COMPLEXITY – ANNOTATED BIBLIOGRAPHY

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Albert-László, Barabási, Linked: The New Science of Networks, Cambridge: Perseus Publishing, 2002

Barabási's Linked is an introduction to the basic ideas of network science, with an emphasis on social network theory. In the early twentieth century Paul Erdős and Alfréd Rényi, experimented with *random network theory*, the idea that everyone is linked to one another in random networks. Frigyes Karinthy later articulated the same theory in a different, more defined way: *six degrees of separation*, that everyone on the planet is connected with no more than five intermediaries between each person. Harvard professor Stanley Milgram later went on to prove the *six degrees of separation* theory through an experiment involving a message that would arrive to a single person through various intermediaries. Milgram referred to such systems of high connectivity as *small world*s.

In his *Strength of Weak Ties*, Mark Granovetter demonstrated that it was in fact the weak social connections that people have with others, rather than strong ties (i.e. acquaintances rather than good friends) that play more important roles in long-range social connectivity (whether getting a job, spreading a fad, etc), because those with whom one is close tend to share experiences and have access to the same information, versus weak links, which tend to have different experiences and information.

Duncan Watts and Steven Strogatz suggested the idea of small, *clustered* worlds; networks are not wholly flat and connections are not equal in distance, rather certain nodes have connections that are of greater distance than others; moreover, *hubs*, those nodes with more connections than others, will exist in naturally occurring networks.

As a result of the emergence of hubs in various networks, hubs tend to have more influence over the network in whole; because of their relatively higher connectivity, the actions, decisions, and nature of hubs will have a greater effect on a greater number of agents. This leads to a *power law distribution*, in which hubs tend to have more power than others, generally in an 80/20 or similar ratio: 20 percent of the nodes control 80 percent of the connections, etc. Networks in which hubs appear—all natural networks—are called *scale-free networks*, those in which connectivity (and therein 'power' or any other variable) is not random or equal.

The imbalance of connectivity in scale-free networks tends to lead to a greater imbalance of connectivity, due to *preferential attachment*. Because hubs are more highly connected, other nodes tend to want to connect with it as well, as the hub has access to more nodes, and as a result, more information, more power, etc. Due to this *preferential* connectivity, what starts as a hub remains an even more connected hub, i.e. the rich get richer (a process also known as a positive feedback loop or network effect). As hubs tend to be the centers of connectivity, they also tend to be the centers of power. Thus, they are in many ways the focal point of a network and if brought down, the network is weakened.

In large part, spread through a network has to do with a *threshold model*, the propensity of an individual to adopt a new idea that has made its way through the network. In sum, the propensity of the network to spread a new idea, based on each individual's threshold, is referred to as the *spreading rate*.

Barabási's primary experience in network theory is with the World Wide Web, which he and his colleagues have tried to map. He has noted that although initially under human control, the Web has in many ways become a dynamic network of its own, with some pages linking to others, and still others being more highly trafficked. Moreover, the web has turned—in large part due to the 'natural' processes described above—into a *directed network*, one which has broken down into easily identifiable fragments that tend to flow into one another based on the nature of each grouping. Barabási goes on to explain the application of these fundamental tenets of network theory to genealogy, company directorship, world economics and other realms.

Anderson, Philip, Gérard Cachon, and Paul Zipkin, "Complexity Theory and Organization Science," ***Organization Science*****, Vol. 1, No. 3, 1999, pp 216-232**

Complex organizations exhibit surprising, nonlinear behavior. Although organization scientists have studied complex organizations for many years, a developing set of conceptual and computational tools makes possible new approaches to modeling nonlinear interactions within and between organizations. Complex adaptive system models represent a genuinely new way of simplifying the complex. They are characterized by four key elements: agents with schemata, self-organizing networks sustained by importing energy, coevolution to the edge of chaos, and system evolution based on recombination. New types of models that incorporate these elements will push organization science forward by merging empirical observation with computational agent-based simulation. Applying complex adaptive systems models to strategic management leads to an emphasis on building systems that can rapidly evolve effective adaptive solutions. Strategic direction of complex organizations consists of establishing and modifying environments within which effective, improvised, self-organized solutions can evolve. Managers influence strategic behavior by altering the fitness landscape for local agents and reconfiguring the organizational architecture within which agents adapt.

Lorenz, Edward, The Essence of Chaos, The Jessie and John Danz Lecture Series: University of Washington Press, 1996

In *The Essence of Chaos,* Lorenz presents the main features of Chaos theory and its implications for fields as diverse as weather prediction and philosophy, and he describes its considerable impact on emerging scientific fields.

Unlike the phenomena dealt with in relativity theory and quantum mechanics, systems described as "chaotic" can be observed without telescopes or microscopes. They range from the simplest happenings, such as the falling of a leaf, to the most complex processes, like the fluctuations of climate. Each process that qualifies, however, has certain quantifiable characteristics: how it unfolds depends very sensitively upon its initial state, so that, even though it is not random, it seems to be. Lorenz uses examples from everyday life, and simple calculations, to show how the essential nature of chaotic systems can be understood. In order to expedite this task, he has constructed a mathematical model of a board sliding down a ski slope as his primary illustrative example. With this model as his base, he explains various chaotic phenomena, including some associated concepts such as strange attractors and bifurcations.

As a meteorologist, Lorenz initially became interested in the field of chaos because of its implications for weather forecasting. In a chapter ranging through the history of weather prediction and meteorology to a brief picture of our current understanding of climate, he introduces many of the researchers who conceived the experiments and theories, and he describes his own initial encounter with chaos. A further discussion invites readers to make their own chaos. Still others debate the nature of randomness and its relationship to chaotic systems, and describe three related fields of scientific thought: nonlinearity, complexity, and fractality. Appendixes present the first publication of Lorenz's seminal paper, *"Does the Flap of a Butterfly's Wing in Brazil Set Off a Tornado in Texas?";* the mathematical equations from which the copious illustrations were derived; and a glossary.

Arquilla, John, and David Ronfeldt, In Athena's Camp: Preparing for Conflict in the Information Age, Santa Monica, CA, RAND Corporation, 1997

The information revolution, simultaneously impacting the realms of organization and technology, is transforming the nature of conflict across the spectrum: from open warfare, to terrorism, crime, and even radical social activism. The era of massed field armies is passing, because the new information and communications systems are increasing the lethality of quite small units that can call in deadly, precise missile fire almost anywhere, anytime. In social conflicts, the Internet and other media are greatly empowering individuals and small groups to influence the behavior of states. Whether in military or social conflicts, all protagonists will soon be developing new doctrines, strategies, and tactics for swarming their opponents — with weapons or words, as circumstances require. Preparing for conflict in such a world will require shifting to new forms of organization, particularly the versatile *all-channel network*, in which every node can communicate with every other node. This shift will prove difficult for states and professional militaries that remain bastions of hierarchy, bound to resist institutional redesign. They will make the shift as they realize that information and knowledge are becoming the key elements of power. This collection of essays by an array of authors in the field discusses the implications of the information revolution on military management (including areas such as the Revolution in Military Affairs and network-centric warfare), the changing nature of warfare and conflict (cybersecurity and decentralization of conflict), the social implications of increased and enhanced information (terrorism, criminal rings, and even less pernicious social organization), and lastly, proposed paradigmatic and intellectual shifts to accommodate the changing nature of society.

