

Peter Senge begins The Dance of Change with a question:

“Does anyone expect the next twenty years to be less tumultuous than the last twenty years? Given the changes expected in technology, biology, medicine, social values, demography, the environment, and international relations, what kind of world might humanity face? No one can say for sure, but one thing is reasonably certain: Continuing changes will tax our collective abilities to deal with them. Failure to rethink our enterprises will leave us little relief from our current predicaments” (Senge, Kleiner, Roberts, Ross, Roth, & Smith, 1999, p.3).

According to Senge, sustaining change will require a “fundamental shift in thinking” away from a mechanistic perspective (1999, p. 10). The scientist Fritjof Capra summarizes the key assumptions underlying the mechanistic paradigm, which has been the dominant paradigm in our culture for several hundred years: “The Newtonian world *machine* was seen as being completely causal and *deterministic* ... a definite cause and gave rise to a definite effect (1996, p. 120-121—italics added for emphasis). Mechanism is generally associated with linear modeling and is often described using the clock metaphor; as long as the parts are in working order, the whole operates efficiently and predictably.

There is a common perception that Newtonian thinking has contributed to the rise of industrialism, ecological destruction, fragmentation of thought, the splintering of cultural groups (Wilber, 1996). Kouzes and Posner criticize traditional management approaches for their implication that “the ideal organization is orderly and stable, that the organizational process can and should be engineered so that things run like clockwork”. (1995, p. 15). The overemphasis on order, stability, and predictability is troubling to other experts; According to Wheatley and Kellner-Rogers, “The mechanistic image of the world is a very deep image, planted at subterranean depths in most of us. But it doesn't help us any longer” (1996, p. 1).

All of these respected thinkers seem to agree on the fact that the mechanistic perspective (also known as the Cartesian, the Newtonian, the mirror of nature, and the reflection paradigm) does not provide the appropriate mental model for organizational

development in this modern era typified by rapid change and unpredictability. These criticisms beg the question: what paradigm is more appropriate as an organizational model for the 21<sup>st</sup> century?

As we transition into the information age, new sciences such as Quantum physics, Complexity Theory, Superstring Theory, Chaos Theory, and recent discoveries regarding evolution and natural systems provide possible alternatives to the mechanistic approach. This paper reviews the seminal texts and landmark studies from various new frontiers of study with the intent of identifying recurrent themes and commonalities between the disciplines. Ideally, these generalizations will be applicable to organizational theory and contribute to an alternative model of organization.

Multiple disciplines have developed frameworks that invalidate much of the classical suppositions that constitute the bulk of the dominant paradigm. At the present, the principles of self-organizing adaptive systems that are becoming manifest in Complexity Theory appear to best address emerging challenges for organizations. Common components from the various disciplines appear to be the center around purposeful, participative efforts guided by iterative feedback processes.

It should be noted that this review is guided by an assumption that scientific theory influences human interactions and organizations. Support for this belief is found in the Ken Wilber's book, [A Brief History of Everything](#) (1996). The differentiation and disassociation of three spheres of influence (arts, sciences, and religion) during the last few centuries has elevated the status of scientific endeavor to a level that now rivals or exceeds that of the sacred and spiritual. As such, in researching alternatives to the mechanistic paradigm, the focus will be restricted to scientific schools of thought. Beginning with an analysis of science as a discipline, reviews of cosmological and subatomic discoveries and their

integration into superstring theory will precede an overview of advancements in the understanding of co-evolutionary biological processes. A summary of recent breakthroughs in the fields of nonlinear mathematics and complex system theory will complete the literature review section. The conclusion will abstract general themes and provide insights into further research arenas.

## **Paradigm Shifts: The Development and Acceptance of New Scientific Theories**

The seminal text on the progressive advancement of scientific theory is The Structure of Scientific Revolutions, written by Thomas S. Kuhn in 1962. Kuhn analyzes profound shifts in theoretical understanding using the term “paradigm,” a usage of which has now become a component of our common vernacular. Kuhn asserts that revolutionary advancements are accompanied by three elements: the previous awareness of an anomaly, the gradual and simultaneous emergence of both observational and conceptual recognition, and the consequent change of paradigm categories and procedures often accompanied by resistance. The emergent paradigm, arising out of a crisis situation in which conventional theory can provide no explanation of phenomena, actually reconstitutes the very fundamentals of the field. This leads to a period in which advocates of the old paradigm use the traditional criteria to quantitatively validate their theory while proponents of the new theory use a different set of criteria. This is a period in which “revolution is not only incompatible but often actually incommensurable with that which has gone on before” (Kuhn, 1962, p. 103). According to Kuhn, “There can be no scientifically or empirically neutral system of language or concepts” (1962, p. 146). Kuhn goes on to assert that no theory can possibly address the variances of context, form, and structure that are in need of explanation, thus there will always be a search for a theory that is “more suitable” than the old (1962, p. 155). Additionally, a new theory attracts proponents incrementally until there is a critical mass, at which point the new theory supercedes the old in a sudden burst somewhat akin to a Gestalt

