Complexity and Its Implications in Advanced Leadership Development

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Abstract: *This article describes an advanced leadership seminar for senior managers and executives. The three module seminar describes how thoughtful leaders can learn to succeed even under conditions of extreme complexity. The first module describes complexity in the scientific sense and highlights the need to allow events to develop so that emergent patterns can be identified. The second module shows how this new complexity perspective can be used to frame and communicate social and economic imperatives in ways that move the organization forward. The third module puts this knowledge to work and enables participants to be better stewards of collective leadership within their organizations. Some reflections on the success of the program and potential improvements are offered in the concluding section.*

Keywords: Complexity Leadership; Collective Leadership; Leadership Development

Introduction

This article describes a complexity-inspired advanced leadership seminar that was given to senior managers and executives at a multi-billion dollar healthcare system in the US. The program was custom designed to offer participants an opportunity for a transformative learning experience (Mezirow, 1991) by offering an alternative view of leadership that can succeed in today's rapidly changing, complex and globally connected political economy. The program assumes that participants already have significant leadership experience and deep academic knowledge of leadership studies.

The article begins with a discussion of what leaders should know. This is followed by an overview of the three modules of the program. It ends with some thoughts on how the program can be improved going forward. Throughout, the term "complex" is taken in the technical sense wherein many interacting events and multiple levels of analysis are being confronted simultaneously with a changing mix of uncertainty and predictability. To succeed in a given situation, a leader must understand what is happening, accept uncertainty and still take appropriate action while leading others who are likewise experiencing uncertain events. This seminar presents complexity leadership as an emerging imperative for today's leaders.

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What Leaders Should Know About Complexity

The suggested approach involves a transformative journey. The facilitator guides the participants in a deepening discourse (Mezirow, 2003) about the challenges that emerge from complexity, a conversation that is further enhanced if the facilitator is able to share stories about the challenges and insights that occurred along his or her own personal journey into and through an acceptance of a world that is chock full of complexity.

The journey involves three modules that together build a foundation from which participants can successfully lead their organizations into the middle of the 21st century. The three modules are intended to clarify 1) how the term "complexity" in this science differs from common use of the term "complex," 2) how these new ideas inform life in today's complex organizations, and 3) how individuals can use these ideas to become more successful as leaders.

During each of these modules, the instructor can go into more or less detail on specific topics depending on the nature of one's own journey, the length of the session, and how deeply the program manager wants to explore the subject matter. (Table 1 presents a list of possible topics.) In addition, from a pedagogical perspective, each session features limited lecture time that is intended to present material for exploration and individualized discovery and includes more or less class discussion and various project-oriented *in situ* exercises. In the healthcare context, specific work situations currently being experienced by the participants are explored using this new perspective to enable participants to internalize what is being learned and apply these ideas in real time to their work. Programmatically, each module begins with a video intended to demonstrate some important and subtle aspect of complexity that will be explored metaphorically throughout the module.

The first module begins the program by immediately addressing the issue of complexity as a discipline and how this usage differs from how the term is used in common language (Anderson, 1999; Marion & Uhl-Bien, 2001; Uhl-Bien & Marion, 2009; Goldstein, Hazy & Lichtenstein, 2010; Lichtenstein, 2014). The second module explores what complexity means for organizations. The third takes a new look at "leadership" as a system or collective phenomenon (Ospina and Foldy, 2015; Yammarino *et al.*, 2012) in the context of complexity (Hazy & Uhl-Bien, 2014).

Module 1: Clarify What Complexity Really Means

The study of complexity science has made considerable progress over the last half a century. At the conceptual level one can think about the study of complexity as an attempt to understand and model phenomena and interaction effects that do not behave linearly. This means that increasing an input, like nursing labor hours, does not necessarily drive a proportional increase in output, such as patient satisfaction. In complex organizations, events do not always drive proportional effects.

This module offers participants a fresh view of how the physical and social world works when complexity findings are incorporated into one's worldview. Its key lessons are: First, a complex system is one where considerable uncertainty still remains in the system. Although a level of predictability is present in complex systems, there is also potential for surprise which can have broad implications. Complexity science builds models, but these models are not the same as the system. The system can surprise even if the model being used does not provide a warning.

Second, patterns and observed stability can be modeled, and this can be used to predict outcomes, but only to a degree (Arthur, 2015). States of localized dynamic stability operate in different path-dependent regimes, and the boundaries between regimes can be discontinuous

(Hirsch, Smale & Devaney, 2004; Mandelbrot, 1982). This means that change is often sudden, even precipitous. It is important for practitioners to know and to expect that when the dynamic stability of a "system" approaches a boundary between stable regions, its stability may be fragile.

Third, when an organization is in a dynamically stable regime it might suddenly "flip" to a different dynamically stable regime due to pressure or stress coming from outside the boundaries of the organizing system. Furthermore, when the organizing system assumes its new state, it doesn't necessarily behave the way that an observer might hope or expect given the purpose of the organization. The trick is to learn to recognize what is driving these dynamic changes and determine how to weaken forces pushing in the wrong direction and reinforce others pushing toward a new state that is more efficacious.

Beauty and Surprise

Although the study of complexity is ultimately a scientific discipline, one of the best ways for managers and professionals to understand and appreciate complexity is to experience its beauty. One way for them to see this beauty is to let them experience and discover it for themselves. This is why it is useful to show a short video before each module. To begin the exploration of the deep meaning of complexity in this first module, a video journey into a Mandelbrot (1982) zoom is useful for setting the stage for a transformative experience (Mezirow,1991). Showing it serves three purposes as the participants' begin their journey into complexity.

First, the Mandelbrot zoom highlights self-similarity (Hirsch, Smale & Devaney, 2004) as well as the depth and sweeping breadth of complexity. Here, the instructor would prompt the participants by suggesting that what they are experiencing emotionally and cognitively during this "zoom" is similar to what is happening to each individual in their workgroups, their department, their organization and their entire ecosystem. Each individual can explore deeply into the system and find the same and different patterns appearing again and again. One job of a leader is to find resonances within this complexity, a leadership imperative that Goldstein, Hazy and Lichtenstein (2010) call "interaction resonance."

Second, this video and what it represents highlights for the viewer the fragile and improbable nature of dynamic stability in a complex world. It demonstrates for participants that in the pattern itself, each of its buds and bulbs, reflects a distinct territory of comfortable predictability, some signifying increased complexity followed by others which represent surprising simplicity. Ultimately, when an individual, work unit, or an organization ventures outside of this beautiful complex shape, complete dissolution of order, a "strangeness" that is sometimes called "chaos," is the result. Another job of the leader therefore is to guide others to enable the collective to stay in a place where one can recognize and appreciate the beauty of order and organization even as events remain complex.

