Emergent Distributed Intelligence as a Rent-Generating Competence:
A Complexity Theory Approach

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Human and social capital development are discussed in the context of increasing corporate IQ, defined as distributed intelligence (DI) in firms, as the basis of economic rent generation. A review of complexity science shows that *adaptive tension* dynamics (Lorenz energy-differentials) may be used to foster adaptively efficacious DI appreciation. The optimal region for rapidly improving adaptive fitness occurs "at the edge of chaos." This region—in which emergent self-organization occurs—exists between the 1st and 2nd critical values of adaptive tension. Below the 1st value there is little change; above the 2nd value the system becomes chaotic and dysfunctional. Various managerial competencies are discussed by which rent-seeking CEOs may create or enlarge the region of emergence, thereby fostering improved corporate IQ.

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1 INTRODUCTION

When share prices fall, CEOs often lose their jobs. The best way to keep share prices high is to produce economic *rents*—defined as profits above the industry average (Besanko, Dranove and Shanley 1996). Porter (1996) says strategy is about finding new niches and then protecting rents by forcing would-be competitors into disadvantageous trade-offs. Prusak (1996, p. 6) narrows this down to rapid knowledge acquisition:

> The only thing that gives an organization a competitive edge—the only thing that is sustainable—is what it knows, how it uses what it knows, and how fast it can know something new!

In a brief study of the definitions of knowledge, intelligence, and information, Allee (1997, p. 42), citing the *American Heritage Dictionary*, defines intelligence as "the capacity to acquire and apply knowledge," noting also that the Latin root, *intelligere*, means "*to choose between*."

Zohar titles her 1997 book *Rewiring the Corporate Brain*. "Rewiring" places emphasis on the alteration of the connections among people—substituting for neurons—in the corporate brain. I will refer to this—the corporate brain—as *distributed intelligence* (DI) in firms. DI is a function of strategically relevant human and social capital assets—the networked intellectual capabilities of human agents (Masuch and Warglien 1992, Argote 1999). Mindful of the conditions imposed in the opening paragraph, my purpose here is suggest ways managers may enhance the IQ of their corporate brain. This means speeding up its ability to absorb new knowledge and develop new insights, all in the context of choice in terms of Porter's trade-offs and other constraints imposed by the competitive context.

The question is: *What should CEOs do to foster the emergence of DI in their firms, speed up its appreciation rate, and steer it in strategically important directions*? Since the "do" verb refers to activities not necessarily easily implemented, they take their place as essential managerial competencies requisite to sustained rent generation. My approach rests on taking a "strict constructionist" reading of complexity theory (Nicolis and Prigogine 1989, Mainzer 1994). I translate the concept of "*energy-differentials*" originating with Lorenz (1963) into the notion of "*adaptive tension*" to make Lorenz's concept more meaningful in an organizational context. Very simply, if a firm is strategically "here" and it needs to be strategically "there" to generate rents, this is adaptive tension. I begin by making the link between DI and Ashby's (1962) definition of emergent order. Then I discuss DI in firms. This is followed with an introduction to basic complexity theory, specifically the Lorenz energy-differentials and the factors defining the region of emergent order "at the edge of chaos." I conclude by outlining several managerial competencies pertinent to the creation of emergent order and DI in firms.

2 INTELLIGENCE AS CONSTRAINED ORDER

According to Merriam-Webster's dictionary (1996, p. 818) "*order*" and its synonyms means "…put persons or things into their proper places in relation to each other." Disorder, to natural scientists, means the 2nd law of thermodynamics, namely, inexorable dissipation toward entropy and randomness. Kauffman (1993) and Holland (1995) use the term, *order*, in the titles of their books, respectively *The Origins of Order* and *Hidden Order*. More specifically they focus on emergent order, equating it to spontaneous, emergent, self-organization.

What causes emergent order and self-organization? The Darwin/Wallace theory of natural selection (Darwin 1859) explains speciation in the biological world, that is: Why are there different kinds of organisms? Durkheim (1893) and Spencer (1898) also define order as the emergence of kinds, specifically, social entities. Half a century later, however, Sommerhoff (1950), Ashby (1956, 1962), and Rothstein (1958) define order not in terms of entities but rather in terms of the connections among them.

Ashby adds two critical observations. Order (organization), he says, exists between two entities, *A* and *B*, only if the link is "conditioned" by a third entity, *C* (1962, p. 255). If *C* symbolizes the "environment," which is external to the relation between *A* and *B*, environmental constraints are what cause order (Ashby 1956). This, then, gives rise to his "*law of requisite variety*" (1956). It holds that for a biological or social entity to be efficaciously adaptive, the variety of its internal order must match the variety of the environmental constraints. Furthermore, he also observes that order does not emerge when the environmental constraints are chaotic (1956, p. ?).