Two important tenets emerge from Kuhn’s work when considering alternatives to a mechanistic framework of organizational structure. Primarily, it should be understood that

any replacement paradigm will be more suitable or appropriate until the limitations of the new theories are exposed through time. That is, the field of theory will constantly be in a state of flux. Secondly, a replacement will build a critical mass incrementally until that mass reaches a critical point, at which juncture the shift will appear immediate. Historically, replacement paradigms have not been so obvious as to quickly attract that critical mass. Replacement theories are not only in competition with the accepted paradigm, but with other replacement candidates as well. Kuhn summarizes his findings as follows:

To the extent that the book portrays scientific development as a succession of tradition-bound periods punctuated by non-cumulative breaks, its theses are undoubtedly of wide applicability ... Historians of literature, of music, of the arts, of political development, and of many other human activities have long described their subjects in the same way. Periodization in terms of revolutionary breaks in style, taste, and institutional structure have been among their standard tools (1965, p. 208).

Kuhn's work implies that the process of punctuated equilibrium that characterizes scientific inquiry is not germane only to the field of science, but to the arts as well. It appears possible that these periodic breaks are also manifest in organizational theory—which often draws inspiration from other disciplines such as science.

## **The Very Large and the Very Small: Cosmology, Quantum Physics, and Superstring Theory**

Newtonian gravitational theories were widely accepted until early in the century when Einstein introduced both Special and General Relativity. Prior to relativistic physics, the common perception was that very large bodies of matter such as planets or stars and their respective clusters in solar systems or galaxies obeyed very simple, predictable natural laws. Particularly when considering the implications of subatomic theories, it is now becoming clear that the purported simplicity is simply not an accurate reflection of reality: “The cosmos came to be viewed as a clockwork marvel, events following from causes like the tickings of brass cogs ... Then quantum chance reared its indeterminate face ... we are obliged to consider that even the largest systems are ruled by quantum precepts that govern nature on the smallest scales” (Ferris, 1997, p. 12). In addition, “The most significant change in the twentieth century, it seems, is our passage from a sense of cosmos to a sense of cosmogenesis” (Swimme & Berry, 1994, p. 2). The cosmos appears to be a manifestation of quantum chance coupled with evolutionary precepts—as we shall see, the importance of these reconceptualizations is that both shifts place emphasis on relationships. In addition, both quantum and evolutionary theories are founded on the idea that dynamism prevails and stasis is merely an abstraction.

Cosmogenesis implies that all matter is inherently connected. Ferris asserts that “it seems both permissible and helpful ... to regard living creatures, planets, stars, galaxies, and the atoms and molecules of which they are made as products of cosmic evolution” (1997, p. 194). The interaction of matter at different levels of scale according to evolutionary precepts contributes to an unpredictable, creative, and dynamic cosmos. Ferris sums up the

components of cosmogenesis as follows: “Every evolutionary process has three aspects—one conservative, another innovative, and the third selective” (1997, p. 197). These aspects can be seen as analogous to local influence (in accordance with the Newtonian paradigm), creative dynamism (from Quantum flux and Chaos Theory), and selection between the most appropriate competing manifestations. This co-evolutionary process, according to Wheatley and Kellner-Rogers, is seen at all levels of scale—ranging from microbes to galaxies (1996). The predominance of the cosmogenetic paradigm implies that the mechanistic perspective has been replaced by a more complex model of understanding structures that are very large in terms of scale. The evolutionary dynamism of the cosmos precludes any deterministic or linear modeling of the universe.

The atomistic or mechanical understanding of very small structures was also seen as deterministic under the Newtonian model. Understanding matter was believed to be a matter of mapping out the fundamental elements; for example, water became  $H_2O$ , salt became  $NaCl$ , and so forth. This form of thinking was again aligned with the clockwork model of the universe: understanding of the parts would supposedly contribute to increased comprehension of the whole. The discovery of subatomic particles such as quarks, gage bosons, and fermions revealed a new level of dynamism. Quantum mechanics (a *quon* is defined as a fundamental element in nature, thus the term *quantum* as a description of subatomic particles) have invalidated the simplicity of atomistic models and profoundly undermined the integrity of all mechanistic theory. According to the particle physicist Brian Greene, “quantum mechanics absolutely and unequivocally shows us that a number of basic concepts essential to our understanding of the familiar everyday world *fail to have any meaning* when our focus narrows to the microscopic realm” (1999, p. 87).

Greene summarizes the discovery of quantum principles: “By 1927, therefore, classical innocence had been lost. Gone were the days of a clockwork universe whose individual constituents were set in motion at some moment in the past and obediently fulfilled their inescapable, uniquely determined destiny” (1999, p. 107). Several key discoveries contributed to the belief in indeterminacy, including Heisenberg’s Uncertainty Principle, wave/particle duality, and Bell’s Theorem of non-local influence.