Third, this module offers a bridge to the modules that follow by offering a hint at the complexity of "leading" in such a dynamic and "strange" world. Complexity helps the participants understand why leadership is so difficult and suggests the unlikely potential for success, unless of course, one is lucky enough to begin in a predictable place and has the wisdom to find a way to allow the organization to prosper by staying there. Often, this involves finding the people who are skilled at engaging complexity and putting them in the right roles as Hazy (2012) demonstrated using computer modeling. During the session, each of these themes is developed through reflection, discussion and group exercises rather than lecture.

After the opening video, this session begins by making a rather counterintuitive assertion: *Engaging complexity actually means reimagining simplicity*. The challenge for the observer is to find and recognize a *new* simplicity that emerges on the other side of complexity. Oliver Wendell Holmes is often quoted as saying: "I would not give a fig for simplicity on this side of complexity, but I would give my right arm for the simplicity on the other side of complexity."

This is relevant for managers because having a better model – where "better" means that it predicts what can be predicted and also accepts what cannot – to predict events in one's organization helps a leader be more effective at his or her job. It also helps one better lead a large organization as it moves from one state of dynamic stability to another within the organization's own "Mandelbrot Set" (Mandelbrot, 1982). It is critical for a manager to realize that finding and understanding *new* simplicity in their organization takes time. "Waiting for the smoke to clear" can be difficult, particularly when events are complex and uncertain and others are looking for direction. However, failure to understand the changing dynamics of stability can mean carelessly stepping across the line into areas of unbridled divergence: dissolution, decay or implosion. Patience and thoughtful vigilance are as essential as timely action. Sometimes a small incremental step that is intended to understand what is happening, what is called generative leadership (Surie and Hazy, 2006), is the right choice. One then iterates the process again.

One of the key discoveries of complexity science is that in very complex environments, even ones that are apparently unpredictable in the details, often the observed outcomes that are most important continue to exhibit a level of predictability. One simply has to peer patiently through the complexity of the moment to see the emergent simplicity. The capacity to focus on what is relevant in the bigger picture, at a higher level of scale, is known as "course-graining" (Gell-Mann, 1995; West, 2017). This is in contrast to being lost in "fine-grained" details that may not be relevant to the big picture.

Fragile Predictability and Emergence

With these ideas as background, the scene is set to explore selected complexity topics in detail. (See Table 1 for suggested areas to cover.) The instruction begins with a discussion about complexity science itself and also about the ways that work life in organizations is complex in this technical sense. The goal is to try to have the participants relate science to experience. The map or model of complexity is not the inherent complexity of the object or the system. A manager's mental model of what is happening in an emergency room during a crisis is not what is actually happening as events unfold. However, it is in the context of models, that one takes action in organizations. At the same time, as Hazy and Backström, (2013a) describe, every individual in the organization has a unique model and all of these unique perspectives interact with one another to produce outcomes.

Even though some aspects of the world appear to be dynamically stable, switching from one state to another state does not necessarily happen smoothly. Often there is a tipping point, which is followed by a sudden change (Thom, 1989; Guastello, 2002). The Mandelbrot zoom is, in fact, a boundary set that reflects transitions between different stability regimes. As an individual agent acting inside an organization, it can be difficult to move the organization from one region of dynamic stability to another. This uncertainty is why organizational life is so difficult to navigate.

The last lesson in this module is critical for success in an organization and serves as a transition to Module 2. When a bounded system, like an organization, is put under pressure from outside, the "system" may respond to events without the need for top down governance. New physical and social structures emerge, and the system spontaneously assumes a new dynamic state that alleviates this pressure more quickly. These emergent regularities (Gell-Mann, 1995) are called "dissipative structures" (Prigogine, 1995; MacIntosh & MacLean, 1999) because they dissipate the pressure more quickly than before. The relevance of these structures is explored in later modules.

Recap of Module 1

The key lessons of Module 1 are: First, a complex system is one where considerable uncertainty still remains in the system. Therefore, although there is a level of predictability, there is also a potential for surprise, and this surprise can have broad implications. Second, states of localized dynamic stability operate in different path-dependent regimes, and the boundaries between regimes can be discontinuous. It is important for practitioners to know and to expect that when the dynamical state of a "system" approaches the boundary of its stable region, its behavior can be wildly unpredictable even in response to minor event like, for example, the angry words of a frustrated manager or leader. Third, when an organization is in a stable regime it might suddenly switch to a different stable regime due to pressures from outside the boundaries of the organizing system. However, when the organizing system assumes its new state, it doesn't necessarily behave the way that an observer might hope or expect given the purpose of the organization.

Module 2: The Complexity of Organizations

The study of complexity in the business and organizational context has become increasingly relevant over the last couple of decades (Allen, Maguire, McKelvey, 2011). At the conceptual level one can think of the human organizational ecosystem as a technology enabled complex system with spatial, temporal and social dimensions all interacting with one another to distribute information (Hidalgo, 2015). Because the events in an organization are complex, events as inputs do not necessarily result in proportional outcomes. As a result, organizational life can be thought of as attempts by individuals to understand, model and predict – in other words make sense of – complex phenomena, including one's own actions, as a means to benefit proactively from an unfolding future.

To make this point, the instructor might ask participants to consider some static "object" or phenomenon from their experience and to ask these questions: How complex is this? How does one quantify something's complexity? Consider a car, for example, a 2012 Toyota Camry LE. With a health care audience, one might reference a magnetic resonance imaging (MRI) machine. How complex is this object in the context of what is relevant to one's life? This perspective reflects the complexity of an object in the context of what an observer sees as relevant at a moment in the ecosystem. Paul Cilliers (2005) would have said that the object itself, when it is removed from its social context, is complicated rather that complex because it can be broken down into component parts and reassembled. But this is not the case when the object is considered not in isolation but in the context of its use. A Camry or an MRI, even when frozen in time, is more than the sum of its parts when considered in the context of its use. One might think of this as the object's "static complexity" as it is used as part of a dynamic process.

Now consider the moving image of that car in-use as it navigates the *process* of passing through a busy traffic circle, or imagine the MRI machine in-use during the process of providing images for a medical team considering treatment options for a struggling patient. How complex is this process? This process of use over time is an example of "dynamic complexity" where one considers an object but this time in the context of its use in a process over time. How complex is the dynamic situation of the object as it interacts with other objects across space and over time? This is a more difficult question to answer. Understanding the complexity or objects in use is important because the level of complexity helps one understand what can be predicted versus what one cannot know before the event occurs. A key learning from complexity is that static thinking is not enough. In complexity, one must always engage in dynamic thinking by assessing every situation in the context of emerging patterns in what scientists call *phase space* (Ruelle, 1989).

