler path forward becomes clear. Restrictive tension forces the firm to limit its options and to do what it does well. This singular focus comes at a cost to the firm; along the way, new opportunities might be missed.

Restrictive tension stresses managers to encourage increased efficiency, specialization or contraction. As Gersick (1989) showed, time is an important resource in this sense. Setting fixed, externally driven deadlines has been shown to be an important determinant of breakthrough innovation projects such as the Apple IIe and others (Lynn & Reilly, 2002). These same studies showed that other externally imposed constraints or requirements—for example, design-to-cost or designing for minimum price points—also encourage innovative success (Lynn & Reilly, 2002). Adaptive tension that applies pressure toward more efficient use of the limited resources that are available from outside the system is called *restrictive tension.* This constraint acts implicitly to reduce the value of the dynamical system's bifurcation parameter and pressures action toward convergence. Applying resource constraints puts pressure on the system to converge, to "solve" the problem, to do something, to stop discussing and get on with action.

Restrictive tension can be applied by uncontrolled events in the environment or it can result from intentional acts by agents. Restrictive tension pressures the system to draw back from a more complex, less predictable attractor cage to a more predictable one. From a practical perspective, this translates into constraining the system by setting a limited number of clear objectives, articulating and enforcing a clear plan to get there and trimming nonessential activities. Restrictive tension constrains work groups forcing them into simpler attractor cages. In other words, the organization becomes more "structured" around a more predictable future state. This implies a proposition:

Proposition 2: *Under restrictive tension, when a resource is constrained (for example, human resources, time, money or knowledge) below a threshold, tolerance for experimentation in the local work group will become negligible and efficiency will be prized.*

Effective leadership promotes convergence within an attractor cage

To the extent the organization is observed to exhibit a level of stability within an attractor cage, it follows that this stability is also reflected in its independent variables such as labor, capital, technology and market prices. Identifying these variables, forecasting them and making adjustments to sustain them within the attractor cage becomes a preoccupation of management in a convergent context. Restrictive tension pressures the attractor cage toward a simpler structure with greater clarity. At the individual level, with increased certainty a more directive leadership approach becomes possible. At this level, convergent leadership facilitates meaning among interacting agents by initiating structure and providing clear direction (Silberstang & Hazy, 2008).

There is a dark side of convergent leadership as well. When questions are raised and novelty arises in the system, they occur within a tightly managed attractor cage. Enforcement processes that sustain the status quo can have negative consequences by crowding out ideas. This happened after Xerox invented the personal computer. Their management did not pursue the invention because it didn't support the firm's strategy (Smith & Alexander, 1988). Leadership in a convergent context can be intolerant of alternatives that do not support its current attractor.

Unlike physical systems, organizations do not automatically follow forces in the environment; they must be brought into convergence by the choices and actions of their members. In fact it is these choices and actions that are of most interest. For an organization to begin to converge, an attractor cage must be identified by certain agents and its nature must be articulated by them so that they and other agents can make choices and take actions according to a program of action (Hazy, 2008c) that bring about stability. This is a collective endeavor and is the essence of meso-level leadership in a convergent context. In social systems, self-organization and emergence don't just happen; they are constructed by the coordinated actions of individuals (Goldstein, 2007).

Leadership adjusts constraints to maintain convergence. For example, even in times of plenty, the budget for the back office can be cut and hiring can be frozen to facilitate a convergence context within support functions. Leadership in this context might involve stiffening boundaries or decreasing their permeability (Hazy, Tivnan & Schwandt, 2004) to actively limit the availability of resources beyond the boundary. Alternatively, leadership might enable convergence toward operational capabilities (Helfat et al, 2007) by enabling transfer pricing mechanisms, inventory management processes and working capital management routines.

When managing the organization or is parts under restrictive tension, leadership orchestrates the exploitation of a given stock of resources at all levels. As these tensions change, the leadership challenges that must be addressed also change, and they do so at all levels of analysis including toward an aggregate attractor cage at the organization level. This leads to a proposition:

Proposition 3: *Tightening constraints beyond the bifurcation threshold brings an organization into convergence toward simpler attractors.* ***Effective leadership*** *in this context operates on constraints and indirectly* **promotes stability.** *It can be evaluated at three levels of analysis:*