Heisenberg’s Uncertainty Principle essentially asserts that we cannot accurately measure both position and acceleration of subatomic particles with any degree of confidence—in scientific terms, the Uncertainty Principle is expressed as  $\Delta p \Delta x > h$ ; where  $p$  is the uncertainty in momentum,  $x$  is the uncertainty in position, and  $h$  is Planck’s constant of action (Herbert, 1985, p. 68). Subatomic particles are in a constant state of motion and, by definition, are diminutive. To measure the speed of movement, energy must be directed at the particle, which influences the position of the particle, thus invalidating the measurement. This phenomena occurs when attempting to discern the location or position of a subatomic particle as well. Greene states the importance of this discovery as follows: “we fundamentally cannot know the precise positions and velocities of constituents of the universe” (1999, p. 341). Obviously, without accurate information, linear modeling, cause and effect studies, and other forms of mechanical thinking are impossible. Indeterminacy is a fundamental attribute of nature.

Quantum physics is also equated with duality as expressed by wave/particle phenomena that is incongruent with mechanistic modeling. Multiple experiments, the most famous of which is Schrödinger’s Cat, verify that subatomic particles exhibit the behavior of both waves and particles simultaneously. Particles generally are perceived to behave with greater predictability due their linear movements, waves and waveform interactions are

typified by a phenomenon known as interference, which leads to greater unpredictability and variance in behavior. According to Greene, “The microscopic world demands that we shed our intuition that something is either a wave or a particle and embrace the possibility that it is both” (1999, p. 103). This duality is also incompatible with simple cause and effect modeling from a mechanistic perspective. Interestingly, the behavior of subatomic elements such as quarks vary their behavior in relation to the nature of the experiment. This has led several theorists to conclude that the imposition of measurement (consciousness) contributes to waveform collapse (Herbert, 1985). In other words, it is the observer who creates reality. The Newtonian paradigm doesn’t allow for the imposition of consciousness to alter the nature of reality.

The third key element of quantum theory is Bell’s Theorem of Non-locality. The theory suggests that two quons can be separated by an infinite distance, yet once the spin of one quon is altered, the paired quon will experience an instantaneous alteration. This theory suggests that there is a superluminal connection between the quons, invalidating Einstein’s assertion that the speed of light is the upper limit of movement in the universe. Physicist Nick Herbert describes the impact of the theory : “Bell maintains that the world is filled with innumerable non-local influences. Furthermore, these unmediated connections are present not only in rare and exotic circumstances, but underlie all the events of everyday life. Non-local connections are ubiquitous because reality itself is non-local (1985, p. 214). As wild as the theory is, it has been confirmed by numerous experiments. Nonlocal influence destroys the possibility of understanding cause and effect, invalidating any linear model. Although there is currently no consensus on why nonlocal influence exists, one famous physicist, John Wheeler, has pondered the possibility that all fundamental components of the universe are actually unified: “I know why all electrons have the same charge and same mass ... Because

they are all the same electron!” (Ferris, 1997). Regardless of the explanation, the fact that there is a fundamental interconnectedness across time and space is incompatible with any fragmented perspective of reality.

The three foundations of quantum mechanics: indeterminacy, duality, and non-local influence, all contribute to a model of thought based on probability. That is, replication of an experiment numerous times will demonstrate regular patterns, yet each individual instance is unique. Physicists refer to this as coarse-graining (generalizing probabilities) and fine-graining (examination of individual cases) (Gell-Mann, 1994). On a coarse-grain scale, quantum physics represents the most accurate and verifiable body of theory ever constructed (Herbert, 1985; Ferris, 1997; Gell-Mann, 1994; and Greene, 1999).

Larger objects are subject to less uncertainty in measurement, thus reducing the effects of Heisenberg’s Uncertainty Principle and legitimizing classical studies and theories regarding common observable physics. However, when applying quantum theory to very large bodies of matter, several conflicts emerge. To explain the apparent conflicts, Superstring Theory has emerged. The basic idea of string theory is that even subatomic particles such as quarks and fermions are not the foundation of matter; the fundamental aspects of reality is a very small multidimensional vibrating string:

Just as the strings on a violin or on a piano have resonant frequencies at which they prefer to vibrate--patterns that our ears sense as various musical notes and their higher harmonics--the same holds true for the loops of string theory ... rather than producing musical notes, each of the preferred patterns of vibration of a string in string theory appears as a particle whose mass and force changes are determined by the string's oscillatory pattern ... Far from being a collection of chaotic experimental facts, particle properties in string theory are the manifestation of one and the same physical feature: the resonant patterns of vibration (Greene, 1999, p. 15).