This second module looks at how managers and leaders might recognize and engage dynamic complexity in their organizations and help others navigate through complexity with them. It begins with a discussion of algorithmic or *descriptive complexity* and suggests how the articulation of descriptive models would enable the leader to exert *informational influence* over others to enact organizational outcomes over time (Prokopenko, Boschetti & Ryan, 2009).

That discussion is followed by a description of *dissipative structures* (MacIntosh & McLean, 1999) and *structural attractors* (Allen & Strathern, 2003) and how these resonate with social structures such as norms that organize human activity (Giddens, 1984). These structures when present exert *normative influence* on individuals and serve to channel choice and action. As such these complex structures are important tools – as well as impediments – for managers and leaders alike.

The third and final lesson of this module is the importance of periodically transferring energy and information into the structure of the system. This serves to both reinforce and reenergize positive structures and to dampen negative ones. Periodic forcing involves regular and continual insistence that useful order be maintained. This is done by inserting requisite energy and resources that are needed to keep things on track. Effective leaders judiciously apply this type of *incentive and coercive influence* as periodic forcing to establish and enforce sets of local interaction rules that keep various parts of the organization connected and moving in the right direction.

Descriptive Complexity and Informational Influence

To set the stage for a discussion of complexity and organization, it is useful to begin this module with a popular complexity video of flocking behaviors in "a Murmuration of Starlings". By observing flocking behavior, participants see first-hand the beauty and "complexity" of organizing as forms morph over time. These organizing forms emerge from relatively simple local rules of interaction as these also interact with objects in their ecosystem. The leadership challenge is to figure out how one should think about influencing complex adaptive systems like these as they unfold over time.

Descriptive complexity and coarse-graining

The idea of coarse-grained "descriptive complexity" is that mathematical or even conceptual models can be used to study complex systems at different levels of scale, depending on the events that are relevant to the observer. The details are not always important or relevant. Some events and some details do not need to be predicted. Consider the problem of predicting the outcomes of a particular system, the starlings swarming in the video, for example, or the hustle and bustle of hospital emergency room during a natural disaster. For a model to be a useful enabler of action, one must first define the purpose of the model and what it is intended to predict. Second, it must be able to process information available at time period t = 0 and produce predictions for time period t =1 before time actually reaches t = 1 (Hazy & Backström, 2013a).

For the leader who seeks to act in a complex organization, the question is this: Given what is relevant under the circumstances – patient outcomes for example – how large would a model have to be for it to take inputs, run and output accurate predictions (some subset of) the outputs of the system (within an acceptable margin of error) in time to take corrective actions before the outcomes actually occur? The size of this model, measured either by the time it takes to run (where the time is less than the time from t = 0 to t = 1) or the memory required to store it, is called *descriptive complexity* (Hazy & Backström, 2013a).

One might note that the size of the model one uses to predict events depends upon how one defines relevant aspects of the physical and social system during what is referred to as the "coarse-graining process." In the Camry example described earlier, the atoms and molecules, and even the parts of the automobile probably don't matter. If one cares only about the Camry as part of a coarse-grained "system" that describes patterns of motion in a traffic circle with five possible exit paths, then the model would only need to predict a single output, the Camry's one exit path from the circle out of five. A model to predict the Camry's exit path might be designed to detect, sample, and process the current state of the Camry's turn signal. This coarse-graining could be a useful model if the potential for error that arises from this gross coarse-graining simplification process is acceptable.

One should note that for this model, most of the state-data (for example, all of the other automotive systems) are discarded during the coarse-graining process in return for the relative simplicity of this predictive model. Also note that the fine-grain physical and social system retains all of its considerable uncertainty; it is only this coarse-grained model that is "simple." In contrast, if it is important for the observer to predict the precise route, timing, and velocity of the car, then the coarse-grained model must be much more complex. For a more complex model to also be more useful – to pilot a self-driving car for example – additional uncertainty and thus additional fine-grain detail must be accounted for by the model. This is the same as saying that more information about the fine-grained dynamics of the system must be incorporated in the observer's model. This, in turn, means that the model must use more memory and take more time to process and would therefore have greater descriptive complexity.

This distinction highlights the importance of selecting the level of coarse-grained scale from which to observe a physical and social system and choosing the relevant variables for modeling. At the same time it also highlights the difference between the complexity of a model of the phenomenon and the complexity of the phenomenon itself. The complexity of the model depends upon the information that is relevant to the observer and is therefore dependent upon the position of the observer in the system. As shown in Table 1, Nobel Laureate Murray Gell-Mann (1995) calls sentient observers within a complex adaptive system "information gathering and using systems (IGUS)" because their behavior depends on the information that they are able to gather and use given their unique and limited position and capacities. To predict the behavior of an IGUS one must also predict the coarse-grained descriptive complexity of its model-in-use.

Descriptive complexity and management

Insights from complexity science about coarse-graining and descriptive complexity are particularly relevant to managers and leaders today because information and communications technologies (ICT) together with machine learning and artificial intelligence (AI) are advancing so rapidly that the old ways of organizing no longer work (Arthur, 2015; West, 2017). New, more thoughtful approaches are needed.

The key lesson for managing through complexity is this: Many aspects of coarse-grain models that worked yesterday still work today even though many, even most of the irrelevant fine-grain details have changed. Furthermore, many of these coarse-grained processes will still be working tomorrow even after all of the complexity is better understood. Routines and processes are the descriptive models that reflect the algorithmic aspects of organizing that managers and leaders can control. They can control them because they designed them to get the job done, and they sustain them through their actions (Nelsen & Winter, 1982; Beyer, 1999). Managers should double down on routine activities that are known to drive outcomes that continue to be relevant.

At the same time, however, there are also other aspects of our businesses that can no longer be run using the same routines or "algorithms" because the old way of working will no longer offer correct or relevant predictions about events and outcomes. These are the activities that the manager did not create and does not sustain by his or her actions. In health care, this might include natural disasters which overwhelm medical facilities or regulatory changes that impact economic flows. In these cases, it is the manager's challenge to search for new and emerging coarse-gained simplicity that will eventually be relevant on the other side of complexity. One can then generate new algorithmic processes to drive desired outcomes.