1. *At the* **micro level**, *individuals adjust constraints (roles, tasks, timeframes, etc.) to below threshold levels so that group members experience "restrictive tension" and respond to simple goals and clear direction.* ***Effective leadership*** *implies that process stability increases among individuals within locally defined attractor cages. However, this attractor may or may not be appropriate for the system overall. The appropriateness of these local attractors depends upon the effectiveness of leadership at the meso-level.*

2. *At the* **meso** *level, leadership articulates programs-of-action for work groups and these become attractors. It adjusts constraints (budgets, boundaries, timeframes, or knowledge resources) to apply restrictive tension on groups, subgroup or individuals.* ***Effectiveness*** *relative to aggregate performance is stability with respect to the attractor cage identified for the aggregate system, for example through profitability or growth targets. However, this aggregate attractor may or may not be successful in the environment. Making appropriate choices for the environment relates to effective leadership at the organization level.*

3. *At the* **macro** *level, when restrictive tension in the environment goes below a threshold level, agents in organizations will attempt to stabilize their performance with respect to a simplified attractor cage such as managing for profitability by valuing consistency, limiting experimentation and enforcing compliance.* ***Effectiveness*** *is stability with respect to an organizational attractor cage and sustainability for the system in the environment.*

Opportunity tension implies a generative context for leadership

Adaptive tension can also come from a perceived increase in access to resources in the environment—whether due to growing demand for the firm's products and services, ready access to financial capital, favorable human and social capital markets or new technology. An environment or market that is flush with resource potential places different demands on leadership which seeks to take advantage of opportunities. Meyer, Gaba, and Colwell (2005) described several industrial environments—nanotechnology being one—with great opportunity. A resource rich environment like those described above creates *opportunity tension* which can be modeled as an opportunity potential function. The resource rich environment effectively loosens constraints and thus implicitly increases the bifurcation parameter. If the threshold is crossed, qualitative change is possible, but it is not assured.

Organizations operating in resource rich environments represent a qualitatively different context for leadership. Stability is no longer the driver; it is opportunity. When information and knowledge are taken to be resources, changes in the environment create opportunities and generate information. When markets, technology, demographics, political or economic conditions change, available information may be gathered and used by agents as they interact with the environment. From this new information, opportunities may become apparent even in otherwise dire situations.

Plowman et al (2007) described a Mission Church under stress due to changes in the community. What had been an affluent church was increasingly embedded in a community with deep social problems. Early leadership regimes looked at declining financial resources and implicitly identified this as a convergent context. They sought to strengthen boundaries to preserve resources, separating the church from the outside world as a means to hold the line against encroachment from the community. These choices only slowed the decline because the system was still constrained by restrictive tension with respect to financial resources. It was only after new leadership acted counter-intuitively to open the boundaries of the church to new members with new experiences and ideas—new information flowed across the boundary—that renewal began. The relaxed constraint led to an inflow of human capital with new knowledge. It was not long before this new awareness and knowledge about the community and its needs was generating new opportunities for the church system within its broader community.

Similarly, early in its existence Apple Computers experienced an inflow of capital after its IPO and its market success. As a result, new possibilities emerged. This led to new projects from which the Apple IIe (Lynn & Reilly, 2002) and eventually the Macintosh (Linzmayer, 2002) emerged. Likewise, when the young Starbucks expanded to a new market in Chicago, the possibilities of increased geographic reach brought a flush of human resources and customers within this broader ecological system that, even in the absence of financial capital, offered new market opportunities that were previously unavailable. This environment led to many breakthroughs in both products and process. For example, they invented a way to package and transport coffee while retaining its freshness (Shultz & Yang, 1997). The relaxation of constraints to allow an inflow of new resources and information is experienced by individuals as *opportunity tension* in the organization when an opportunity potential function is identified in the environment.

In their study of a Mission Church described above, Plowman et al. (2007) observed the regeneration of a community in decline. The transformation seemed unintentional, even serendipitous to those inside. This is not always the case. Such change can be intentional and can be the result of leadership. Surie and Hazy (2006) described an intentional regeneration of an Indian automotive firm from a small domestic equipment company into an international player in automobile manufacturing. When constraints are relaxed, experiments occur, and opportunities are recognized. These conditions imply a *generative context for leadership*. They do not imply that adaptation actually happens, however, only that experimentation and the potential recognition of opportunities (and a potential function) occurs.

The common element in stories of successful organizational renewal like those above is the simultaneous presence of two things. First, there is experimentation, and within some of these experiments a larger effect is uncovered that is characterized by some kind of previously unnoticed divergence, something new that won't go away. Second, the organization's dynamic fluctuations, its improvisations, experiments, and new approaches—including components with divergent dynamics—take place within an environment that reflects ordering forces and an opportunity potential function that is playing out over a longer time scale.