Zohar (1997) starts her book by quoting Andrew Stone, a director of the global retailing giant, Marks & Spencer: "My work is in a building that houses three thousand people who are essentially the individual 'particles' of the 'brain' of an organization that consists of sixty thousand people worldwide" (p. xv). Each particle presumably has some intellectual capability—what Becker (1975) terms human capital, *H*. And some of them talk to each other—what Burt (1992) calls social capital networks, *S*. Together, *H* and *S* comprise *distributed intelligence* (DI).

Order and DI, thus, consist of the same basic ingredients, nodes and links for order; *H* and *S* for DI. Connecting DI with Ashby's definition of order, we see that what appears to be DI involving entities *A* and *B*, defined as networked human capital, that is, *S* and *H* combined, cannot be DI unless the emergent *S* is in the context of nonchaotic environmental constraints C_i, *i* being the number of nonchaotic external constraints. This view of intelligence—based as it is on links among nodes that emerge in the context of environmental constrains—fits current views about the evolution of human intelligence (Campbell 1974, Plotkin 1993, Azevedo 1997) and the importance of social context in the structuring of the human brain (Brothers 1997, Markóczy and Goldberg 1998). Davenport's (1997) focus on the "information ecology" of firms is well within this view of intelligence.

Recent writing about competitive strategy and sustained rent generation parallels Prusak's emphasis on how fast a firm can develop new knowledge—the result of higher corporate IQ. Rents are seen to stem from staying ahead of the efficiency curve (Porter 1996), seeing industry trends (Hamel and Prahalad 1994), winning in hypercompetitive environments (D'Aveni 1994), and keeping pace with high-velocity environments (Eisenhardt 1989b) and value migration (Slywotzky 1996). Further, advocates of the resource- and competence-based view emphasize unique resources, distinctive/dominant/core competencies, dynamic capabilities, learning, and knowledge creation.[1] It advocates moving firms toward more sophisticated skills and technologies. As a result, the increased level of causal ambiguity (Lippman and Rumelt 1982, Mosakowski 1997), and complexity (ogilvie 1998), learning and innovation are not only more essential (Ambrose 1995), but also more difficult (Auerswald et al. 1996, ogilvie 1998). Dynamic ill-structured environments and learning opportunities become the basis of competitive advantage if firms can be *early* in their industry to unravel the evolving conditions (Stacey 1995). Drawing on Weick (1985), Udwadia (1990), and Anthony et al. (1993), ogilvie (1998, p. 12) argues that strategic advantage lies in developing new useful knowledge from the continuous stream of "unstructured, diverse, random, and contradictory data" swirling around firms. Becker (1975) defines knowledge/skills held by employees and their intellectual capabilities as *human capital* (*H*), and having given knowledge and capability economic value, adds it to the production function.

Human capital is a property of individual employees. Taken to the extreme, even geniuses offer a firm only minimal adaptive capability if they are isolated from everyone else. A firm's core competencies, dynamic capabilities, and knowledge requisite for competitive advantage increasingly appear as *networks* of human capital holders. These knowledge networks also increasingly appear throughout firms rather than being narrowly confined to upper management. Employees have become responsible for adaptive capability rather than just being bodies to carry out orders. Here is where networks become critical. Especially in the last two decades, much of the effectiveness and economic value of human capital held by individuals has been shown to be subject to the nature of the social networks in which the human agents are embedded (Granovetter 1985, 1992; Burt 1997), as a reading of the various chapters in Nohria and Eccles (1992) also suggests. Burt (1992) go so far as to move networks into the realm of economic value by terming them *social capital* (*S*), saying that competitive advantage is

[1] Resource-based: Penrose 1959, Teece 1984, Wernerfelt 1984, Rumelt 1987, Barney 1991, Teece, Pisano and Shuen 1994. Competence-based: Selznick 1957, McKelvey 1982, Prahalad and Hamel 1990, Hamel and Heene 1994, Heene and Sanchez 1997.

a function of network relations, not individual knowledge attributes (1992, p. 3). Combining the need for both H and S, the production function, thus, becomes $Y = f(K, L, H, S)$, where Y = income. But, since Porter (1996) now argues that K and L portions of the equation no longer guarantee sustainable rents, this leaves all the emphasis on H and S, which is to ask, *How to raise corporate IQs*?