In these cases, the leader must enable a generative process (Surie & Hazy, 2016) where each member of the organization has the knowledge, skills, and capacity to build his or her particular piece of this new model that is customized for use in his or her particular situation. But at the same time, all of these models must fit together to be effective in the context of the organization's mission and objectives within its ecosystem (Surie & Hazy, 2006; Hazy & Backström, 2013b). By communicating, supporting and evolving existing models that still work, while at the same time building new coarse-grained models of emerging complex structures, today's leaders use their position and power to exert informational influence across the organization and enable others to be successful in their organizations.

Dissipative Structures and Normative Influence

Models of events in the physical and social world are one thing, but complexity also helps us understand the ordered structure of the physical and social world and events within it. To lead others in a complex world, managers must accept that, although organizations are dynamically stable at the coarse-grained level in the short term, they are also constantly changing at the fine-grained level. This means that every individual must create and maintain his or her own individual internal model to predict unfolding events. This can be difficult and time consuming.

Further, if each person had to do this independently, there would be considerable redundancy and conflict. Fortunately, conceptual models can be shared (Tomasello, 2014). However, to do so effectively and without loss of predictive power, they must all be built upon a common and robust conceptual and analytical platform which is likewise shared.

Dissipative Structures

One type of dynamic pattern that can be identified and modeled by managers as coarse-grain organizing structures are called "dissipative structures" by Nobel Laureate chemist Ilya Prigogine (1995). Prigogine studied dynamic flow structures that emerge in closed systems in response to excess energy entering the system from outside the system's boundary (Lichtenstein, 2014). He found that these new flow patterns served to dissipate the excess energy accumulating inside the system by sending it back across the boundary and into the ecosystem more quickly.

For example, consider the case where heat is applied to a "closed system" – a round glass container, flat on the bottom and top – containing a viscous liquid. Before heat is applied, the viscous fluid can be represented using a coarse-grained model that reflects a relatively homogeneous highly symmetric fine-grained system in thermodynamic equilibrium. As low heat is applied to the bottom of the container, however, the molecules of fluid on the bottom become warmer until internal fine-grained differences in temperature appear as the system gradually transitions into a more heterogeneous non-equilibrium fine-grained system. In this low heat phase, excess heat is dissipated through the system by fine-grained conduction dynamics without the need for disruptive change in organizing structure. During *conduction*, molecules – or "agents" – in the liquid remain roughly in the same place, bouncing off one another in fine-grained interactions. As this occurs, kinetic energy (and information) are gradually transferred to neighboring molecules. Eventually, the heat is dissipated into the environment as molecules collide with other molecules on the boundary and beyond.

As the amount of external heat applied at the bottom of the container is increased beyond a threshold point, a *phase transition* suddenly occurs as circular convection flows appear to dissipate excess energy from the system more quickly. Molecules at the bottom of the container move *en masse* to transport heat more quickly from the hot bottom region to the cool top region. During the transition at the fine-grained scale, the observer must likewise transition from a conduction coarse-grained model to a new coarse-grained model where convection "cells" are modeled as coarse-grained "dissipative structures." This discontinuous change is represented in phase space as "coarse-grained simplicity on the other side of fine-grained complexity." It is easy to see why organizational theorists find metaphorical relevance in dissipative structures for the study of organizations (Lichtenstein, 2014). However, one must be careful not go too far and confuse mere metaphor with hard science (Hazy, 2014).

Coarse-grained structures drive normative influence

What is important to realize about dissipative structures is that coarse-grained models of fine-grained regularities are sometimes able to consistently predict behaviors at a higher coarse-grained level of scale than that of an individual agent. This implies that when dissipative structures form, individual agents are influenced to move *en masse* with others according to shared expectations even though they may not realize why they are doing this. From the participating agent's perspective, it just makes sense to go along, to "go with the flow." By conforming, these agents increase the pressure on others to likewise conform, and so on and so forth. This is how *normative influence* acts to organize individuals. It biases or "attracts" the choices and actions of individuals by enabling them to resonate with one another, reducing cognitive load and simplifying the individual choices that must be made. In this sense, one can see how social structures (Giddens, 1984) can act as "attractors" (Surie & Hazy, 2006).

There is a need for caution here. A dissipative structure (and therefore normative influence more broadly) forms inside a system to resolve local tensions or problems. The structure does not form to further the organization's objective. In a recent US government scandal at the Veterans Health Administration (VHA), the health system had too many patients coming in and too few doctors to provide treatment for them (Bronstein & Griffin, 2014). As a result of tension from excessive patient demand flow that conflicts with available resources and institutional performance metrics, a dissipative structure formed as health care professionals began to refuse to add new patients to the waiting list. This allowed the system to maintain dynamic stability, albeit it did so by failing to serve its institutional purpose.

This obvious misstep is not the fault of the individuals. It is a system failure. But even more, it is a leadership and management failure. If no one recognizes that a pathological structure is forming or no one has the foresight and skills to guide its development in a productive direction, the system as a whole can become counter-productive to the organization's stated objectives. Leaders and managers must be aware that this occurs and learn how to guide these complex dynamics toward an organizational purpose.

This caution aside, leaders and managers can learn to use normative influence to further an organization's objectives by constructing and reinforcing useful dissipative structures that form in organizations to solve local problems (MacIntosh & MacLean, 1999). They can also learn to counter the influence of dissipative-like structures that are counter-productive and learn to do so before these structures harden into the more entrenched structural attractors, like a smoking area, for example, the very presence of which attracts certain activities toward them (Allen & Strathern, 2003). Because human beings have cognitive abilities that allow them to overcome normative influence (Tomasello, 2014), leaders can learn to overcome counter-productive normative influence in organizations by using informational influence. Effective leaders must be skilled at each of these influence types, as well as a third type, *incentive and coercive influence*, that operates at the physiological and safety layers of Maslow's (1943) hierarchy of needs.

Periodic Forcing through Fine Grained Incentive and Coercive Influence

Once social structures have formed within a system, and once models are generated and articulated, individuals can use the information in them to predict events. Models motivate individuals through payouts (of various types) while norms enable cooperation by coordinating collective behaviors (Hazy & Backström, 2013a). In this way, both informational and normative influence act upon individuals to move the organization forward. This occurs whether the ecosystem forces that are driving order and biasing collective behavior across levels of scale were formed spontaneously to relieve local stress or were guided by leadership to serve organizational purposes.

However, due to "frictions" within the ecosystem, additional energy (and information) must be injected into the system periodically to reinforce and evolve processes, functions and orderly activity. Like peddling a bicycle, *periodic forcing* applies incremental energy into the system to sustain dynamic stability. Like a clock that signals a shift change in a hospital, *periodic forcing* can also inject "time ordering" into the organizing system. In organizations, temporal order can be reinforced through *periodic forcing* of reporting requirements or status meetings that sustain the organization's "ordering" regime through space and time. This extrinsic force is called *incentive and coercive influence* and is discussed in more detail as part of module 3.