Jervis, Robert, "Complex Systems: The Role of Interactions," <u>Complexity, Global Politics, and National Security</u>, David Alberts and Thomas Czerwinski (eds.), Washington, DC, National Defense University Press, 1996

Jervis describes the role of interactivity and its understanding in the science of complexity systems in global affairs and international politics. Global politics is described as a system when "(a) a set of units or elements are inter-connected so that changes in some elements or their relations produce changes in other parts of the system and (b) the entire system exhibits properties and behaviors that are different from those of the parts."

The vast interconnectivity of a system as complex as global politics makes it such that chains of consequences extend "over time and many areas" and that the effects of even a single action are always great in number, such that "we can never merely do one thing." Due to the nonlinearity of complex systems stemming from high interconnectivity, a small amount of a cause can have an immense effect, or conversely, a great amount of a variable can change very little, all depending on which other variables are present.

Additionally, strategy often depends on the strategies of others, based on how actors anticipate the actions and intentions of other actors. The success or failures of strategies are contingent on others, and are thus determined interactively. Behaviors change the environments in which agents act, such that initial behaviors influence later ones, producing dynamics that explain larger-scale change over time. *Coevolution* thus results: agents not only adapt *to* their environment, but adapt *with* and *change* it.

Interactivity occurs at such an immense rate that it is often difficult to discern between actors and their environments; products of interaction themselves become the units of analysis. Systems can also produce *circular effects* as actors respond to environments and change themselves in the process.

Jervis uses detailed examples from global politics and political history to explain each of the phenomena that he describes, and suggests that adapting to effective politics and governance—or indeed analysis—in such an era requires a change in perspective from parts to wholes and systems, and from ______ to patterns of behavior.

Bellavita, Christopher, "Changing Homeland Security: Shape Patterns, not Programs," *Homeland Security Affairs,* Vol. 2, No. 3, 2006

Bellavita argues that homeland security strategy, the "pattern of consistent behavior over time," is simultaneously intentional and emergent. To improve the current homeland security system, he suggests focusing on managing systemic patterns, rather than focusing on specific programs.

A central aspect of homeland security decision-making, particularly in an age when outcomes are unpredictable and uncertain, is to "make strategic decisions [today] that will be sound for all plausible futures." Decisions and policy dynamics are significantly influenced by how stakeholders *perceive* a specific issue. Bellevita uses the *Cynefin framework* as a sense-making taxonomy.

The Known or Simple domain is where cause and effect are understood and predictable; everyone thus knows how to act. In homeland security, some futures can be foretold with a great degree of certainty, and decisions can be made accordingly.

The Knowable or Complicated domain is where cause and effect relationships are difficult to understand, but, given time and resources, can be determined by experts. In homeland security, technology and expertise can play a role in ascertaining cause and effect relationships, and decisions made in the light of this knowledge.

The Complex domain is where cause and effect are only understandable in hindsight, and there is no assurance that they will persist. Most of the significant issues in homeland security lie in this domain, and the effects of present decisions can only be understood through "retrospective coherence." The issues in this domain are open problems, in that they are never resolved, and can be highly interactive.

The Chaotic domain is where cause and effect are unknown, and there is no certainty in the consequences of one's actions. There are no patterns in this domain, stability may have to be *imposed* through knowledge, authoritarian response, or charismatic leadership.

The disordered is where there is “insufficient stakeholder agreement about how to make sense of an issue.”

To cope with the latter three realms, Bellavita suggests the following: (1) Make a decision based on what is sought, and enable the capacities through immense communication across scale and jurisdiction; (2) Assess the future based on potential contingencies; (3) Expand the future to assess the *interactive effects* of the selected homeland security issues; (4) Incorporate the environment that could affect these contingencies, such as politics, demographics, economics, etc; (5) reassess the initial decision.

Strategy combines visions of the future with emergent adaptations, and to act in complex or otherwise unknown domains, “establish boundaries, use attractors to seed beneficial patterns, and when a desired pattern forms, stabilize it, and when undesirable patterns form, disrupt them.” In other words, we must use complexity, take advantage of its properties as a way to strengthen the process and substance of homeland security strategy.

Maxfield, Robert, “Complexity and Organization Management,” <u>Complexity, Global Politics and National Security</u>, David Alberts and Thomas Czerwinski (eds.), Washington, D.C., National Defense University Press, 1996

Maxfield argues that complex systems metaphors provide a valuable intellectual framework for understanding the human world and managing the organizations in it. He articulates the primary properties of complex systems as follows:

- *Self-organization* is the emergence of new entities or stable aggregate patterns of organizations and behavior arising from the interactions of agents. Every agent is a member of a several other levels of organization, across scale (some agents serve as the building blocks for others) and across organization (there are complex webs of interconnections at all levels).
- *Evolutionary Trajectories* means that the future history of a system from a given time can not be determined by even complete knowledge of the present state; every trajectory will most likely be unique.
- *Co-Evolution* states that instead of having a stable environment in which to develop fitness, agents perceived environments are also a result of their interactions with other agents, who are themselves adapting. Each agent interacts not only with other agents at the same level, but also across scales. This adaptation is contingent on the artifacts available to the agents (tools and products, as well as knowledge and information).

- *Punctuated Equilibrium* is the tendency of a complex adaptive system (CAS) to have stable patterns of activity for long periods of time, then have a short transition period of very rapid change in patterns, followed by new stable patterns of activity.

Maxfield argues that organizations in the high-tech sector provide the greatest move away from the conventional mechanistic understanding of the organization. Those that are most successful must deal with rapid change in both the agents with whom they compete and interact as well as their component agents and artifacts. An organization must *match the rate of change in its environment*, regardless of the resources at its disposal. Additionally, organizations must realize that *people are the key asset of any organization*, since they are the adaptive element of organizations; "learning and innovation come only from human cognition."

The machine metaphor that we have employed for human systems for centuries reinforces our tendencies to neglect the importance of dynamic adaptation. By using the CAS metaphor to describe organizations, the human members therein will be enabled to self-organize and co-evolve with their equally dynamic environments to cope with and prosper in change.

High-tech companies that employ these metaphors consider it counter-productive to have highly detailed procedures for action, rather allowing maximum flexibility among the members of the organization to create responses on their own, responses and behaviors that are simply framed by clearly communicated guiding *values* of the organization. High-tech companies rely on the *informal* organization—the networks of relationships that arise naturally from purposeful collective action—and on temporary groups, rather than formal structures or protocols to facilitate rapid responses. Formal structures simply *guide* the process of self-organization, and organizations must have a number of possible structures that can be employed in different cases. While enabling autonomy and flexibility might allow incoherence and chaos, Maxfield argues that networks of personal relationships have the effect of tempering individual and aggregate behavior towards the collective purpose.

Adaptation, the incremental improvement by continual attempts at small change, and innovation, dramatic improvement by seeing different ways to approach a problem, must be encouraged through incentive and reward systems that reward success, but do not punish failure.

In terms of relationships with the environments in which organizations exist, Maxfield notices a few trends. *Business contracts* are becoming simpler, based on trust rather than standardized processes. Firms are *reducing the number of suppliers* but *forming much closer relationships* with the selected suppliers.

Long-term strategy under conditions of complexity is challenged, as conventional views of planning have an underlying assumption of order and linear predictability, which are not the case in complex systems. Thus the type of strategy depends on the degree of certainty that an agent has. Two types of changes—cognitive, changes in interpretation of the world, and structural, changes in types and instances of agents and artifacts—affect this clarity, and *generative* *relationships* are Maxfield's proposed method of managing change. Certain relationships "stimulate cognitive reinterpretations of the world by their participants, leading to the cascades of change of constructive positive feedback…which in turn lead to actions which cause structural change which generates possibilities for new generative relationships." Maxfield cites the example of his old firm, ROLM PBX, in managing change.