According to the theory, different “tones” of vibration give rise to apparently indeterminate events, also influenced at small scales by multidimensional interference. String theory unifies

relativity and quantum theory due its prediction of gravity (an unexplained phenomenon in quantum theory), and has been touted as the potential “Theory of Everything” by notably physicists (Gell-Mann, 1994). In addition to the earth-shattering implication that all matter derives from space (the strings are infinitesimally small), String Theory also brings with it the unbelievable assertion that multiple dimensions exist and have an influence on the observable reality: “For string theory to make sense, the universe should have nine space dimensions and one time dimension” (Greene, 1999, p. 203). According to the theory, several dimensions collapsed during the Big Bang, leaving three spatial and one time dimension expanded. However, the other six dimensions are encapsulated in the strings in the form of Calabi-Yau shapes. Additionally, the supersymmetric component of string theory infers that there are complementary components to the elements of the cosmos that are equivalent in inverse proportions—for example, a quon with a radius of 1/10 of a unit would be *exactly* equivalent to a quon with a radius of 10. The implication is that the very small components of matter may be *identical* to very large items. Experimental work is currently being conducted on comparing the properties of black holes to subatomic phenomenon with astonishing results to date (Greene, 1999).

The commonality between cosmogenesis, quantum physics, and now superstring theory is a similar emphasis on uncertainty and nonlocality. The inference that multidimensional effects may play a part in creating the indeterminacy is counterintuitive, yet appears to be the leading explanatory candidate at this time. In addition, cosmogenetic, quantum, and superstring theories also legitimize the influence of relationships among the object and its environment, subatomic particles, and even multiple dimensions.

## **Life: Biological Models and Co-evolution**

Thus far the review has focused on inanimate properties such as matter. A brief analysis of advancements in the field of biology and living systems is necessary when considering the impact of scientific advancements on organizational theory. Senge asserts that we need to “think less like managers and more like biologists” (Senge, Kleiner, Roberts, Ross, Roth, & Smith, 1999, p. 6). Robert Cooper indicates that “... there are signs that the emerging model of organizational intelligence will be based far more on the principles of ... biological systems” (1997, p. xxvii). In essence, the movement in biological research has been towards an ecological model that attempts to understand environmental interactions in describing emergent properties or behaviors.

The first step is to understand operational definitions of “life” and “living” in terms of biological thinking. Currently, the favored explanations consist of three parts related to autopoiesis: patterns, structures, and cognition. Patterns refer to the organizational patterns of living systems, structures are generally understood within the context of dissipative structures, and cognition is currently seen as a co-evolutionary process (Capra, 1996).

Autopoiesis, from the Greek word for self-production, is generally defined in terms of three criteria: the system must be self-bounded, self-generating, and self-perpetuating. Lynn Margulis, coauthor of the Gaia theory, asserts confidently: “There is little doubt that the planetary patina--including ourselves--is autopoietic” (Capra, 1996, p. 215). One of the interesting features of autopoietic systems is their interaction with the environment; a living system interacts with its environment through “structural coupling,” that is, through recurrent interactions, each of which triggers structural changes in the system. This coupling ensures that the environment and the autopoietic system are constantly exchanging

information that alters their capacity (Capra, 1996). This exchange of information is fundamental in any living system, and the relationships that define the interchange of information serve to monitor, regulate, and regenerate life.

In terms of structure, living systems resemble dissipative structures, whose properties include both self-amplifying feedback loops and self-balancing loops. These feedback mechanisms push the system farther and farther from equilibrium until it reaches a “threshold of stability,” also defined mathematically as a bifurcation point (Capra, 1996, p. 171). The development of the living system is dependent on the continued ebb and flow of information passing through the feedback loops in order to sustain itself (information can include the exchange of matter such as food or water). In other words, environmental disturbances play a crucial role in developing stability in the dissipative structure, demonstrating how “disorder can be a source of order ... growth is found in disequilibrium, not in balance” (Wheatley, 1992, p. 19-20). According to Capra,

“Many of the key characteristics of dissipative structures—the sensitivity to small changes in the environment, the relevance of previous history at critical points of choice, the uncertainty and unpredictability of the future—are revolutionary new concepts from the point of view of classical science but are an integral part of the human experience. Since dissipative structures are the basic structures of all living systems, including human beings, this should perhaps not come as a great surprise” (1996, p. 192).

These key features, including unpredictability, were also evident in the research concerning inanimate systems.

The third component of a living system is the capacity for cognition. Theories of cognition vary, but one recurrent theme is that the brain does not function in isolation of other body parts (Capra, 1996; Allman, 2000; Caine & Caine, 1997; Cooper & Sawaf, 1997). Rather, there is a dynamic interplay between the nervous system, emotions, and synaptic responses. Another current that is gaining strength in the realm of cognitive science derives

from advances in cybernetics and uses computer simulations to create cognitive machines (Gell-Mann, 1994; Waldrop, 1992). There is a great deal of debate at the moment about whether cognition can be modeled using binary networks, which are essentially series of “on” and “off” switches. The interplay between specialized and non-specialized brain functions appears to suggest that cognition is not formulaic, especially considering the influence of peptides and nervous system influences (Allman, 2000). Regardless of the explanation, both binary network models and non-formulaic theorists place cognition within a web-like model, suggesting that a systemic approach is fundamental in thought processes.