In the case of the Indian automotive firm described earlier, partnerships with foreign firms were used to expand the firm's internal capabilities. During these interactions, however, the firm's aspirations with respect to future customer possibilities also began to expand, to diverge. Information about foreign markets introduced expanding opportunity potential into their previously narrowly defined market scope that was limited to a well-identified set of local customers, a fixed point attractor. As foreign partnerships became more common in the firm, the new potential involving distant market opportunities opened new market space for the system (Surie & Hazy, 2006), and the firm's attractor cage became more complex. When resource constraints and thus control parameters are loosened beyond a threshold, novelty that expresses divergence along some dimension may open new possibilities for the organization. This discussion implies a proposition:

> ***Proposition 4:*** *When conditions change or agent actions occur such that resource constraints on the system are relaxed, opportunity tension increases in the organization or group. Beyond a threshold value, the bifurcation point, and under the right parametric conditions, a generative context results wherein leadership relates to activities that gather, share and process new information, try out and experiment with new approaches and ideas, and organize to take advantage of potential opportunities.*

Leadership and the emergence of novelty within organizations

No individual in any organization is completely isolated from the environment. In fact, it is a characteristic of human systems that each individual interacts with the environment every day. Thus an organization's boundaries remain permeable to information flows both into and out of the system (Hazy, Tivnan & Schwandt, 2003). When the information flowing into the systems is relevant to the organization, for example when it clarifies what the community needs and expects from the organization as happened at Mission Church (Plowman et al., 2007), the organization exists in an information-rich environment.

Interactions that occur inside the system—like those among the engineers that invented the Intel microprocessor (Hazy, 2008a)—involve the processing of information that may be brand new to the system and was previously invisible to the agents. Information from fluctuations in behavior along the newly discovered dimension, an emerging market or technology, might at first appear random. If the information signal is detected at all, it would most likely be discarded as noise. But the fluctuations may actually suggest an entirely new direction is possible. When new ideas emerge in this way, the leadership interactions that enable them have been called adaptive leadership (Uhl-Bien et al., 2007). Dynamical systems techniques have been used to study the process of creativity and the emergence of new ideas among individuals and in groups (Guastello, 2002). Changes to group direction that emerge from these activities may or may not align with the overarching organizational direction. As such, they may appear disconnected from the system as a whole. On the other hand, they may also represent local novelty that may ultimately spread across the organization as an emergent global property—for example, Intel became a "microprocessor company"—that changes the direction of the larger organization.

As novelty emerges in teams, it is important to recall that although it occurs locally, the team also interacts with the larger organization which is part of the team's environment. Local novelty occurs at different points within the organization, and it is influenced by internal resource flows. These flows reflect the stresses put on the system by adaptive tensions beyond the organization's boundaries certainly, but they also reflect decisions taken within the system itself. The diffusion of innovation in organizations has been described using dynamical systems techniques (Latane, Nowak, & Liu, 1994; Jacobsen & Guastello, 2007)

The extent to which local novelty has seeded self-organizing at the macro-level—new structure resulting from internal processes but under the influence of nonspecific external forces—activities across the system are correlated in a type of symmetry. Macro-ordering of this type can be measured with correlation length at the system level. This is the "distance" in state space across which correlations in micro-dynamics remain significant. The importance of the correlation effect was visible at Intel with respect to their common process technology extending across both memory and microprocessor work activities (Burgelman, 1994; Hazy, 2008a). At the Mission Church, service to the community emerged as a common value in the clinic, in the soup kitchen and across other initiatives, a correlation in values across the whole organization that held it together.

The above descriptions raise the question about when and how leadership relates to the emergence of local novelties and how they become successful innovations for the organization overall. When leadership is effective, the combination of local novelty and selected positive feedback can result in extending correlation length at the organization level. This happened at Intel, albeit with serendipity (Hazy, 2008a). It also enabled Apple to develop the same technologies (Linzmayer, 2002; Lynn & Reilly, 2002) that Xerox could not (Smith & Alexander, 1988). Innovation that is grown in this way may involve spreading changes to routines or organizational capabilities (Helfat et al, 2007), or it may involve the spreading influence of new product or technology ideas (Christenson, 2000).