Generative relationships are fostered through *aligned directedness*, that participants have a compatible orientation of their activities; *heterogeneity*, that participants have different competencies, access to other agents, or points of view; *mutual directedness*, a recurring pattern of interactions; *permissions*, the authorization to engage in open and extensive dialogue; and *action opportunities*, the opportunity and need to engage in joint action.

McKelvey, Bill, "What is Complexity Science? It is Really Order-Creation Science," ***Emergence*****, Vol. 3, 2001, pp 137-157**

McKelvey begins by introducing the different types of "order" highlighted in much of the literature of complex systems. The process by which sense is made from what is otherwise perceived as chaos is due to a few effects: 1) most historical quantities are ignored or summed-over, largely through the term *ceteris paribus*; 2) the correlated histories that become important do so because of the particular time and place—the context.

A more direct process of "order-creation" emerges from "the collapse of chaos" in which 1) there is an emergence of feedback loops that join entities that would otherwise evolve separately; 2) entanglement pools—the way that agents and their processes become networked—are rarely random, rather, emergent structure can follow statistical features or computational complexity; many types of correlated histories (genes, molecules, organisms, etc) are distributed *probabilistically* rather than randomly; 3) many kinds of emergence do *not* stem from statistical distributions; 4) some kinds of emergence (such as crystallography) are immune to entanglement with others; and 5)physical systems tend to minimize their energy such that small-scale dynamics are minimized.

Prigogine's *Dissipative structures* refer to the process by which atoms and molecules show different momenta and coordinates, and reduce to a "sea of highly multiple correlations." *Control parameters* refer to external forces causing the emergence of dissipative structures in the region of complexity, tied to *critical values* in the energy that compel dynamics. *Phase transitions* refer to the transformation of systems from one state or phase to another due to abruptly met thresholds of energy transition.

Organizations are simultaneously the *conscious intentionality* and the *naturally occurring* structure and processes emerging through coevolving individual behaviors. The naturally occurring order in firms emerges from the "conflation of stochastic idiosyncrasies of individuals' aspirations, capabilities, and behaviors—i.e. *entanglement*. Environmental constraints thus provide the impetuses for order-creation within firms, due to "adaptive tension." Without entanglement (strong networks) *within* a firm, altering adaptive tension with the environment can produce maladaptive results.

Watts, Duncan, <u>Six Degrees: The Science of a Connected Age</u>, W.W. Norton and Company, 2003

Watt's elucidation of the major tenets, properties, and research of networks draws immensely from both social and mathematical realms. The *Small World Phenomenon*, the notion that all agents in a network are connected through a finite, even small, number of intermediaries, was tested by Stanley Milgram in 1967. The emerging network was a *branching network*, in which one degree of separation connects with 100 people, 2 degrees with 10,000 people, and so on exponentially. In the real world, however, Watts notes that many friends share friends, such that there is a great degree of *clustering*; nonetheless, it is possible to travel the whole network in relatively few steps.

Paul Erdõs & Alfred Renyi explored *random graphs*, networks of nodes randomly connected by links, some nodes lack links, while others have more. While the average links per node is less than 1, network connectivity is statistically zero because randomly added links are most likely to connect isolated links. As the average links per node exceeds one, the fraction of nodes in the network that are all connected increases rapidly; the threshold between relative isolation and a connected network is one link. In an isolated network, events stay local, but in an interconnected network, local events can affect the whole network through rapid cascading effects.

In the 1960s, Anatol Rapoport analyzed human epidemiological networks, and noted *homophily*, the tendency of people to congregate with people similar to them, and thus the friend-of-a-friend is also considered part of the network; *triadic* connections were thus established. Triadic connections connect three nodes simultaneously due to bias association, and are more common in social networks than in random networks. The probability of a certain configuration of a network is based on the prior configuration.

Change in networks is largely contingent on the tendency of individual nodes to be affected by the change, or the environmental threshold that compels each individual node. Watts uses the example of directional electrons in a set of magnets in determining the orientation of a magnetic field. Each electron can only affect its neighbors, but at the transition point to magnetism, all behave as if they can communicate globally. The *correlation length* refers to the distance at which each node appears to communicate (i.e. the ostensible effect each has); *criticality* is the point at which the correlation length crosses the entire system (each node affects every other); and a *phase transition* refers to the sudden transformation between states, rather than a gradual one; ultimately, there is global coordination without a central authority. This model is applied to spontaneous coordination of clapping crowds, freezing of liquids, transition to superconductivity, & random graph connectivity.

In their alpha model of Small World Networks, Duncan Watts and Steven Strogatz study the effect of *clustering*, how the importance of mutual friends affects the creation of new links in a network. Using critical path analyses, Watts discusses how connectivity emerges from clustered networks, and applies the model to the popular Six Degrees from Kevin Bacon, which, like power grids, or neural networks, are *small world networks*, highly connected networks with path lengths between nodes that are close to those of random graphs, but for which the clustering coefficient is high.

Scale-Free Networks are those that are not "equal," but rather, favor certain clusters or nodes. Such networks do not equally distribute power, but rather follow *power law distributions*, in which both super-connected nodes (hubs) and many nodes with fewer links exist. Albert-Lászlo Barabási and Réka Albert, the originators of the scale-free network, discuss how such networks develop—unevenly—over time, stating that those nodes that begin with greater connectivity continue to have greater connectivity due to *preferential growth.*

Watts applies the network model to epidemics and failures, such as biological diseases and cascading power outages, comparing the types of networks that prevail in each—random graphs, lattice, clustered models, etc. Percolation is largely due to the susceptibility of each node to receive and transmit the information or signal. Policy prescriptions for networks such as disease control and airlines emerge from the types of networks they inhabit and the manner by which change spreads.

Collective behavior in networks is partly due to the conflagration of cooperation-vs.-competition, information externalities (the effect of the whole on the individual), and issues of the commons. Individuals receive signals from their networked neighbors and behave accordingly; concerted behavior often emerges, uncontrollably, from such dynamics. Likewise, information can cascade, or spread dramatically, across a system due to rapid concerted behavior and information sharing in connected networks (as in cooperation, financial crises, social fads, etc.). Watts describes the specific characteristics—both qualitative and quantitative—in information cascades.

Watts describes adaptation in concerted networks by discussing the Toyota-Aisin crisis, in which the two companies had just-in-time inventory systems (parts were produced only as needed), there was simultaneous engineering (enabling rapid decision changes), high division of labor, and a high level of cooperation between member firms, to the point of personnel exchange. The factors of Aisin, the sole provider of P-valves, burned down overnight, stopping all Toyota production.

Hierarchies function when markets are well understood. If there is ambiguity, however, decisions and problem-solving must occur at lower levels of production rather than through the hierarchy. Ambiguity requires more communication than does a hierarchy, which requires many steps through a structure to reach different nodes. Building shortcuts between neighbors, rather than randomly adding shortcuts, creates local teams at each level of the hierarchy to communicate and solve problems. *Multi-scale networks* allow for the formulation and execution of responses to issues at multiple scales, such that the response of each level of the organization reflects its familiarity or specific purview, while giving it access to and communication with other nodes in the hierarchy as needed. Taken collectively, individual level responses can be coordinated into a comprehensive organization-wide response. By allowing mission-oriented teams to emerge from coordination between different levels of a hierarchy, multi-scale networks enable a concerted and whole-scale adaptive response to broad challenges.