Perhaps the most valuable contribution from the field of cognitive science is a reconceptualization of evolution. The Darwinist, classical definition essentially refers to random mutations, competition, and natural selection. The modern definition stresses cooperation and symbiogenesis, using examples such as DNA recoupling to support the perspective that most advances occur through symbiotic relationships (Gell-Mann, 1994; Allman, 2000; Swimme & Berry, 1994; Wheatley & Kellner-Rogers, 1996; Waldrop, 1992). Capra asserts that “evolutionary change is seen as the result of life's inherent tendency to create novelty, which may or may not be accompanied by adaptation to changing environmental conditions” (1996, p. 192). This evolution is seen as creative, a stark contrast to the destructive model that pervades the traditional definition.

In addition, this evolution (sometimes referred to as *co-evolution* in light of the structural coupling with the environment), is participative in that nothing exists in isolation. This harkens back to Bell's Theorem of Nonlocal influence: “The webs of coevolution are so intimately intertwined that we cannot understand anything in its separateness” (Wheatley & Kellner-Rogers, 1996, p. 29).

Wilber redefines evolution as the process of transcending and including previous forms of organization:

The standard, glib, neo-Darwinian explanation of natural selection--absolutely nobody believes this anymore ... For the moment, everybody has simply agreed to call this "quantum evolution" or "punctuated evolution" or "emergent evolution"--radically novel and emergent and incredibly complex holons come into existence in a huge leap, in a quantum-like fashion--with no evidence whatsoever of intermediate forms ... Evolution is a wildly self-transcending process ... which incorporates what went before and then adds incredibly novel components. The drive to self-transcendence is thus built into the very fabric of the Kosmos itself (1996, 23).

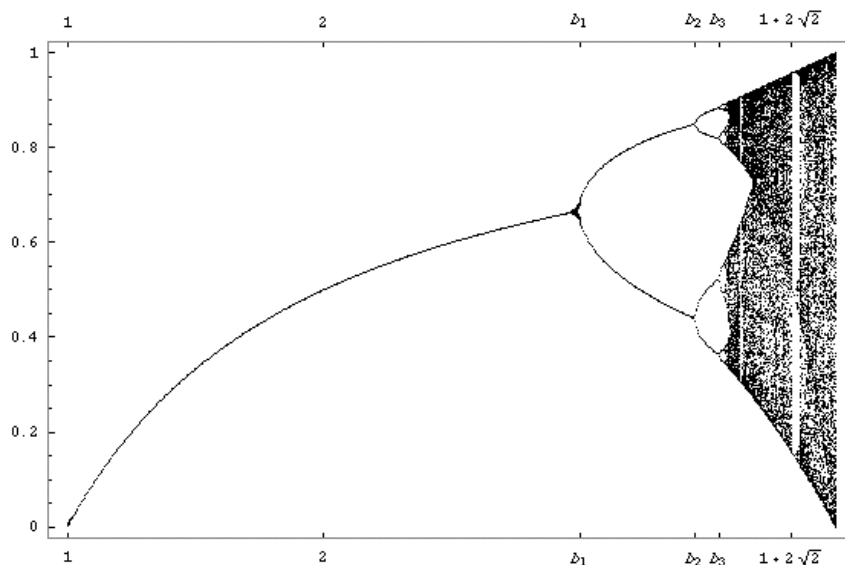
Wilber's description is reminiscent of Kuhn's model for emergent paradigms, in which incremental change builds to a critical mass, at which point the Gestalt-like transformation appears sudden. Herein lies the link between cognition and evolution—the perspective that is gaining momentum is that neural networks generate numerous possibilities through an evolutionary process. The most suitable possibility is chosen based on the environmental and situational context. Thought, it appears, obeys similar rules that govern interstellar interactions and the formation of the universe.

In addition to the recurrent theme of evolution, particularly in its modern incarnation, living systems appear to exhibit several key features that are generalizable and relevant to organizational theory: structural coupling, which links life to the environment through the exchange of information; using feedback to move away from equilibrium, then stabilizing through exchanging information; and developing cognitive abilities through some of network systematization. The constant flow of information and use of feedback ensures that life remains unstable and unpredictable. The importance of maintaining a state of disequilibrium becomes more exigent in light of Chaos Theory discoveries. The network model, which focuses on interactions and relationships, will also become a critical issue in other disciplines.

## Chaos: the Emergence of Nonlinearity and Complexity

Advances in computational ability through new technology has opened new frontiers in mathematic understanding. Iterative functions can now be calculated with unprecedented accuracy and detail. The knowledge gained from such calculations has reshaped mathematical conceptualization of nonlinear processed, best expressed through the emergent field of Chaology—the study of chaos. According to the landmark text, Chaos: Making a New Science: “Where chaos begins, classical science stops” (Gleick, 1987, p. 3). Through nonlinear modeling, the study of chaos focuses on the global nature of systems— analogous to the coarse-graining of quantum theory.