Recap of Module 2

The key lessons of Module 2 are: First, leaders must learn how to recognize and engage dynamic complexity in their organizations. A nuanced understanding of *descriptive complexity* helps a leader articulate models such as economic games which exert *informational influence* over others to enact organizational outcomes (Prokopenko, Boschetti & Ryan, 2009). Second, leaders must learn how to recognize normative influence forces exerted through structural attractors such as dissipative and social structures which organize human activity at the institutional level (Giddens, 1984). The final lesson highlights the importance of periodically transferring energy and information into the system to replenish what is dissipated by frictions and doing so in ways that reinforce and reenergize positive structures and dampen negative ones. Effective leaders apply incentive and coercive influence to guide the choices and actions of individuals to keep the organization moving in the right direction.

Module 3: The Implications of Complexity for Leadership

The third module applies what was learned in the prior modules to identify lessons for leaders in today's complex organizations. It is useful to begin the session with a video of busy activity at a local establishment, preferable one that is familiar to the participants, like a local Starbucks. This video will be used later to offer some examples about how leadership and management work in familiar complex contexts.

The goal is for participants to search inside themselves and explore how they can have a greater impact, and how they can help others to be more effective. Complexity leadership offers a new way of thinking (Hazy & Uhl-Bien, 2015). It offers different insights because it focuses on what leadership does for an organization, and why leadership is needed to keep social systems moving in the right direction. This is in contrast to more common leadership approaches that help an individual learn to be perceived as a leader or to accumulate power that can be used to move others in a desired direction.

The Complexity Leadership Difference

Complexity leadership approaches are distinct from and complementary to traditional leadership study. This is because traditional approaches (which may be discussed in some detail during the session but are not discussed here) relate to how the leader activates the follower to move in a certain direction, but they are agnostic about that direction. The underlying assumption in traditional leadership theories is that the leader knows what to do and how to do it and that the only challenge is organizing others to follow that direction.

In contrast, complexity leadership is interested in the process of identifying, framing and then moving the system in the right direction. The implicit assumption is that organizations need to continually acquire and process the resources that they need while adapting to change under uncertainty. As such, leadership is a collective phenomenon. As Hazy (2012) shows through agent-based computer simulation, the hard part of leadership is figuring out what things needs to be done, who can do them, and how. Once the way forward is identified and the team is organized around a champion, all of the traditional leadership approaches are useful in various situations according to the capabilities and needs of the organization (Helfat, Finkelstein, Mitchell, Peteraf, Singh, & Teece & Winter, 2007).

Part of the process of moving the organization forward in a collective leadership effort includes shepherding individuals and groups on a journey through fine-grained complexity to find the coarse-grained simplicity that emerges on the other side. This module describes how a leader can act as a catalyst by framing and shaping the environment to channel *influence* interactions that enable the organization as a whole to identify and achieve its objectives.

Generative Leadership and Informational Influence

The first leadership challenge involves navigating and directing an organization through the information gathering and using process to find, create and achieve value for stakeholders on a competitive landscape (Gell-Mann, 1995; Hazy & Uhl-Bien, 2015). We call this process "generative leadership" because it recombines an organization's existing capabilities (Helfat et al, 2007) in the context of emerging value potentials in the ecosystem. By doing so, it *generates* the next iteration of the organization, and then the next, and so on (Surie & Hazy, 2006). One can think of this metaphorically as identifying and facilitating the nascent formation of purposeful dissipative-like structures (Prigogine, 1995) as the organization exchanges information and resources with other entities in the ecosystem (Goldstein, Hazy & Lichtenstein, 2010).

Across the organization, recombination decisions are framed as choices to be made at various positions and in various contexts. This approach is distinct from command and control leadership since is places decision authority with those who are in the best position to identify and realize the value potentials that are available to move the organization in new and innovative directions (Hazy & Uhl-Bien, 2015). The generative leadership approach activates intrinsic motivation by acting at the self-esteem and self-actualization levels of Maslow's hierarchy of needs (Maslow, 1943).

From a practical perspective, generative leaders combine behavioral economics (Kahneman, 2011) and economic game theory (Von Neumann, Morgenstern, 1944) to organize and coordinate individual choices in the context of organizational needs and goals. The idea is that the challenge of getting any organizing initiative going is a game with a perceived payoff matrix – or "value potential" – for players. The goal is to frame information about the situation in terms of the payout (monetary and otherwise) that each player will receive under various outcomes (Guastello, 2002). By framing situations in this way, generative leadership uses information about potential benefits to participants to exert *informational influence* on each individual's choices and actions as they interact in a specific "organizing game" that the leader designs. Note that the payoffs and choices can vary among players and can be competitive or cooperative (Axelrod, 1984, 1997). To complicate the matter, some individuals might be vying for promotions while others might be worried about putting their kids through college.

Community-Building Leadership and Normative Influence

The approach described in the prior section assumes that actors are motivated by their individual payoffs. But often, the maximum payoff can only be achieved with a level of cooperation (Axelrod, 1984, 1997). Thus, another significant leadership challenge involves building a generalized sense of trust in the organization (Zak, 2017). To do this, leadership must create, nurture and support a strong community with a shared identity that enables cooperation (Hazy & Silberstang, 2009).
Trust is closely related to the sense of physical and psychological safety that is engendered by being part of the group. Evolutionary biologists call this "nesting safety" (Nowak, Tarnita, & Wilson, 2010) because with trust, individuals can let their guard down (Zak, 2017) along some dimensions. Together, they become "us" through what Maslow (1943) calls "belongingness." The "attraction" to be one of "us," enabled through *generalized trust*, reduces cognitive load by enabling *normative influence* that biases individuals toward cooperative choices. Individuals are able to reduce their cognitive load by imitating those around them.

From the perspective of the "system of individuals in an organization," one can see that the formation of "us" is related to the formation of dissipative structures (Macintosh & MacLean, 1999). Under the distorting presence of a huge payoff, like an initial public offering (IPO), or a loss, like in a bankruptcy, a dissipative structure might form to generate normative influence that helps organize individuals to act *en masse* to realize an organization level opportunity or avoid a threat. Hazy and Boyatzis (2014) argue that such changes would be signaled by an alignment of the emotional states of individuals in a common direction through a process of emotional contagion. This distorting potential can be strong enough to dominate the *individual identity* that, absent the activation of an overriding social identity, would cause an individual to "defect" in an effort to satisfy his or her own narrow interests. When one is feeling the "power of us," one is being attracted by the gravity-like pull of normative influence.