These dynamics represent leadership at all levels of analysis where future possibilities are generated for the organization. Effective leadership in the generative context means that somewhere within the organization, resource constraints have relaxed beyond the bifurcation point along at least one dimension, that appropriate experimentation is occurring, and that information is flowing through the organization to enable correlations across significant "distances" in state space. This leads to a proposition:

> ***Proposition 5: Effective leadership*** *in a generative context* ***identifies and nurtures opportunities****. It can be evaluated on three levels:*
>
> 1. ***Effective leadership*** *at the* ***micro*** *level relaxes resource constraints beyond a threshold to encourage boundary spanning, learning, communication, the exchange of ideas, experimentation and thus* ***promotes the emergence of organizational novelty****. The novelty may or may not be useful for the organization.*
>
> 2. ***Effective leadership*** *at the* ***meso*** *level indirectly regulates resource constraints at local points across the organization and thus varies levels of experimentation, manages the flow information, knowledge and feedback and* ***expands correlation length*** *with respect*

to positive novelties in the system. This expanded order regime may or may not enhance the organization's overall survival potential.

3. *At the **macro** level, **effective leadership** in a generative context **relates to increased growth in new and adjacent markets** according to the opportunity potential function.*

Decompositional tension implies a unifying context for leadership

Due to geographic and social status heterogeneity, local conditions and local access to various types of resources are not uniform for all parts of the organization. Thus, adaptive tension is also not uniform and can be manifested locally as restrictive tension or as opportunity tension depending upon the resource in question, the location of the group within the organization, and the system's structure and boundaries, both internal and external. For instance, tensions may vary across different product families or divisions in a business or among various agencies in a non-governmental organization (NGO). As an example, a shortage of accountants in New York City might place restrictive tension on the finance department there even as other locations are flush with highly skilled accountants who are being encouraged to try out new ideas and approaches. At the same time, sales might be booming for the company overall creating opportunity tension for the organization in its markets. By synthesizing these various contexts, the theory describe herein provides additional insights into the dynamics of both exploitation (a convergence context) and exploration (a generative context) that are described in the literature on ambidextrous organizations (Gibson & Birkinshaw, 2004).

In large organizations there is prior organizing structure and hierarchy, and these can act as structural attractors, protecting some pockets from fluctuations and innovation and nurturing innovation in others. Internal boundaries, seams and silos that remain from the organization's prior history can distort the flow of resources inside of the organization until the patterns that are experienced on the boundary of the organization are lost or remain invisible to those inside. It is not surprising that those charged to maintain stability in the organization are often found supporting prior structures rather than identifying and reinforcing emerging ones that might be destructive to the prior order (Christensen, 2000).

In complexity leadership theory, the activities which support the current structure and hierarchy are called administrative leadership (Uhl-Bien et al., 2007). Visibility to the outside environment can be obscured for these individuals, so that they act with little or no awareness of the larger adaptive tensions or opportunities in the environment. Xerox's Palo Alto Research Center (PARC) famously invented the technologies of personal computing—including the mouse, the laser printer and the graphical user interface. But management missed the opportunity because decisions were made by administrative leaders at headquarters who were guided by backward-looking structural attractors in the organization such as their "strategy" (Smith & Alexander, 1988).

Because organizations are decomposed into components, external adaptive tension pressure is not propagated uniformly throughout the system. In this process, relevant information about the environment may be overwhelmed by this internally generated noise. This effect—called *decompositional tension*—would be observed as inter-group conflict and confusion caused by resources flowing around barriers and obstacles in the organization just as a flowing river forms rapids around rocks in the riverbed.

The above illustrates the challenges inherent in complex dynamics. As things change—as the system diverges in one way or another—a sense of "unity" among disparate groups, some perhaps operating with incompatible attractors cages, must be maintained to hold a system together. The divergence introduced through the nascent clinic at the Mission Church might have been incompatible with the divergence introduced by the soup kitchen (Plowman et al, 2007). This conflict might have split the organization into two irreconcilable community-service groups, each with a distinct attractor cage incompatible with the other. Unity had to be maintained in the face of divergent dynamics. Convergent variables like shared values or a common mission had to be reinforced within a common attractor to retain the system within its increasingly complex attractor cage. If this was not accomplished, the system overall would diverge and thus lose its identity as an ordered state.