McKelvey, Bill, "Transcendental Foresight: Using Complexity Science to Foster Distributed Seeing," in Haridimos Tsoukas and Jill Shepherd (eds.), <u>Probing the Future: Developing Organizational Foresight in the Knowledge Economy</u>, London: Blackwell Publishing, 2003

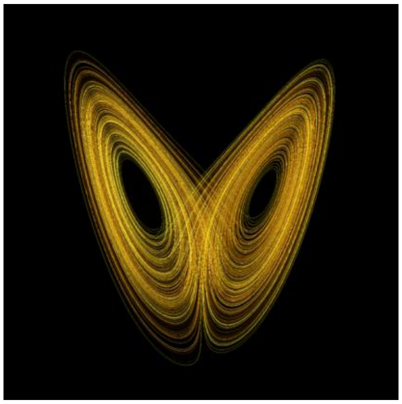
McKelvey defines foresight as the "ability to see through apparent confusion, to spot developments before they become trends, to see patterns before they fully emerge, and to grasp the relevant features of social currents that are likely to shape the direction of future events." *Distributed seeing* refers to how the views of a number of 'seers' can inform the combined foresight of a collectivity, as "distributed seeing is far better than the vision of a single CEO." To bring about distributed foresight, "adaptive tensions are set up to motivate self-organization."

In complexity theory, order creation is seen as the result of nonlinearities separated by periods of relative equilibrium, driven by the *environmental context above* and *coevolving lower-agents below*. Foresight is thus seen through supra- and sub-drivers. A firm's core competencies, dynamic capabilities, and knowledge required for competitive advantage increasingly appear as *networks* of human capital holders. However, to enable those lower-level networks to realize foresight, the environmental context—through *adaptive tension*—often must compel adaptive action and self-organization.

Adaptive tension requires a critical value that compels change that (1) confirms that behavioral symptoms do not impinge on agents; (2) motivational valances are altered to move the level of adaptive tension as required; and (3) widening the distance between critical values. Additionally, bureaucratic negative feedback systems operate around *point attractors*, those that *drive* the system but do not define it, providing frameworks for novelty and innovation. Managers can use adaptive tension to steer agent self-organization toward more efficacious distributed seeing. However, the potential exists for managers to *undermine* such seeing.

Gleick, James, <u>Chaos: Making a New Science</u>, Penguin Press, 1988

Gleick offers a brief history of the key principles of dynamical system theory, popularly known as chaos theory, and the people that produced its original insights. In 1960, the meteorologist Edward Lorenz created a simply weather model in which ostensibly irrelevant changes in initial conditions led to immense changes in the outcome. This 'observation' was noted as "sensitive dependence on initial conditions" or the *butterfly effect* (the notion that the flap of a butterfly's wings in Texas can change the course of a hurricane in Haiti next month). Long-range prediction of systems that are measured imprecisely or imperfectly—a condition endemic to *all* systems—becomes an impossibility.



Lorenz also found repetition that was never exactly identical, and studied nonlinear systems that never reached a steady state. When such systems were graphed, the Lorenz Attractor—a bounded by never-repeating pattern—emerged.

In 1959, Stephen Smale studied an oscillating system and found that his hypothesis—that systems tend toward a steady state—is not valid for certain dynamical systems. *Phase-space graphs* were created to illustrate the phenomenon. Smale's work was a greater graphical demonstration of the sensitive dependence on initial conditions.

Philip Marcus created a computer model of atmospheric turbulence in Jupiter demonstrating "islands of structure appearing within the disorder," a self-organizing stable-chaos. James Yorke studied nonlinear systems such as the logistic growth equation, showing that a population equilibrium would oscillate between two values, and that if a regular cycle appeared, the same system would take on regular cycles of every other period, as well as other chaotic cycles. Yorke first used the term 'chaos' to describe dynamical systems.

Robert May applied Yorke's discoveries to population growth models in biology, drawing from a *bifurcation diagram*, in which a system aggregates until it splits into alternative paths. The two demonstrated that chaos applied to 'real' systems as diverse as the effects of populations and the effects of measles inoculations on disease incidence—these focused on how strange (nonlinear or unpredicted) behavior would emerge when systems are perturbed.

In 1060, Benoit Mandelbrot analyzed cotton markets, and found recurring patterns at every scale. He had also studied transmission line noise and concluded that noise was patterned in structured sets, such that at any scale the proportion of noise-containing periods to error-free periods was constant; planning could thus incorporate redundancy. Mandelbrot described the *Noah Effect*, in which sudden discontinuous changes can occur; and the *Joseph Effect*, in which persistence of a value can occur for long periods, but change suddenly thereafter. He also demonstrated that a coastline's length and patterns vary with the scale of the instrument of measurement, and resemble each other at all scales. The *Koch Curve* demonstrated self-similarity (i.e. irregulatity is constant) over different scales, through *fractals*, the repetition of self-similar patterns across

levels or scale. Later models demonstrated that biological systems—circulatory and bronchial systems—also fit the fractal models.

Lev Landau's exploration of fluid dynamics suggested a gradual buildup of complex patterns through competing patterns; however, chaotic complexity can also emerge suddenly. David Ruelle described turbulent systems as being varied around a *strange attractor*, which attracts the orbit. The loops and spirals that move about the attractor (analogous to an epicenter) are infinitely deep in a three-dimensional space, never quite joining or intersecting. The Poincaré section is a cross-section of an attractor that demonstrates the structure in two-dimensions.

Bar-Yam, Yaneer, <u>Making Things Work: Solving Complex Problems in a Complex World</u>, NECSI Knowledge Press, 2004

Bar-Yam's *Making Things Work* is a foray into the application of complexity science and its principles to a number of more applicable problems and issues, moving beyond the largely theoretical literature that has dominated complexity science. The book is broken into two parts: a brief introduction to the concepts of complex systems, and the direct application of these concepts to 'complex problems': military conflict, healthcare, education, third world development, global ethnic violence and terrorism; these problems are the products of conferences that brought together complex systems scientists and specialists in the specific field.

The first section introduces the focus of complexity science on *parts, wholes, and relationships*. While classical science takes breaks systems into their component parts, complex systems considers the relationships between parts and how components interact to form collective behaviors and interactions with the environment. *Emergence* refers to how components give rise to the behaviors of whole systems, while *interdependence* studies the effects of changes in one part of a system on the other parts. Chapter Two focuses on self-organizing *patterns*, and how they emerge from interactions between the parts of a system. Some patterns include the emergence of fads, panics, and cliques in human systems, while the same rules apply to physical and biological systems. A third section discusses how patterns emerge from *networks* of interacting agents, and explains the models used to describe networks in social, physical and biological systems with the nervous system and creativity therein as a metaphor.

The patterned behavior of a system also defines the *space of possibilities*, all the possible arrangements and patterns a system can assume. An exploration of the space of possibility is related to a trade-off between *scale* and level of *complexity*, the two being balanced against one another. What a structure or organization is capable of is related to complexity and scale—the *law of requisite variety* states that the complexity and scale of an organization must match the complexity and scale of its task. *Evolution* refers to how making many incremental changes can be an effective way to create and manage complex systems; evolution uses both elements of competition and cooperation, which are ultimately complementary

The second section on applying principles from complex systems to solving complex problems begins with *military warfare and conflict*. A method of understanding how organizational form is related to task performance capability is central. A prime lesson from Vietnam and Afghanistan was that the *scale of challenge and response* is of vital concern. Large-scale tank divisions are effective at fighting conventional wars, while decentralized Special Forces are more effective for lower scales. The complexity and scale of the force must be matched with the complexity and scale of the task; trade-offs between scale and complexity have been made throughout the military, but perhaps insufficiently.