Often, the parable of the butterfly flapping its wings and creating a tornado is used to explain chaotic phenomenon, but this parable lacks the richness of a well-rounded explanation. An explanation of the science of Chaos necessitates extrapolation of several key components: nonlinearity (best expressed through a pitchfork bifurcation model), universality, fractals, and strange attractors.



The graphic above represents a pitchfork bifurcation diagram, complete with period doublings and chaotic regions. The graphic is derived from the equation  $x_{\text{next}} = rx(1-x)$ , which is generally used to study limits in population studies (Gleick, 1987). Close scrutiny of the chaotic regions illustrates that there are subtle patterns within the “noise,” including small pictures which resemble the entire diagram. The meaning of the diagram is clear:

The diagram shows how changes in one parameter ... would change the behavior of this simple system ... as the parameter rises further, the equilibrium splits in two, just as turning up the heat in a convecting fluid causes an instability to set in; the population begins to alternate between two different levels. The splittings, or bifurcations, come faster and faster. Then the system turns chaotic ... and the population visits infinitely many values (Gleick, 1987, p. 71).

This nonlinear model reflects the very attributes that eluded mechanical formalism, namely unpredictability, instability, and the profound manner in which small changes affect the entirety of the system. It mathematically verifies the perplexing conclusions from quantum studies and emergent evolution. Also apparent is the “punctuated” element of co-evolution, in which the system appears to be fairly stable and predictable for long periods, then undergoes profound and rapid transformations upon reaching a bifurcation point. According to scientists, the physical world is “relentlessly nonlinear,” meaning that the properties of nonlinear systems apply to much of the observable universe (Capra, 1996, p. 123).

These conclusions would not be so dramatic were it not for the discovery of nonlinear universality. Mitchell Feigenbaum discovered that, upon analysis, *all* nonlinear systems exhibited similar characteristics. This similarity had eluded researchers due to limitations in technology, but also due to self-imposed limitations; Feigenbaum describes his discovery: “One has to look for scaling structures—how do big details relate to little details ... At some level they don't care very much what the size of the process is—it could be the

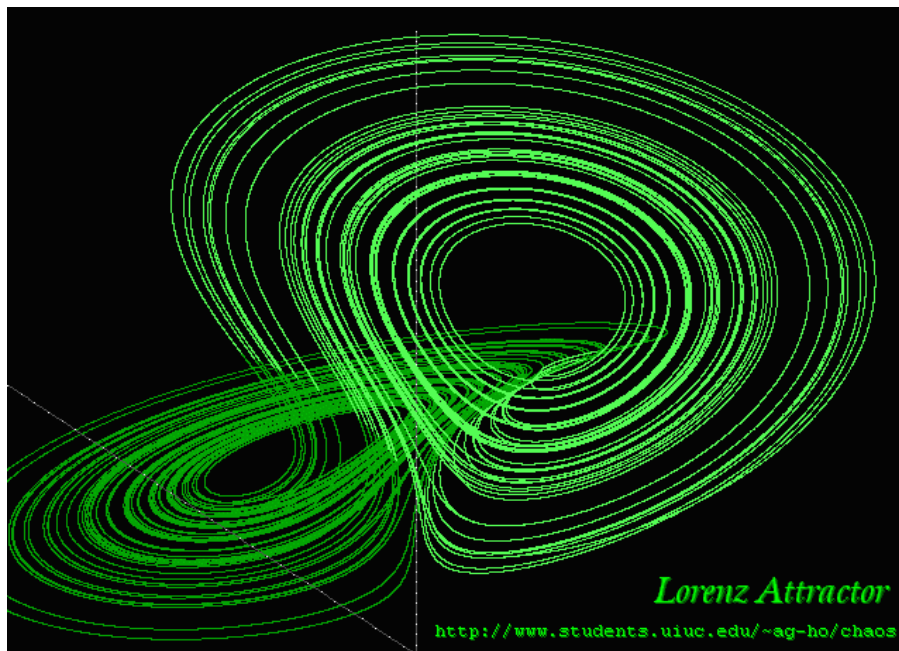
size of a pea or the size of a basketball. The process doesn't care ..." (Gleick, 1987, p. 186). In other words, nonlinearity is a process—not an item—that exhibits similar properties in phenomenon at all levels. Universality, based on mathematical models, is analogous to the supersymmetric element of string theory. The independent discovery of this scaling phenomenon is a powerful verification of the idea that systems exhibit similar characteristics.

Benoit Mandelbrot took the idea of universality and applied the concept to multidimensional analysis, leading to the creation and spread of the science of fractals. Fractal shapes are developed through iterative non-linear functions, creating captivating patterns rich with complexity. According to Capra, “The most striking property of these ‘fractal’ shapes is that their characteristic patterns are found repeatedly at descending scales, so that their parts, at any scale, are similar in shape to the whole” (1996, p. 138). Applications of fractal studies abound, ranging from a re-evaluation of the structure of the human heart to measurement of coastlines (Gleick, 1987). Fractal studies have also contributed to an understanding of “basin boundaries” between order and chaos. A graphic representation of a fractal structure is included below for visual depiction.