Decompositional tension implies that within the same organization it is likely that some parts will have more than adequate resources of certain types and others will have less. Those with resources (and that are above the bifurcation point) have the potential to explore and learn about new phenomena. This learning may introduce divergence into the system, and this divergence might, in turn, resonate with ordering forces that are acting on the system. Those parts of the system under restrictive tension (below the bifurcation point) will struggle to preserve what they have. These differences create the need for an internal management focus aimed at gathering and preserving access to resources, adjusting flows and restructuring the organization for more appropriate functioning in each of these contexts. Leadership that navigates decompositional tension occurs in a *unifying leadership context.* These observations imply a proposition:

> ***Proposition 6:*** *The presence of* ***decompositional tension*** *implies that* ***effective leadership*** *also* ***focuses on unifying*** *activities that evolve local and global attractor cages to maintain stability by reinforcing a common convergent dimension such as a vision, mission, strategy or shared values. For example, unifying leadership resolves conflicts between pockets with a generative context versus those with a convergent context by establishing, breaking down and reestablishing internal and external boundaries while appealing to overarching shared values or beliefs.*

The unifying leadership context: The mixing & coupling of the whole

One observation from complexity science is that the seeds of novelty and change occur locally and emerge from local interactions. Novelty spreads across the organization through an information transport and mixing process. As described in the previous section, this is because heterogeneity of information and individual attributes can lead to unpredictable results. Local novelty can be quickly dampened and eliminated through convergent leadership, or it can be reinforced with generative leadership. Information about novelty spreads across the system through unifying leadership. The specific complexity context that is at work depends upon the local intra-organizational environment in which it is occurring. This in turn depends upon the local resource constraints, where they are, and whether relevant thresholds are overcome.

These ideas illustrate the importance of transporting information from place to place in the organizational mixing process. To do this, an information signaling network (Holland, 2001; Hazy, 2008c) is needed to enable information transport and coupling among pockets of novelty. This network provides a level of coherence among different locally emergent phenomena and an expanding correlation length with respect to the rules of interaction governing agents' behaviors. A network of this type was observed over 18 months in a 50 person venture capital backed company where the individual agents responded to leadership influence (Hazy, 2008b). The spread of leadership initiatives—both top down and bottom up—could be observed as their influence diffused through the organization's communication network. If there is communication between a group and its neighbors, the novelty—such as a leadership initiative—may be imitated in its local neighborhood and then replicated broadly. As more units adopt the initiative, an ever increasing number of others become exposed to it and learn the practice. As a result of an information transport process like this, the number of those who have adopted the practice increases and correlation length expands, an indication that self-organization is occurring through agent interactions.

It is often assumed that in a large organization, communication is primarily top-down with the downward articulation of strategy being the major flow of organizing information. Research in upper echelons and top management teams (Hambrick & Brandon, 1988; Waldman & Yammarino, 1999) as well as a good deal of transformational leadership (Bass & Avolio, 1994; Bennis & Nanus, 1985; Kouzes & Posner, 1987) and charismatic leadership (Conger & Kanungo, 1987; House, 1977) research implicitly make this assumption: The leader articulates a vision and people organize around that vision.

The complexity paradigm offers a different perspective with bottom-up and side-to-side communications given parity with the top-down channel (Lichtenstein et al., 2006; Panzar, Hazy, McKelvey, & Schwandt, 2007). Siggelkow and Rivkin (2005) explored how upward information flows impact decision making and found exceedingly complex relationships, a situation that is particularly germane in decentralized organizations (Solow & Szmerekovsky, 2006). The critical question in complex adaptive systems is how disparate organizing projects that emerge locally eventually become part of a coherent whole.

Bottom-up, emergent novelty implies a level of coherence among participating agents, but there is no guarantee that these activities are related in any way to a broader organization. The Xerox PARC example earlier shows that profound invention at one location does not necessarily translate into relevance at the organization level (Smith & Alexander, 1988). Pockets of novelty are not necessarily part of an innovation system. They become innovation within a larger system when non-trivial correlation lengths are observed at the organization level along one or more of the dimensions that define the system's attractor cage (Hazy, 2008c). The transformation of Intel is an example of this. Over time, the dynamics of the "microprocessor project" expanded their influence and eventually governed other interactions that were occurring in operations, engineering, marketing and eventually even the executive offices. By recognizing the change to Intel's business, Andy Grove rose to the office of CEO (Burgelman, 1994; Hazy, 2008a).