The *Healthcare System* of the United States is tackled on two levels: medical errors and healthcare management. The issues of scale and complexity are applied to both; large-scale centralized flow of money is given to a highly complex task of medical treatment, a major imbalance. Efforts to lower costs by increasing efficiency are incompatible with complex specialized treatment and are leading to increasing medical errors and decreasing quality of care. We must recognize which parts of the system can be made more efficient and separate those from others that should not be. Primary, large-scale tasks—those that should be made more efficient—are population-based care for healthy persons such as screening tests and immunizations. By tackling separate issues based on their respective scale and complexity, healthcare provision can be made far more effective.

On the larger issue of healthcare management, communication and coordination issues must be recognized. The *space of possibilities*—that which an organization *can* do, rather than what it *should* do—is explored. The communication channels between physicians and pharmacists is analyzed, demonstrating how communication can be improved so that the system can effectively deal with these many possibilities to reduce dramatically or eliminate errors.

Education is another complex challenge that has two tiers: education [provision] and education management. As the complexity of a system must match that of its environment—and children are not in control of their learning environment—there must be greater compatibility between the education environment and the child/student. In the current system, children are treated in similar ways even though their capacities are different. We must recognize the importance of individual differences and design the environment (and teaching system) to accommodate those differences

As per education management, standardized testing for evaluation attempts to place a large-scale, low complexity (simple) response to a lower-scale, high complexity (complex) challenge. Specialized skills are needed in today's economy and world, and the education system must provide a greater variety of pathways for students to follow, and to create a process by which each student (with parents) can determine the education he or she receives through alternative pathways.

Focusing on *international development*, Bar-Yam posits that anticipating, designing or planning the behavior of a highly complex organization such as an economy—as large-scale intervention agencies such as the World Bank endeavor to do—is fallacious. Large-scale endeavors can be destabilizing because they neglect socio-economic networks and interdependencies. Using pattern formation and evolutionary dynamics can overcome the issue of scale in economic development efforts, and a *multi-scale* approach that links different levels or scales of a society, that acts primarily through small interventions will enable the address of local issues based on local information. These goals can thus contribute to the development of larger-scale institutions.

Discussing "*evolutionary engineering*," Bar-Yam states that "in the mid 1990s, after twelve years of effort and a cost of $3-6 billion dollars, a project to redesign the U.S. Air Traffic Control

System was abandoned without replacing a single part. The existing system, developed forty years earlier (1950s), was still using vacuum tubes." A prime reason for such design failures is that *planning* or *controlling* highly complex systems does not work; breaking a complex system into its component parts to be designed separately will ensure that the system will fail when the parts are summed together. *Evolution* must be employed to enable *multiple parallel incremental changes* to create complex systems; an environment conducive to this process must be provided.

The issue of *ethnic violence and terrorism* is linked to changes in global cultural structures. Bar-Yam argues that the Islamic world and the West differ in the way their social organizations balance scale and complexity; the 'clash is civilizations' is thus nothing more than a process of "clarifying the boundaries between distinct cultural systems." These systems may not be compatible in the same place at the same time, so mixing them locally creates global pattern formation where cultures form distinct regions. Bar-Yam argues that "accelerating the *establishment of well-defined boundaries* appears to be the best strategy to achieving global peace."

Holland, John H., <u>Emergence: From Chaos to Order</u>, Cambridge, MA, Perseus Books Group, 1998

John Holland, the world's first PhD. in computer science and the creator of 'genetic algorithms' sets out to discover the process by which complex patterns and structures *emerge* from systems, based on rules of interaction, schemata, and the 'building blocks' of life. Building blocks provide a way of extracting repeatable features from the otherwise perpetual novelty of emergent systems. The assumption or hypothesis of the book is that all phenomena are *emergent*, i.e. resultant from the interaction between the system's parts, which is ultimately greater than the mere sum of the parts. Holland hopes to understand general rules about emergence, laying the groundwork for a science of emergence that can explain phenomena and also enable "re-engineering" of emergence.

Holland is of the mind that "the emergence is closely tied to the ability to specify a large, complicated domain via a small set of 'laws'," a premise that rings loudly through the book. Models of all sorts—as simple as checkers and as complex as genetic algorithms of the human neurosystem—are generated and used to understand and extract broader laws of emergence. Models are used to understand the relevant aspects of a system; the notion of relevance is summed by the *constrained generating procedure* (CGP) through which a "mechanism" is a transition function operating on a set of states and inputs to produce a new set of states, that enables variable interconnections. These generations of states produce *hierarchical* organizations of systems in which certain components and CGPs are used as the building blocks for more complicated CGPs at different levels.

Laws enable an understanding across models, as the sets they generate are great and diverse. Using a great number of models with finite rules of interaction, Holland states that: "even simple rules can generate coherent, emergent phenomena; emergence centers on interactions that are more than a summing of interdependent activities (imposed by nonlinear rules); and persistent emergent phenomena can serve as components of more complex emergent phenomena."

Holland states that the models used and describe—like all scientific models—are primarily for the sake of *metaphor*, and patterns seen from them can be used to generate innovation in science. Primary conclusions of the book include that: 1) emergence occurs in systems that are *generated*; 2) the whole is more than the sum of the parts in these generated systems; 3) emergent phenomena in generated systems are, typically, persistent patterns with changing components; 4) the context in which a persistent emergent pattern is embedded determines its function; 5) interactions between persistent patterns add constraints that provide increased 'competence'; 6) persistent patterns often satisfy 'macrolaws'; 7) differential persistence of patterns is a typical consequence of the laws that generate emergent phenomena; and 8) higher-level generating procedures can result from enhanced persistence.

Axelrod, Robert and Michael Cohen, Harnessing Complexity: Organizational Implications of a Scientific Frontier, New York: Free Press, 1999

Robert Axelrod and Michael Cohen, two pioneers in the field of complex systems describe the ubiquity of complex systems in the world: military management, epidemiology, evolution, and elsewhere. Axelrod's key research focuses include game theory and the trade-off between competition and cooperation, while Cohen focuses on organizational learning. In Harnessing Complexity—a phrase they use to mean "deliberately changing the structures of a system in order to increase some measure of performance, and to do so by exploiting the understanding that the system is itself complex"—the authors seek to give lessons for organizational management drawing from complex systems as diverse as information technology, business, disease dissemination, and other areas. A Complex Adaptive System (CAS) is one in which many agents interact in diverse ways to constantly alter their collective future. Agents revise their strategies, adapting to dynamic environments and contexts. As a result of co-evolution, they simultaneously change the environments in which other agents are trying to adapt. In complex systems, *prediction* has no place in strategy, as the systems themselves are not deterministic.

Key focuses of the book are *variation, interaction,* and *selection.* Variation focuses on the trade-off between variation and distribution on the one hand, and centralization and concentration on the other. Decentralized creation of variety, coupled with centralized maintenance of standards was the primary determinant for success in Linux's open source movement. Variation is needed when dealing with problems that are long-term or widespread, provide fast feedback, with a low risk of *catastrophe* (rather than error) from exploration, and that have looming disasters. Routines must balance exploration and exploitation, and processes that generate extreme variation must be linked to processes that select with few mistakes in credit attribution.