As many have experienced, once a group forms it can become more effective than the sum of its parts. The presence of structures, even an identity structure like "us," attracts others who seek to join, a process called cumulative advantage (Barabasi, 2002). These social and physical *structural attractors* (Allen & Strathern, 2003) "attract" others to participate in them because doing so provides benefits. How leaders create, evolve and use physical structural attractors – like warehouses and office space design – or social structures – like project teams and affinity groups – to guide, dampen and amplify informational and normative influences on members of the organization are a critical aspects of effective leadership in complex organizations.

Administrative Leadership exerts Incentive and Coercive Influence

Structural attractors are self-reinforcing artifacts in the physical, social, or the symbolic world that, like dissipative structures, by their dynamic presence exert *normative influence* on individuals, biasing their choices in their direction (Allen & Strathern, 2003). For many readers and students, this sounds like a roundabout way of saying "bureaucracy" which is indeed an important part of the structural attractor landscape in organizations.

Bureaucracies and structural attractors more generally are used by leaders and managers to organize recognizable signals that individuals can sense and unconsciously decode to do their jobs. Because they carry information about process and function, they are also useful transmitters of *informational influence*. A written agenda, a meeting room table, an amphitheater, even roads, highways and bridges are structural attractors that can be used to organize routine work. Warehouses and factories, hospitals and clinics, shopping centers and main streets, even social structure and status (Giddens, 1984) carry signs and signals that enhance their usefulness as attractors to organize of human activity.

Because they are so powerful, it is important to remember that bureaucracies and structural attractors can influence individuals both for good and for ill. This is because they form initially as agents act to dissipate tensions that are *locally* stressing the system (Macintosh & MacLean, 1999). An overwhelmed manager may ask for weekly status meetings as an *ad hoc* or stop gap measure to figure out what to do, for example, but it is not uncommon for those meetings to continue to occur regularly, months or even years later. Thus, an organizing structure that solved a local problem at a point in time may soon become counter-productive. Corrupt practices, for example, might begin with harmless good intensions – to clear a warehouse of old inventory – but then over time could become institutionalized in a corrupt practice wherein remaining inventory "falls off the truck" at the end of each month. As these examples show, a structural attractor that forms doesn't necessarily guide the "dissipation of tension" in a manner that serves the organization's purpose.

For these reasons, a complex organization requires administrative leadership to continually "administer" the extrinsic forces that are exerted by structural attractors, reinforcing positive forces and dampening negative ones. Effective leaders learn how to manipulate the local environment to use these powerful sources of influence to guide the organization in the desired direction. To do this, leaders must realize that beyond their normative influence, physical assets such as financial resources, and social assets like reputation and status, can be manipulated to become vehicles of extrinsic motivation at the individual level. Control of these resources by the leader provides a means to offer incentives or exercise coercion in order to promote compliance. This type of influence acts on individual motivation at the physiological and safety levels of Maslow's (1943) hierarchy.

Even as effective leaders apply the brakes to stale routines, they reinforce useful ones (Hazy & Uhl-Bien, 2014). Administrative leadership is responsible for establishing and reinforcing structural attractors including their informational and normative influences. To do so, leaders must periodically exert targeted incentive and coercive influence at the individual level to inject energy, information and order into the system to sustain its useful functioning.

Traces of Leadership in Daily Activities – An Illustration

In a seminar setting, to make these points it is useful to observe an *in situ* structural attractor that is quite complex and perhaps one that is familiar to participants. A video of the morning rush at a Starbucks or perhaps a trauma center can be used as an example because it readily shows the many information signals and normative influencers that enable efficient operations under changing ecosystem conditions. Here we consider the Starbucks case.

One can observe in such a video that generative leadership implemented by Starbucks management in the past has "set the agenda" for a "Starbucks morning" game. One can see that over the years Starbucks leadership has created an informational and normative influence environment that draws the consumer into the "game" without that individual even being aware that he or she is playing the Starbucks game by Starbucks rules. Although originally created years ago, these structural attractors have been reinforced or dampened over time to optimize game play for the benefit of several sets of stakeholders. This is done through the skillful application of *periodic forcing* of daily routines using measured incentive and coercive influence that ensures, for example, that tables are regularly cleared and cleaned and inventories are restocked. This is an illustration of how the "structural attractors" that organize human activity are sustained and evolved.

Leaders must remember that structural attractors, like bureaucracies, are not machines. They are organic entities. As such they respond and grow according to local conditions without regard to the broader mission or purpose of the organization. As a result of the many mindless adjustments that have occurred locally over months and years to accommodate idiosyncratic local conditions, structural attractors meander like rivers. They morph opportunistically around obstacles, as happened when the US Veterans Administration employees simply stopped adding new patients to the waiting list to meet their numbers.

Sometimes meandering organizations can completely change direction as happens when an enterprise becomes corrupt. It is therefore important to realize that just because a structural attractor has momentum doesn't mean it is furthering the larger goal. Leaders must use their knowledge of complexity to stop what needs to be stopped, change what need to be changed, and reinforce what continues to make sense in the broader context of the organization's purpose.

Recap of Module 3

The key lessons of Module 3 relate to the levers of influence that leaders can use to move their organizations forward in complex ecosystems. First, generative leadership actualizes models and descriptive complexity to frame as organization's coarse-grained outcomes so as to exert *informational influence* across the organization. Second, community-building leadership engenders and defines shared identities that support evolving structural attractor forces which exert efficacious *normative influence* on the organization's members. Finally, administrative leadership exerts *incentive and coercive influence* to reinforce various routines and capabilities that hold a complex and dynamic organization together.

Concluding Thoughts: Outcomes And Next Steps

This seminar was offered twice in 2016 to executives from a not-for-profit health care system in the US that employs over 100,000 medical, technical and administrative personnel mostly in the eastern and mid-western US. The thirty-seven participants over the two sessions were midcareer and all were chosen because they were in line for promotion into the top management roles of the governing organization. Each seminar occurred over three days, and each of the modules described herein took place in a three hour time-slot. Other topics were covered in other time slots.

Participant responses to this complexity-informed advanced leadership development program have been very positive and supportive. Participants consistently rated the program highly (scoring between 4 and 5 on a low = 1 to high = 5 satisfaction scale) with respect to both interest and relevance. Comments tended to highlight the importance of relating the complexity material to the workplace.