Several researchers became captivated by the striking imagery of fractal and bifurcation diagrams. Using different sampling methods, it became apparent that nonlinear functions organized themselves around “strange attractors” that served to constrain the

random activity generated by chaotic instability (Gleick, 1987; Wheatley, 1992). The method for discovering strange attractors was essentially to sample phase activity on a two-dimensional grid resembling a Cartesian coordinate map—however, the strange attractor is plotted by measuring each iteration against previous iterations, making it self-referential. The strange attractors implied that, although chaos and dynamism was inherent in nonlinear systems, some degree of conservatism was also embedded in the process. The Lorenz Attractor, the true inspiration for the so-called “butterfly effect” is included below as an example of a strange attractor.



The advancements in our understanding of chaotic phenomenon as a result of our improved ability to use technology to model nonlinear equations has contributed to the rise of another new field of study: complexity. Complexity theory essentially focuses on the intermediate region between chaos and stability, exemplified by fractal basin boundaries and somewhere prior to the third period doubling a typical nonlinear equation. However, complexity theory attempts to generalize the fundamentals of this border region to massive systems such as the economy, the human body, computer networks, and cosmology.

M. Mitchell Waldrop, the author of Complexity, proclaims that “The edge of chaos is the constantly shifting battle zone between stagnation and anarchy, the one place where a complex system can be spontaneous, adaptive, and alive” (1992, p. 12).

Murray Gell-Mann, winner of the Nobel Prize in Physics for his discovery of the quark, defines complexity in terms of algorithmic information content. Stability is fairly easy to describe algorithmically, as is complete chaos—it is the intermediate region that requires the greatest amount of refinement in terms of communication. Thus, the border between chaos and order is the most complex area, the most vibrant, and full of the greatest potential. (Gell-Mann, 1994). Gell-Mann was instrumental in the founding of the Los Alamos Institute, a multidisciplinary retreat for collective study of complex phenomenon (Waldrop, 1992).

The study of this border region has led to the development of theories about complex adaptive systems, residing at the edge of chaos and responding to information in such a way that the system balances between order and chaos. Integral components of complex adaptive systems are purpose (generally survival), feedback (for balance and reinforcement), and participation in the structural coupling with the environment. Control of a complex adaptive system tends to be highly dispersed—there is no master neuron in the brain, for example, nor is there any master cell within a developing embryo. The dispersion pattern is *always* in the form of a network. Within the complex adaptive system, a fractal quality exists in that less complex subsystems obey the same organizational principles; an example is the human body, consisting of multiple complex systems such as the nervous system, the respiratory system, and temperature modulation systems. The goal of a complex adaptive system is to remain far from equilibrium—stability means the death of complex adaptive system such as the human body. In pursuing balance, complex adaptive systems

are perpetually experimenting with new forms of being that would contribute to greater sustainability (Waldrop, 1992). This creative aspect is tantamount to symbiogenesis and obeys the laws of emergent evolution.

One of the profound insights from the study of complexity is that this rich phenomenon emerges from very simple foundations. Complexity in natural systems arises from local control, experimentation, and feedback. Complex systems are nested within a holarchy of other complex systems, always interacting with one another. The economist Brian Arthur reflected on the development of complexity theory: “As we begin to understand complex systems, we begin to understand that we're part of an ever-changing, interlocking, nonlinear, kaleidoscopic world” (Waldrop, 1992, p. 333).

Other scientists are hailing the studies of complexity as “one of the most important events in twentieth-century science” (Capra, 1996, p. 112). Integrating tenets of co-evolution, nonlinear dynamism, dissipative structures, fractals, structural coupling, and nonlocal influence, it can be said that complexity is the science of emergence. This attention on emergent phenomena counters the Newtonian emphasis on machine-like performance and presents an opportunity to influence organizational theory on a new level.

## Conclusions

Newtonian mechanism has been a pervasive influence in human thought for centuries, yet it appears as if there are many suitors ready to assume the mantle of the emergent paradigm. Cosmogogenesis, Quantum mechanics, Superstring Theory, co-evolution, Chaology, and the studies of complexity all appear to offer a framework that invalidates much of classical science. Determinism, linear systems, and any conceptualization of reality as machine-like are non-existent phenomenon in today's pursuit of scientific advancement.

The most striking commonality of the new sciences is the shift from the parts to the whole. From the very large cosmogenetic principles to the very small Superstring discoveries, there appear to be certain generalizations at all scalar levels of study. There is an interconnectedness, a dynamism, and a creative aspect to all levels:

The key characteristics of systems thinking ... [is] the shift from the parts to the whole ... Ultimately—as quantum physics showed so dramatically—there are no parts at all. What we call a part is merely a pattern in an inseparable web of relationships (Capra, 1996, p. 36-37).