In the venture backed software company described earlier (Hazy, 2008b), correlations could be seen in the production group and in sales, but less so across departments. Other dimensions might include: key technologies, a key enabler of Wal-Mart's success (Slater, 2003), a common skill-set among employees, the enabler of IBM's transformation in the 1990s (Gerstner, 2002), or financial performance metrics which drive conformity across conglomerates such as the General Electric Company (Slater, 2001). Supplier agreements, divestitures, acquisitions or outsourcing contracts, change system boundaries to approximate the extent of coherence along various dimensions (Williamson, 1975).

Adaptive tension in the environment and especially decompositional tension within the organization can make the unifying context difficult to navigate. As a signaling network is implemented and boundaries are navigated, one would expect that effective leadership in a unifying context would enable and reinforce correlations of substantial length that "hold the firm together". This implies that leadership creates a coherent *structural core* with correlation length that spans the organization along at least one dimension. For example, organizations with effective leadership would be expected to have a more coherent strategy, a heightened sense of mission, and a strong organizational identity with a correlation length across all agents in the organization (Hazy, 2008c). Taken together, these ideas imply a final proposition:

> ***Proposition 7: Effective leadership*** *in a unifying context enables and promotes* ***correlations in agents' attitudes, values and behaviors that span the organization****. It can be evaluated at three levels of analysis:*
>
> 1. ***Effective leadership*** *at the* ***micro*** *level* ***relates to*** *defining common symbols, grammars, lexicons, meaning and interaction protocols among individuals and groups to facilitate* ***the transmission of organization-relevant information between the workgroup and the system****.*
> 2. ***Effective leadership*** *at the* ***meso*** *level* ***relates to establishing a multi-directional signaling network*** *to identify and channel relevant signals through the organization as a whole to couple organizational units and maintain coherence along relevant dimensions, a process* ***that can be measured by correlation length*** *in various regimes.*
> 3. *At the* ***macro*** *level,* ***effective leadership*** *in a unifying context is positively related to organizational attributes such as a coherent strategy, a common sense of mission, a shared organizational identity, a positive climate and high levels of employee engagement, that together form a coherent* ***structural core*** *that spans the organization.*

Taken together the theory and propositions described in this article represent an overarching typology of the various complexity contexts in which leadership occurs and what differentiates leadership focus in one context versus another. This typology is summarized in Table 1.

| Insert Table 1 about here |

CONCLUSION

The complexity of human systems implies an endlessly changing environment wherein the organization and its leadership must react and adapt. Unlike physical systems, human systems rely on the choices and actions of agents to organize them. These ever changing dynamics also imply that leadership in organizations faces different challenges depending upon the specific complexity context that is encountered.

In some cases, when part of an organization is under *restrictive tension*, leadership responds to help the system converge to an attractor that uses resources more efficiently. In this context, one would expect more centralized, traditional management structures—aspects of this have been called administrative leadership (Uhl-Bien et al., 2007)—to emerge as a dominant mode of organizing. In other cases, the leaders of an organization might find themselves in a relatively fecund ecology where resources are plentiful. However, information is distributed and thus difficult to interpret. In this case, *opportunity tension* creates its own demands on leadership. Potentially divergent novel approaches to organizing are encouraged and, if useful, must be nurtured and amplified. Encouraging innovation in this way has been called adaptive leadership (Uhl-Bien et al., 2007).

Decentralized decision-making and locally generated resource pools present their own challenges to leadership which must work to foster change and fight off disintegration of the whole even as these dynamics occur in the context of past history. *Decompositional tension* arises when resource flows within the organization are distorted by emerging and historical organizational structures. Because of this distortion, many actors experience complexity contexts that are only indirectly related to what is actually occurring in the environment.

Leadership dynamics impact the level of fitness achieved by the system in the environment. In particular, novelty and its mixing and coupling within and across the system may help the organization and its members act in new ways to enable the system to adapt. However, regardless of the organization's internal dynamics, there are also evolutionary selection pressures at work in the environment such that some organizations fail while others survive. A unique aspect of human systems is that survival often implies that the organization can replicate its processes in other organizations as Toyota has broadly propagated its system into other manufacturing companies beyond its boundaries. This occurs as agents change affiliation or through formal knowledge transfer initiatives. It is important to note that surviving organizations have presumably developed leadership capabilities within the convergent¸ generative and unifying contexts, and these increase an organization's survival potential. As agents move around and as these dynamics are imitated by other organizations, organizational forms evolve in the environment and the leadership meta-capability described by Hazy (2008c) expands.