In terms of future improvements, the team is developing additional connections between complexity ideas and real-life conditions in today's complex workplace. These connections will be used as prompts to enable fruitful discussions about immediate and relevant work situations that could benefit from the complexity perspective. Likewise, the team is developing experiential exercises that relate directly to the executive work situation, learning-by-working to solve their current leadership problems. Finally, the program would benefit from the addition of one-on-one counseling sessions that would help participants apply what is being learned directly to their organizational situation and according to their personal leadership style.

References

Allen, P. M. Maguire, S. & McKelvey, B. (eds.) (2011). *SAGE Handbook of Complexity and Management*. Thousand Oaks: Sage.

Allen, P. M., & Strathern, M. (2003). Evolution, Emergence, and Learning in Complex systems. *Emergence, 5* (4), 8-33.

Anderson, P. (1999). Complexity theory in organization science. *Organization Science. 10,* 216-232.

Arthur, W.B. (2015). *Complexity and the Economy*. Oxford: Oxford University Press.

Axelrod, R. (1984). *The Evolution of Cooperation*. New York: Basic books

Axelrod, R. (1997). *The Complexity of Cooperation*. Princeton: Princeton University Press.

Bak, P. (1996). *How Nature Works*." New York: Springer-Verlag.

Bak, P. & Paczuski, M. (1995). Complexity, Contingency, and Criticality". *Proceedings of the National Academy of Sciences of the USA,* 92 (15), 6689–6696.

Barabasi, A. L. (2002). *Linked: The New Science of Networks*. Cambridge, MA: Perseus Publishing.

Beyer, J. (1999). Transforming an industry in crisis: Charisma, routinization, and supportive cultural leadership. *Leadership Quarterly, 10*(3), 483.

Bronstein, Scott; Griffin, Drew (April 23, 2014). "A fatal wait: Veterans languish and die on a VA hospital's secret list". CNN. Retrieved February 16, 2015.

Burt, Ronald S. (1992). *Structural holes: The social Structure of Competition*. Cambridge, MA: Harvard University Press. ISBN 978-0-674-84371-4.

Cilliers, P. (2005). Complexity, Deconstruction and Relativism. Theory, Culture &Amp; Society, 22(5), 255-267.

Cover, T, & Thomas, J. A. (2004). *Elements of Information Theory 2nd Edition*. Hoboken, NJ: Wiley-Interscience

Crutchfield, J (1994). Is anything ever new? Considering emergence. In G. Cowan, D. Pines & D. Meltzer 9eds.), *Complexity: Metaphors, Models, and Realty* 515-537, Reading, Massachusetts: Addison Wesley Publishing.

Crutchfield J.P. & Feldman, D.P. (1997). Statistical complexity of simple one-dimensional spin systems, *Physics Review E* **55 (2)**, 1239-1242.

Epstein, J. M. (1997). *Nonlinear Dynamics, Mathematical Biology, and Social Science* (Vol. IV). Reading, Massachusetts: Addison-Wesley Publishing.

Feldman D. P., & J. P. Crutchfield (1998). Statistical Measures of Complexity: Why? *Physics Letter A*, 238 (415), 244-252.

Fleming, L., & Sorenson, O. J. (2001). Technology as a Complex Adaptive System: Evidence from patent data. *Research Policy, 30,* 1019–1039.

Forrester, J. W. (1987). Nonlinearity of High-order Models of Social Systems. *European Journal of Operational Research, 30,* 211–221.

Gell-Mann, M. (1995). *The Quark and the Jaguar: Adventures in the Simple and the Complex*. New York: Henry Holt & Company.

Giddens, A. (1984). *The Constitution of society*. Berkeley, CA: University of California Press.

Goldstein, J. Hazy, J. K. & Lichtenstein, B. (2010). *Complexity and the Nexus of Leadership*. New York: Palgrave Macmillan.

Guastello, S. (2002). *Managing Emergent Phenomena: Nonlinear Dynamics in Work Organizations. Mahwah*. NJ: Lawrence Erlbaum Associates.

Granovetter. (1973). The strength of weak ties. *American Journal of Sociology, 78*(6), 1360–1380.

Haken, H. (2006). *Information and Self-organization: A Macroscopic Approach to Complex Systems*. Berlin: Springer.

Hazy, J. K. (2012). Leading Large Organizations: Adaptation by Changing Scale-Free Influence Process Structures in Social Networks. *International Journal of Complexity in Leadership and Management, 2(1/2), 52-73.*

Hazy, J.K. (2014). 'Is This "Thermodynamic Inquiry" Metaphor or More?', *Journal of Consulting Psychology*, **66**(4), 200-305.

Hazy, J.K.. and Backström, T. (2013a), 'Human Interaction Dynamics (HID): Foundations, Definitions, and Directions', *Emergence: Complexity and Organization*, **15**(4), 91-111.

Hazy, J.K.. and Backström, T. (2013b), 'Editorial: Human Interaction Dynamics (HID)—An Emerging Paradigm for Management Research', *Emergence: Complexity and Organization*, (15)4, i-ix.

Hazy, J. K. & Boyatzis, R. E. (2015). Emotional Contagion and Proto-Organizing in human Interaction Dynamics. *Front. Psychol. 6*:806. doi: 10.3389/fpsyg.2015.00806

Hazy, J. K. & Silberstang, J. (2009). The Emergence of Collective Identity as a Means for Creating and Sustaining Social Value. In J. A. Goldstein, J. K. Hazy and J. Silberstang (Eds.), *Complexity Science and Social Entrepreneurship,(pp.447-470)*. Litchfield Park, AZ: ISCE Publishing.

Hazy , J. K. & M. Uhl-Bien. (2014). "Changing the Rules: The Implications of Complexity Science for Leadership Research and Practice ." In *The Oxford Handbook of Leadership and Organizations,* edited by D. Day, 711 – 32 . Oxford : Oxford University Press .

Hazy , J. K. & M. Uhl-Bien. (2015). "Towards Operationalizing Complexity Leadership: How Generative, Administrative and Community-Building Leadership Enact Organizational Outcomes." *Leadership* 11 (1): 79 – 104 .

Helfat, C. E., Finkelstein, S., Mitchell, W., Peteraf, M. A., Singh, H., Teece, D. J. & Winter, S.G. (2007). *Dynamic capabilities: Understanding Strategic Change in Organizations*. New York: Blackwell Publishing.

Hidalgo, C. (2015). Why Information Grows: The Evolution of Order, from Atoms to Economics. new York: Basic Books.

Hirsch, M. W., Smale, S., & Devaney, R. L. (2004). *Differential Equations, Dynamical Systems and an Introduction to Chaos* (2nd ed. Vol. 60). Amsterdam: Elsevier Academic press.