This attention to relationships has profound implications for organizational theory. What structures best support the development of relationships, and how do we apply the principles of nonlinear processing to improve organizational effectiveness? It appears as if nature works through networks nested within networks; systems are networks of smaller components, themselves components of a multilayered system of yet more networks. These networks, consisting of mostly space, can only be understood in the context of the intra- and inter-relationships that typify the system.

The processes which allow the networks to self-organize are purpose, participation, and feedback. It appears that the creative, evolutionary aspects of reality are embedded within every level of organization, spurring the system to experiment and change. Nothing

is static. Local and nonlocal influence derive from the mandatory participation of the dynamic networks. Interconnectedness is also embedded into the system. Balancing and reinforcing feedback keeps the network system on the edge of chaos, in the fractal basin boundary exhibiting the greatest creativity, spontaneity, and capacity for growth. Changes come in punctuated bursts at bifurcation points, constrained only by the strange attractors that give order to a quasiclassical reality.

The new sciences indicate that these networks need to exhibit fractal, self-similar qualities guided by harmonic purpose. Participation should be between and across the networks and feedback should be systematized to monitor and guide progress. Yet fragmentation, specialization, and isolation remain pervasive in organizations. The discoveries that have energized the scientific community have yet to manifest themselves:

We are now at the beginning of such a fundamental change of worldview in science and society, a change of paradigms as radical as the Copernican revolution ... The recognition that a profound change of perception and thinking is needed if we are to survive has not yet reached most of our corporate leaders ... or the administrators and professors of our large universities (Capra, 1996, p. 4).

These findings indicate that there is a need to share the phenomenal discoveries of the new sciences in a comprehensible fashion with the layperson. Several attempts have already occurred, the most widely-recognized of which is the work of Margaret Wheatley in Leadership and the New Science (1992) and A Simpler Way (Wheatley & Kellner-Rogers, 1996). Other attempts include William Fullmer's Shaping the Adaptive Organization (2000), Joel De Rosnay's thesymbioticman (2000), and Surfing the Edge of Chaos: The Laws of Nature and the New Laws of Business (Pascale, Millemann, & Gioja, 2000). Peter Senge's popular books on systems thinking also incorporate many of the tenets of these scientific advancements.

Further research is needed to understand the different approaches that are currently being used to apply non-classical science to organizations. In particular, the educative system needs to be analyzed and reconceptualized under the lens of the emergent paradigms.

References

- Allman, J. (1999). Evolving brains. New York: Scientific American Library.
- Blase, J., & Kirby, P. C. (1992). Bringing out the best in teachers: What effective principals do. Newbury Park: Corwin Press, Inc.
- Caine, G., & Caine, R. N. (1997). Unleashing the power of perceptual change: The potential of brain-based teaching. Alexandria: Association for Supervision and Curriculum Development.
- Capra, F. (1996). The web of life. New York: Anchor Books.
- Cooper, R. K., & Sawaf, A. (1998). Executive EQ: Emotional intelligence in leadership and organizations. New York: Perigree Books.
- Ferris, T. (1997). The whole shebang. New York: Simon & Schuster.
- Fulmer, W. (2000). Shaping the adaptive organization. New York: Amacom.
- Gell-Mann, M. (1994). The quark and the jaguar. New York: Freeman.
- Gleick, J. (1987). Chaos. New York: Penguin Books.
- Greene, B. (1999). The elegant universe. New York: Vintage.
- Herbert, N. (1985). Quantum reality. New York: Anchor Books.
- Kouzes, J. M., & Posner, B. Z. (1995). The leadership challenge. San Francisco: Jossey-Bass Books.
- Kuhn, T. S. (1962). The structure of scientific revolutions. Chicago: University of Chicago Press.
- Pascale, R., Millemann, M., & Gioja, L. (2000). Surfing the edge of chaos. New York: Crown Business.
- Rosnay, J. d. (2000). The symbiotic man. New York: McGraw-Hill.
- Senge, P. (2000). Schools that learn. New York: Doubleday.

Senge, P., Kleiner, A., Roberts, C., Ross, R., & Smith, B. (1994). The Fifth Discipline Fieldbook. New York: Bantam Doubleday.

Senge, P., Roberts, C., Ross, R., Smith, B., Roth, G., & Kleiner, A. (1999). The dance of change. New York: Doubleday.

Swimme, B., & Berry, T. (1992). The universe story. New York: HaperCollins.

Waldrop, M. M. (1992). Complexity. New York: Simon & Schuster.

Wheatley, M. (1992). Leadership and the new science. San Francisco: Berrett-Koehler.

Wheatley, M., & Kellner-Rogers, M. (1996). A simpler way. San Francisco: Berrett-Koehler.

Wilber, K. (1996). A brief history of everything. Boston: Shamhala Publications.