The approach described here uses the complexity science tool-kit to describe leadership in mathematical as well as practical terms. Researchers can model leadership approaches computationally to simulate and predict expected outcomes. If these predictions are supported empirically, perhaps a deductive approach to leadership research can emerge as a full and useful complement to the inductive approaches that have thus far characterized the field.

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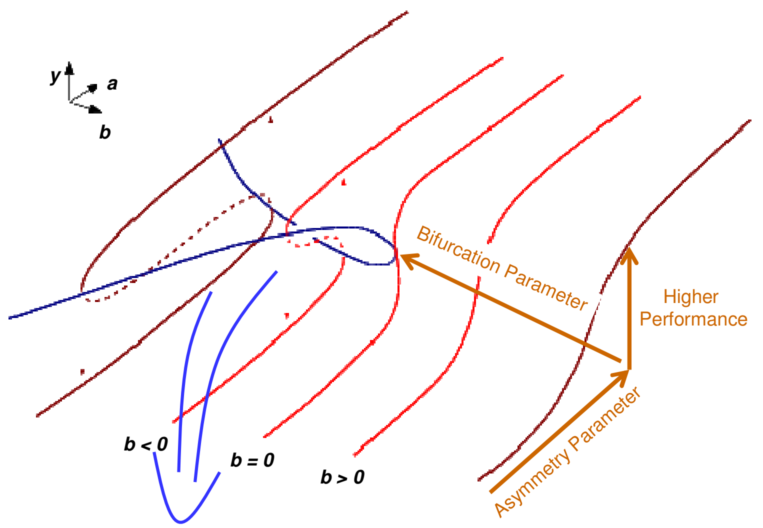
Table 1.

A typology of leadership contexts in complex organizations at three levels of analysis.

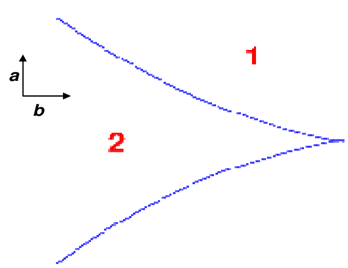
	Convergent	**Generative**	**Unifying**
Micro: Individual and intra-group interactions	Wasteful or distracting actions must be dampened to enable a stable program of action and constraints must be adjusted to create a simpler attractor cage.	Information sharing and creative interactions are needed to enable the emergence of novel ideas.	A common language and symbols are needed to enable mixing of novelty and to couple disparate units with one another and with central groups.
Meso: Interaction across groups and divisions	Change may cause bifurcations to bi- or multi-stable states; groups must choose a future (attractor cage) and adjust resource constraints to enable convergence to it.	Inter-group feedback processes (positive & negative) needed to select, reinforce and spread positive novelty by using a signaling network.	A signaling network and changing internal and external organizational boundaries and interaction protocols among them are needed.
Macro: Organizations and divisions	*Restrictive tension* creates pressure for clear and consistent objectives and stable performance along publicly identified metrics.	*Opportunity tension* creates potential for multiple futures and for innovation, adaptation & growth.	*Decompositional tension* can be leveraged and/or mitigated to provide a coherent strategy and a common organizational identity across a structural core of a common mission and values.

Figure 1. **Panel A:** In projection of a three dimensional plot (see dimensions in the top right), system performance is represented by the surface lines and responds differently as control parameters change; under certain parameter setting two stable solutions are possible. This situation is visible in the range where b < 0. **Panel B:** Cusp shape in parameter space *(a,b)* near the catastrophe point separates the region with two stable solutions from the region with one. **Panel C:** A different 2-dimensional projection showing pitchfork bifurcation at *b=0* projected on the surface where *a=0.*