Holland, J. H. (1975). *Adaptation in Natural and Artificial Systems*. Cambridge, MA: The MIT Press.

Holland, J. H. (2001). *Exploring the Evolution of Complexity in Signaling Networks*. Retrieved August 22, 2002, 2002, from http://www.santafe.edu/sfi/publications/wplist/2001

Kahneman, D. (2011). *Thinking, Fast and Slow*. New York: Farrar, Straus & Giroux.

Kauffman, S. A. (1995). *At home in the Universe: The Search for the Laws of Self-Organization and Complexity*. New York: Oxford University Press.

Lichtenstein, B. (2014). *Generative Emergence*. Oxford: Oxford University Press

Lorenz, E. N. (1963). Deterministic nonperiodic flow. *Journal of Atmospheric Science 20*, 130-141.

MacIntosh, R., & MacLean, D. (1999). Conditioned emergence: A Dissipative Structures Approach to Transformation. *Strategic Management Journal, 20*, 297-316.

Mandelbrot , B. (1982).*The Fractal Geometry of Nature*. New York: W H Freeman & Co, 1982; ISBN 0-7167-1186-9

Maslow, A.H. (1943). A Theory of Human Motivation. *Psychological Review, 50*, 370-396.

Marion, R., & Uhl-Bien, M. (2001). Leadership in Complex Organizations. *The Leadership Quarterly, 12*(4), 389-418.

Mezirow, J. (1991). *Transformative Dimensions of adult Learning*. San Franciso: Jossey-Bass.

Mezirow, J. (2003). Transformative Learning as Discourse. *Journal of Transformative Education 1*(1), 58-63.

Nelson, R. R., & Winter, S. G. (1982). *An Evolutionary Theory of Economic Change*. Cambridge, MA: The Belknap Press of Harvard University Press.

Nowak, M., Tarnita C.E., & Wilson, E.O. (2010). The Evolution of Eusociality. *Nature* 466, August 26, 2010, p.1057. doi: 10.1038/nature0920.

Ospina SM and Foldy EG (2015) Enacting Collective Leadership in a Shared-Power world. In Perry JL, Christensen RK (eds) *Handbook of Public Administration*, 3rd ed. San Francisco: Jossey-Bass, 489–507.

Prigogine, I. (1995). *The End of Certainty: Time, Chaos, and the New Laws of Nature*. New York: The Free Press.

Prigogine, I. & Stengers, I. (1984). Order out of Chaos. New York: Heinemann.

Prokopenko, M., Boschetti, F. & Ryan, A. J. (2009). An Information-Theoretic Primer on Complexity, Self-organization and Emergence. *Complexity, ISSN 1099-0526, 15(1), 11-28.*

Ruelle, D. (1989). *Chaotic Evolution and Strange Attractors*. Cambridge: Cambridge University Press.

Surie, G., & Hazy, J. K. (2006). Generative Leadership: Nurturing Innovation in Complex Systems. *Emergence: Complexity and Organization (E:CO), 8*(4), 13-26.

Thom, R., (1989), *Structural Stability and Morphogenesis: An Outline of a General Theory of Models*, Addison-Wesley: Reading, MA.

Tomasello, M. (2014). *A Natural History of Human Thinking*. Cambridge, MA: Harvard University Press.

Uhl-Bien, M., & Marion, R. (2009). Complexity Leadership in Bureaucratic Forms of Organizing: A Meso model. *The Leadership Quarterly, 20*, 631–650.

Von Neumann, J. and Morgenstern, O., (1944), *Theory of Games and Economic Behavior*, Princeton: Princeton University Press.

Watts, D. J. (1999). "Networks, Dynamics, and the Small-World Phenomenon". American Journal of Sociology. **105** (2): 493–527. doi:10.1086/210318.

West, G. (2017). *Scale: The Universal Laws of Growth, Innovation, Sustainability, and the Pace of Life in Organizations, and Companies.* New York: Penguin Press.

Yammarino FJ, Salas E, Serban A, Shirreffs K, and Shuffler ML (2012) Collectivistic Leadership Approaches: Putting the "we" in Leadership, Science and Practice. *Industrial and Organizational Psychology* 5(4): 382–402.

Zak, P. J. (2017) The Neuroscience of Trust. *Harvard Business Review, January-February*, 84-90.

DOI: http://dx.doi.org/10.20377/cgn-50

Table 1 – Important Complexity Concepts That Can Be Covered

Concept	*Relevance*	*Researcher*
Self-Similarity & Fractals	Stability or instability at a level of scale are also likely at other levels of scale.	Mandelbrot (1982) Ruelle, (1989)
Critical Points: Tipping Points, Bifurcation &, Self-Organized Criticality	Conditions that enable stability can change quickly and unpredictability.	Bak (1996); Bak & Paczuski (1995) Thom (1989)
Algorithmic or Descriptive Complexity	Naïve-simple models, such as heuristics, can predict outcomes that one can control. Complex models predict the behavior of a system outside one's control. Complex models are probabilistic.	Crutchfield (1994) Crutchfield & Feldman (1997) Feldman & Crutchfield (1998)
Information Gathering & Using Systems (IGUS)	Complex systems select pathways that are modeled. The action of each "agent" is limited by the information it can access.	Gell-Mann (1995) Cover & Thomas (2004)
Self-organization as information storage	Discontinuous change is signaled by information buildup. "Learning" takes time.	Haken (2006)
Dynamical Systems & Phase Space	Each spatial dimension has two degrees of freedom: position and rate of change in position. This implies thinking in 6-dimensional *Phase Space*.	Hirsch, Smale & Devaney (2004) Forrester (1987) Epstein (1997)
Sensitivity to Initial Conditions & Attractors	Significant changes in outcomes follow small changes in inputs. "Butterfly Effect"	Lorenz (1963)
Complex Adaptive Systems (CAS)	Complexity involves individual "agents" interacting according to each one's local rules of interaction.	Holland (1975, 2001) Axelrod (1984, 1997)
Fitness Landscape and Social Networks	Too many control signals among individuals agents leads to catastrophe. Too few connections reduce adaptability.	Kauffman (1995), Burt (1992) Barabasi (2002) Granovetter (1993) Watts (1999)
Dissipative structures in a non-equilibrium system.	Recognizable structures form spontaneously as excess energy flows *through an organization*. These dissipate excess *energy* to prevent "overheating".	Prigogine (1995) Prigogine & Stengers (1984).
Cumulative Advantage	Positive feedback that is proportional to size allows "the rich get richer."	Barabasi (2002)
Structural Attractor	Physical and social artifacts that provide signals about "choices" to help individuals navigate complexity.	Allen & Strathern (2003)