Interaction between the agents of a complex adaptive system manifests in various types of networks; in social systems these networks are based on *trust*. Strong and redundant horizontal links have advantages over less cooperative, vertically integrated groups. Interaction works through *proximity*, *activation* (of ties), and *space*, both physical and conceptual between agents. *Driving mechanisms*—both internal and external—provide a way for diverse agents to adapt appropriately. Networks of reciprocity must be facilitated, while assessing the capacity for the spread of consequences in those networks.

Selection refers to the creation of strategies—keeping those that are successful, and eliminating those that are not, using the biological view of evolution. The types of agents that are suitable for the appropriate strategies are decisions that are made both consciously and emergently (thus collectively). Social activity must be used to support the growth and spread of valued criteria, while shorter-term measures of success must be compatible with long-term goals. The best selection processes are facilitated by leaders who understand new environments, while the worst selections are often made by those hindered by old standards.

Alberts, David and Richard Hayes, Planning: Complex Endeavors,

Washington DC: CCRP Publication Series, 2007

There are two major drivers of the need for disruptive innovation, sometimes referred to as transformation, in the Information Age. The first and arguably the most compelling driver is the changing environment in which an entity operates. For militaries, this is the changing nature of their adversaries, their strategies and tactics, as well as the "non-traditional" nature of the missions they are expected to undertake. Significant similarities related to the nature of the "solution" or how to cope with the new environments in which both militaries and businesses find themselves. As a result, individual entities and group of entities with common goals need to be more agile to be successful in the Information Age.

The “complexity” of an endeavor is defined by the number and diversity of participants such that there are multiple interdependent ‘chains of command’ with ostensibly clashing objectives and perceptions; and the effects space spans multiple domains and there is thus a lack of understanding of interactive cause and effect relationships, and an inability to predict effects stemming from alternative courses of action, due to nonlinearity.

Complex endeavors require *effects-based approaches to operations*, determining effectiveness not by process, but by ultimate product; as well as *network-centricity*, the focus on distributed and decentralized channels of communication that facilitates widespread knowledge of the system as a whole. Command-and-control must be reassessed to take changing realities into consideration: sense-making and decision-making become more distributed, and as a result, more ubiquitous in both time and space of an organization. Planning in network-centric environments also takes on new meaning, as it becomes more specific to the relative information location of the planner, and must learn from itself and surroundings in a cyclical manner, as opposed to the linear manner that typifies hierarchies. While objectives are largely articulated from the top, planning and execution must occur more fluidly through coordination of all levels of command.

Even in such distributed, adaptive organizations, patterns of interaction certainly emerge, and they become vital for managing change in organizations and their responses themselves. Experimentation must simultaneously occur in order to adapt to changing circumstances, and also to refine the networking process itself.

Johnson, Steven. Emergence: The Connected Lives of Ants, Brains, Cities, and Software, **New York: Touchstone, 2002**

Johnson's key premise is that *emergence*—the notion that a small number of rules processed by individual units are the best method of explaining the aggregate behavior—provides the metaphor for a paradigm shift in the 21st century, moving us away from the mechanistic view of the enlightenment. The legacy of this mechanistic view leaves us with the tendency to look for centralized authority—the "myth of the ant queen"—rather than interactive emergence in all systems.

Johnson analyzes the behavior of ant colonies and the interaction of all the individual ants, based on localized rules of action and adaptation, that create the macro-level structures and processes that typify colony behavior. The system as a whole is *smarter* than the individual members, and acts as a collective decision-making process. Johnson reviews key sources in communication theory, computer science, biology, psychology and urban development, to understand the *ubiquity of emergence* across disciplines and phenomena.

The information age is a particularly susceptible to lessons and principles from emergence when designing new systems and improving existing ones. *Clusters* of consumers or agents will emerge, creating their own systems of understanding. The internet will create a forum for meta-information about the whole to emerge from communication, and clusters will be able to self-organize therein.

Emergence, Johnson states, will be the key metaphor for describing and organizing media and communications, which will become increasingly ubiquitous in the information era. The future will need systems that are highly adaptable on the grassroots level, enabling agents access to information and resources from various inputs. Our information management and processing systems must mirror natural networked systems that enable emergence.

Prigogine, Ilya, The End of Certainty: Time, Chaos, and the New Laws of Nature, New York, NY: Free Press, 1997

While Einstein once referred to Time as an illusion in classical science, relativity, and quantum physics, Prigogine states that time takes on a central role in the sciences of non-equilibrium physics and dynamical systems such as those described by chaos and complexity theory. Thus in chemistry, geology, cosmology, etc, time—in the sense of the distinction between past and future—is central to the emergence of states and patterns of states.

The ‘new science’ of non-equilibrium has produced concepts like *self-organization* and *dissipative structures* that demonstrate the role of time in evolution and dynamism. The last few decades of science have demonstrated that irreversible nonlinear nonequilibrium makes different phenomena in the world possible. While classical science emphasized stability, order, predictability and equilibrium, we now see fluctuations, instability, variance, and unpredictability. Including chaos and instability to the laws of classical and quantum physics that have taken us so far will move us from prediction to probabilities and possibilities; probabilities rather than false hopes of certainties.

It is through irreversible processes related to the passage of *time* that the most complex structures emerge in *far-from-equilibrium* situations; change and even life itself is only possible in non-equilibrium, a proposition that is a direct challenge to conventional science. The distinction between reversible and irreversible processes is made through the notion of *entropy* articulated by the *Second Law of Thermodynamics*; in this law, irreversible processes produce entropy, while in reversible processes, the entropy is left constant.

The *physics of populations* stated that “stresses applied to systems at or near equilibrium lead to dampened fluctuations… [while] a far-from-equilibrium system may evolve spontaneously to a state of increased complexity.” Equilibrium systems follow near-universal laws of thermodynamics, while the dynamics of far-from-equilibrium systems become dependent on type.

Dissipative structures, the formation of new, complex structures where interacting particles exhibit major fluctuations and dynamics while retaining their fundamental structural properties, give rise to *self-organization*. While possibilities for path selection may be known, the specific state 'chosen' emerges as a result of fluctuations. *Indeterminism* is increasingly a factor in physics, while *bifurcations* are considered sources of diversification and innovation.

Both equilibrium and non-equilibrium are needed to describe the world; both governing laws and dynamic creativity prevail, and chance and probability become part of an amended *rationality*. "In accepting that the future is not determined, we come to the end of certainty." This, Prigogine states, is not an admission of defeat for the human mind, but rather, a success. The universe is a giant thermodynamic system that operates at far-from-equilibrium conditions, in which fluctuations, instabilities, and evolutionary patterns exist.

Juarrero, Alicia, <u>Dynamics in Action: Intentional Behavior as a Complex System</u>, Cambridge, MA: The MIT Press, 2002

The distinction between voluntary and involuntary action has implications beyond the philosophical, extending into the legal, scientific and moral realms. *Action theory*, a branch of philosophy that has generally dealt with intentionality and action, has been unable to sufficiently account for the disparities, stemming from action theory's dependence on linear causality and reductionism. To make up for these deficits, Juarrero looks to insights from the study of complex systems and dynamical systems theory.

In a brief overview of complex systems, Juarrero states that self-organization occurs when a system is driven *away from equilibrium*, resulting in the system's inability to dissipate energy at a sufficient rate. The structure and behavior of a system occurs through the existence and operation of constraints; bottom-up constraints are responsible for the initial formation of macroscopic order among the micro-components, and subsequently, top-down constraints bind the micro-components within the whole. Thus constraints simultaneously limit and enable the system's range of possibilities, by defining the bounds up to which agents can adapt, and beyond which agents can push.