Panel A



Panel B



Panel C

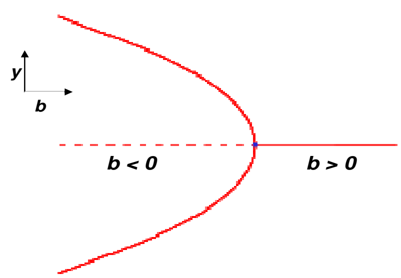
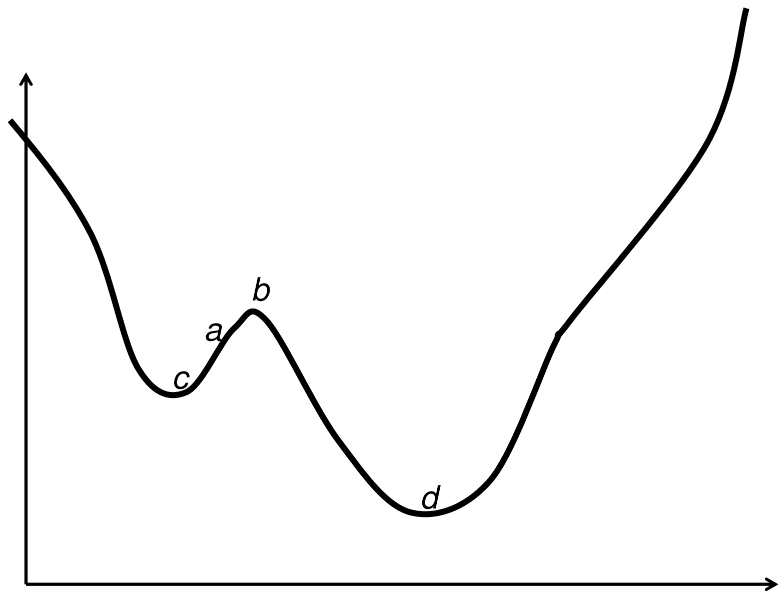


Figure 2. Organizations can exhibit bi-stability (shown here) or multi-stability where multiple configurations are possible depending upon the systems history and dynamics; both *c* and *d* represent stable configurations. A system starting at point *a* would naturally tend toward point *c* unless it is "perturbed" through an experiment to point *b* in which case it might either converge to *c* or *d* depending on whether it backslides or is transformed.



Endnotes:

[1] For example, the dynamical system might describe the attributes of a business, its markets, its financial situation, its knowledge management systems, its climate and its culture. These variables might be $q_1, q_2, q_3,\ldots,q_n$ which we collectively designate as ***q***, a vector whose value represents a particular location in state space *S* of dimension *n*. The organization as it exists at a point in time would occupy a position ***q*** in state space depending upon the specific values taken by the various components, q_i. A financial manager might only be interested in profitability and therefore might only be concerned with—and recognize the importance of—q_3 for example, if q_3 measures profits. This does not mean that there aren't other relevant state variables, i.e. $q_1, q_2, q_4, q_5,\ldots,q_n$, for the system and that they are also important, only that this particular manager does not recognize nor use them.

In contrast to individual managers, complexity researchers are interested in the function $f(t)$: S → *S* that describes how all of the components of ***q*** change over time. The changes are designated ***dq/dt*** for the particular initial conditions $\boldsymbol{q_0}$. The individual path that a system traces out in state space over time is called its *orbit*. If such a system could be defined—and of course, doing so is not always easy—the dynamical system would describe how the states of these variables as a configuration change over time. Once defined, mathematical results can be used to infer important characteristics of the dynamical system and thus, presumably, the organization being studied.

[2] This is sometimes also called "chaos", and these attractors are sometimes called "chaotic attractors"; as there are multiple incompatible uses of the word "chaos" and well as the phrase "edge of chaos" I avoid them here. I also avoid the term "strange attractor." A technical discussion of these attractors and their degree of complexity is beyond the scope of this paper. I refer the reader to any number of books on the subject, for example Guastello (2002).

[3] Thus, a more general expression of the relationship for change to ***q*** over time is one that includes surprises—that is, it includes a stochastic term. An equation that is often used to represent this situation is called the Langevin equation:

$$dq/dt = K(q) + F(t) \qquad (1)$$

Here, the change in the state of the system depends upon a deterministic part, *K*, and *F* which describes the random fluctuation—the surprises—inherent in the system.

In terms of equation (1) above, a non-zero value for $F(t)$ implied that the state of the system ***q*** at time t + 1 changed in stochastic ways. Less destabilizing fluctuations—where there is no divergence introduced into the system—are also possible and happen all of the time as. For example, individuals call out sick, or accidents occur in the work place. Many times, these "fluctuations" are quickly absorbed and dampened within the operating dynamics at work with little lasting impact.

[4] Haken (2006) describes self-organizing situations in the simple case where the ordering force described is itself changing over time. As an illustration, applying equation (1) to the order parameter $\boldsymbol{\xi}$ itself and assuming the equation has the following form:

$$d\xi/dt = \lambda\xi - \beta\xi^3 + F(t) \qquad (2)$$

where λ and β are parameters of this newly emerging dynamic system, the amplitude of the ordering factor can also increase and is likewise subject to stochastic fluctuations.