Due to nonlinear feedback loops, redundancy in connections, and bottom-up constraints in the brain's neural network, micro-level neural activity becomes synchronized when driven away from equilibrium. The self-organization that results creates different *attractors* and constraints towards and against which actions are framed and driven.

Viewing intentionality in agents and their cognitive dynamics as complex systems leaves us with the understanding that self-organizing systems are naturally goal-directed towards dissipating a potential; the interplay between system levels in response to dynamic environments. Complex systems theory can explain the compression of various behavioral alternatives that occurs when certain intentions are chosen, and are accounted for by dynamic system constraints. Thus systems are able to regulate "without there being a regulator."

Juarrero explains intentional behavior (in addition to any nonlinear phenomen) through an analysis that moves between and across levels of organization, and considers the action's historical and environmental context; environmental *noise* can corrupt the intentionality or purposiveness of a behavior.

Kauffman, Stuart, The Origins of Order: Self-Organization and Selection in Evolution, New York: Oxford University Press, 1993

In Origins of Order, Kauffman seeks to look at evolutionary biology in a broader way that expands current thinking about the phenomenon and can be applied more widely to fields outside of biology. After a brief contextualization of evolution within biophysics, Kauffman returns to *mathematical biology* and *statistical mechanics* of evolutionary biology. Using these tools, as well as a few models described later in the text, Kauffman concludes that generic self-organizing properties are largely unavoidable due to selection; and that selection maximizes evolvability by adjusting control parameters and thus self-organizing properties of complex systems.

A central contribution of Kauffman's work is the *NK rugged fitness landscapes*, a method of testing adaptation in dynamic systems. In the NK model, N is the number of agents in a system that contribute to the system's *fitness*, and K is the number of interactions among the components. The model is applied to genotype models, and modeling demonstrates that in K=0 fitness landscapes, there is one global optimum, while as N increases, the local optima reaches the average typic fitness of the landscape—these landscapes are *rugged*. (The NK model has since been adapted into management theory, reflecting both the internal and environmental composition of a firm vis-à-vis its fitness).

Selection can move the selected population to otherwise unlikely regions of the landscape, and create order that would otherwise not be attained spontaneously. However, if internal adaptations such as mutation or drift are more potent, effects of selection will be minimized. Kauffman elaborates these "complexity catastrophes," in which populations resist selection.

Kauffman explores the idea of the *edge-of-chaos*—a dynamical state between the area where the system is frozen into stable states and the other extreme, where long, complex cycles of activity exist—and its applicability for evolution, and the possibility that evolvability is attained by natural selection.

Kaufmann develops a model through which he tests the likelihood that a random collection of catalytic molecules could form a closed autocatalytic set (one that generates itself and others). This method of *generating organization* is central to the emergence of specific organisms and phenomena, such as eggs, jets, mushrooms, etc.

He concludes by addressing the issues of developmental biology (particularly considering his explanation thus far of the generation of distinct biological sets), differentiation and morphogenesis. Among the products of his analysis is the model of possible genetic *regulatory* networks whose statistical properties can be analyzed; such networks may not need selection to explain their behavior.

Kauffman, Stuart, At Home in the Universe: The Search for Laws of Self-Organization and Complexity, New York: Oxford University Press, 1995

Autocatalytic set theory is a theory proposed by Kauffman which states that life is a collection of molecules that catalyze—initiate and expedite—each other's formation. Every molecule has the ability to catalyze some reaction. The catalyzation process will emerge due largely to the large number of existing molecules interacting with one another, the effects of which will be based largely on probabilities and thresholds of interactivity. Thus life can emerge without specific prescriptions of DNA or natural selection.

Kaufmann argues that Darwinism had a few key flaws: 1) natural selection cannot be the single source of order; 2) the nature of Darwinism is largely accidental; 3) Darwinism is excessively reductionist; 4) neo-Darwinism focuses excessively on the gene and on DNA; and 5) gradual accumulation of minor improvements may not work. Kauffman argues that we need "a new conceptual framework that allow us to understand an evolutionary process in which self-organization, selection and historical accident find their natural places with one another."

Rather than the accidentalism proposed by Neo-Darwinists, Kauffman seeks to find the natural laws of complexity that endeavor to minimize the emphasis on randomness. Thus Kauffman proposes *Holism*, stating that the whole has emergent properties that the parts do not. If complexity increases beyond a threshold, life emerges suddenly as a whole; not gradually or incrementally, but suddenly. This view of life as emergent from interaction stands in contrast to the conventional emphasis on DNA, in which the informational building blocks of life and adaptation are all specified and contained within DNA coding.

Many creationists criticize Darwinism due to the latter's emphasis on gradualism; Kauffmann agrees with the criticism, but his reasoning is due to the complexity paradigm, which states that large-scale generations of evolutionary change can occur, bypassing incremental steps towards that process. These 'jumps' are based on the arrival to thresholds in the level of complexity. However, calculating these thresholds is an issue of which Kauffman is not yet certain.

Lewin, Roger, Complexity: Life at the Edge of Chaos, Chicago, IL: University of Chicago Press, 1999

Roger Lewin's text follows in the line of Waldrop's famous exposition of the Santa Fe Institute which gave rise to the science and pedagogy of complex systems. While the characters and story of the institute's development are at the center of Waldrop's book, however, Lewin focuses on Complexity theory in the broader sense, including ideas from non-Santa Fe personnel such as biologist Edward Wilson, Gaia theorist James Lovelock, and philosopher of consciousness Daniel Dennett.

Advances in computing technology had made previously theoretical sciences into experimental sciences—in the sense that ideas could be modeled—and an increasing reliance on nonlinear dynamics and chaotic systems has enabled the models to bear closer resemblance to the real world. Additionally, disciplines themselves were converging in the new field of complex systems.

Increasing returns and *lock-in*, the notion that initial advantages or tendencies in a system may remain, due to their relative initial ubiquity and advantage, and influence the development and progress of a system manifold; *sensitive dependence on initial conditions*, *unpredictability* as a result of nonlinearity and uncertainty, and other properties began to articulate phenomena across scientific disciplines. Murray Gell-Mann, Nobel Laureate in biophysics, W. Brian Arthur, an economist, John Holland, a computer scientist and biologist, Stuart Kauffman, a biophysicist, and others, were among the first few to bring together the ideas known as *complexity.*

Complex systems were systems that were composed of many *agents*—molecules, neurons, species, consumers, etc—that are constantly *organizing* and reorganizing themselves into larger and more complex structures through the interplay of competition and cooperation. At each level of organization, emergent structures would form and themselves participate in emergent behaviors. Stemming from studies in thermodynamics and artificial intelligence, complex, coevolving systems tend towards the *edge of chaos*, exhibiting balancing tendencies of order and chaos, and a region where "sustained fitness is optimized.

Lewin extends this view to other systems dynamics that many complex systems theorists tend to neglect—broader issues such as ecology and geophysics, and even civilizational development. As per the latter, Lewin looks to the rise and fall of the Anasazi culture in Central America, viewing its development as an evolutionary process of interaction between culture, geography, technology and history. As per the former, Lewin discusses the *Gaia Hypothesis* of James Lovelock, who states that the physical components of the earth (the cryosphere, hydrosphere, atmosphere, and lithosphere) all comprise an emergent, interactive complex system that brinks on *life itself*.

Additionally, Lewin delves into the implications of complexity on mind-brain philosophy, stating that consciousness itself is "an emergent phenomenon from a complex adaptive system" that is guided by the mind and brain, but open to external influences. Lewin ends the text with brief surveys of how complexity can be applied to fields such as management, engineering, and philosophy.

Stacey, Ralph, Douglas Griffin, and Patricia Shaw, Complexity and Management: Fad or Radical Challenge to Systems Thinking?, London: Routledge Press, 2000

Complexity and Management is the first book in a six-part series that surveys the breakthroughs made by the nexus between complexity theory and management studies. While complex systems theory—including emergence, self-organization, and other phenomena—have received much address in management literature, this book seeks to extract the essence of these contributions, and move away from the formerly popular "systems theory" approaches that, while looking at organizations holistically, tend to reinforce conventional notions of *command-and-control*, and regulation and control-based top-down management.

While the authors "emphasize the radically unpredictable aspects of self-organizing processes and their creative potential" in a way that "weaves together relationship psychologies and the work of complexity theorists who focus on the emergent and radically unpredictable aspects of complex systems," they also recognize that many management theorists have invoked empty metaphors, and justified superficial science, citing the complexity paradigm.

A key focus of the author's review is the "dynamic interplay between stability and change" that extends into all realms of management, particularly novelty, innovation, and creativity. Following a brief theoretical overview on the teleological/purposive causes behind theory, the authors come out on the side of *transformative teleology*, a view of causality in which change is highly interactive, and in which "the future is changing the past just as the past is changing the future."

After offering a deep criticism of the "general systems theory" thinking that has dominated management literature, the authors turn towards a view of how complexity theory makes a "move away from thinking about an organization as a system, to thinking about organizing as highly complex, ongoing *processes* of *people relating* to each other." The human aspect of management is central to this analysis, in which the authors discuss—in anthropological and psychological terms—the processes of reciprocity in which reality in an organization is socially constructed: it is the *relationships* and dynamic daily interactions between people that make agency in organizations an emergent property of individual and group identity, simultaneously.

Organizational management is fundamentally the understanding and management of *processes* and *relationships*, rather than entities. With this fundamental premise, the authors pave the way for the next books in their series to expound on the remaining issues in further depth.

Lichtenstein, Benjamin, Mary Uhl-Bien, Russ Marion, Anson Seers, James Douglas Orton & Craig Schreiber, "Complexity Leadership Theory: An Interactive Perspective on Leading in Complex Adaptive Systems," in James Hazy, Jeffrey Goldstein and Benjamin Lichtenstein (eds.), <u>Complex Systems Leadership Theory: New Perspectives from Complexity Science on Social and Organizational Effectiveness</u>, *Exploring Organizational Complexity*, Vol. 1, Mansfield, MA: ISCE Publishing, 2007

Traditional, hierarchical views of leadership are decreasingly useful in light of the complexity of the modern world. Leadership theory must transition to new perspectives that account for the complex adaptive needs of organizations. The authors propose that *leadership* (rather than leaders) is itself a complex dynamic process that goes beyond the capacities of individuals alone; it is the product of interaction, tension, and exchange rules that govern changes in perceptions and understanding: a *dynamic of adaptive leadership*.

A *Leadership event* is a perceived segment of action whose meaning is created by the interactions of actors involved in producing the action itself. A number of innovative methods for capturing and analyzing these contextually driven processes include: 1) identifying and shaping interaction events; 2) capturing and organizing these interactions; 3) processing and understanding the patterns of behavior and interaction that develop over time; 4) forming a collective identity; and 5) analyzing data with an eye to their *dynamics* and *interdependencies*.

The authors conclude by surveying some of the implications of the altered understanding of leadership, including nonlinear implications of activity; defining and articulating strategy; and computational analyses of organizational change and direction.

Nicolis, Gregoire, and Ilya Prigogine, <u>Exploring Complexity: An Introduction</u>,

W.H. Freeman and Company, 1989

In this text the authors present a broad review of the phenomena of "complex systems," with detailed descriptions of their incidence primarily in the physical and biological sciences. The authors begin with an explanation of convection Benard cells, a key experiment conducted by Prigogine himself that resulted in the understanding of *dissipative structures* and *far-from-equilibrium*, a profound challenge to the conventional view of thermodynamic equilibrium that typified classical sciences. These advances also gave rise to other phenomena such as *self-organization* that typify dynamical systems.

The dynamics between stability and change are discussed with respect to a number of thermodynamic and mathematical systems, in a segment on the vocabulary of complexity. *Symmetry breaking* in complexity means that the homogeneity of a current order is broken and new patterns emerge; the phenomenon can be understood as a generator of information, in the sense that when a pattern of homogeneous data is broken by differentiated patterns, the new patterns can be read as ‘information.’ *Dissipative Structures* refer to the spontaneous emergence or appearance of symmetry breaking and the formation of new, complex structures where interacting particles exhibit major fluctuations and dynamics while retaining their fundamental structural properties. The radical, nonlinear change from one phenomenon or status to another is referred to as a *bifurcation*, though the alternatives may be greater than two.

Feedback is the signal or information that is looped back from the agents within a system to the input, shaping the system within itself. *Nonlinear* dynamics emerge, as feedback can either amplify even small causes to produce larger effects, or minimize large effects to produce small causes. *Attractors* are sets around which dynamical systems adapt in the course of their evolution—they take the form of both attracting and repelling the agents in a system, even if the latter are slightly disturbed.

The dynamics of complex systems can be modeled to give insights as to the system’s future evolution. These analyses of evolution are based on the system’s *stability* around certain trends or patterns.

Asbhy, Ross, An Introduction to Cybernetics, London UK: Chapman and Hall, Ltd., 1957

Cybernetics, a phrase coined by Norbert Weiner in his *Cybernetics, or Control and Communication in the Animal and Machine*, is an interdisciplinary framework that describes communication processes within all sorts of systems, which is in many ways a precursor to complex systems science. This introduction by Ross Ashby presents some of the fundamental phenomena and principles of cybernetics, split into three main portions: 1) Mechanism, 2) Variety, and 3) Regulation and Control.

The section on *mechanism* discusses the chief principles of cybernetics, such as *stability*—a state of equilibrium that is unchanged by transformation—and *feedback*—circularity of action between parts of a dynamic system. Other topics discussed include sets, functions, transformations, vectors, phase space, and vectors. These principles are broadly applicable, to mechanical, living, neurological, and other systems.

Part II discusses *variety* and in doing so, introduces *information theory* and the generation of *random responses*. Among the ideas discussed is the notion of how information is coded when passing through a mechanism or transmitter of any sort. *Noise*—extraneous variety within the transmission of a signal, and considered relative to the recipient of analysis—can be a component in the transmission of a message or obstruction thereof.

The third focus on *regulation and control* in both determinate and random systems. *Game theory* is one of the tools that Ashby uses to demonstrate the regulation of the outcome of a game. Additionally, regulation in biological systems, games and strategies, and regulation in large systems, are discussed. "An *amplifier*, in general, is a device that, if given a little of something, will emit a lot of it." The *law of requisite variety* states that the internal diversity of any self-regulating system must match the variety and complexity of its environment if it is regulate that environment. Two types of regulation included *error-controlled regulation*, which is based on past information, and thus reactive, passive, post hoc adaptation; and *cause-controlled regulation*, which uses active regulation, which is more information-intensive, requiring an anticipation of threats to which there is pro-active response.

The models of control and regulation—along with the 'tools' and principles presented—are given context through a number of examples, such as human neurology and the functioning of the brain, a key research interest of Ashby's, as well as more mechanistic examples such as physical machines. The rules for regulation of these 'living' systems, Ashby argues, are similar enough to draw parallels.