3 DISTRIBUTED INTELLIGENCE

I draw on both modern brain and distributed computer systems research to demonstrate that Becker and Burt each are half right.[2] Respectively, they naïvely could be interpreted to imply that "isolated geniuses" or "networked idiots" can generate rents. More likely, they would agree that H and S are *jointly* important. If so, the theory of the firm most relevant to rent generation appears as:[3] $Y = f(K, L, D)$, where D stands for the configuration of H and S likely to produce optimal DI for a particular firm. DI—in brains and in parallel processing computer systems—is a function of both the knowledge in the nodes (minimal in brains) and in the emergent connections among nodes (primitive in computer systems). Leaving aside nodes for the moment, intelligence is a function of links among nodes.

DI in a brain is entirely a function of its capability for producing emergent networks among neurons. Molecular neurobiologists now view brains as having four levels—individual cells, pairs of cells connected by synapses, networks of interacting cells, and brain regulation systems (Levitan and Kaczmarek (1991, p. 4). The most important cells for intercellular communication are the *neurons*. DI in brains is totally connectionist—meaning that intelligence is a function of the *connections* among neurons (the agents in this case). Neurons behave as simple "threshold gates" that have one behavioral option—fire or not fire (Fuster 1995, p. 29). As intelligence increases, it is represented in the brain as *emergent* connections (synaptic links) among neurons. Different aspects of intelligence and different mental functions usually are distributed across different sets of neuronal agents, often in different physical locations.[4] The emergent "whole" of genius, magnetic personality, or a nonschizophrenic self-concept that is externally recognizable is housed in the brain as networks of minimally capable agents—neurons. Human intelligence is "distributed" across really dumb agents!

DI in parallel processing computer systems is mostly a function of the built in intelligence capability of computers-as-agents, with minimal DI improvement stemming from emergent networks among the computer/agents.

In computer DI systems, computers play the role of neurons. They are more "node-based" than "network-based." Artificial intelligence resides in the *intelligence capability* of the computers as agents, with emergent network-based intelligence rather primitive (Blanning 1992, Taylor 1992, Garzon 1995). Durfee notes that "providing artificial agents with better local control mechanisms and thereby increasing their self-awareness can lead to better cooperative reasoning" (1988, p. 25). Computer-based DI systems have, in addition to their computer/agents, some kind of superordinate organizing program that acts to manage an efficient network that corrects for computer/agent failures or, alternatively, pursues some kind of "objective function" that seeks to make "…intelligent coordination decisions…so that network performance improves" (Durfee 1988, p. 25; plus note). Garzon (1995) interrelates the use of agent-based models for the purpose of designing computational devices consisting of many simple units evolving in time, lacking a central global coordination and control executive unit, and spread across space without instant remote communication. In adaptive-learning models, computer/agents evolve a simple intelligence appropriate to the conditions. Garzon's analysis notwithstanding, the distributed computer literature shows only marginal progress toward *emergent* DI, whether at the agent *or* network levels.

Artificial intelligence (AI) models increasingly are used to simulate learning processes in firms,[5] though their intelligence capability is not fully connectionist and the intelligence of their agents is mostly limited to neuronal "on-off" intelligence capability—far below that, even, of PCs (Masuch and Warglien 1992). Network sociologists are beginning to model the

[2] The literature on "shared mental models" offers an alternative view of DI focusing more on agents' cognitive preparation and predisposition toward integrating the unique knowledge of individual agents (Cannon-Bowers, Salas and Converse 1993, Klimoski and Mohammed 1994).

[3] Substituting D for H & S in the equation also solves the problem that H is not independent of S.

[4] Needless to say, I have grossly oversimplified what is known about brain function, as a reading of Levitan and Kaczmarek and Fuster will show.

[5] Seminal papers applying distributed, agent-based, artificial intelligence to organizations appear in Masuch and Warglien 1992. Other key papers focusing on learning are: Cohen 1986, 1992; March 1991, Carley 1992, 1997, forthcoming **(up-date);** Warglien 1992, Bruderer and Singh 1996, Carley and Svoboda 1996, Cheng and Van de Ven 1996, Abrahamson and Rosenkopf 1997, Dooley 1997, Levinthal 1997, 1998; Levinthal and Warglien 1999, Lomi and Larsen 1999.

dynamics of emergent networks (Macy 1991, Carley 1992, 1997; Carley and Prietula 1994, Carley and Svoboda 1996, Kim and Bearman 1997), with some emergent connectionist organizational learning based on social networks, but with limited agent intelligence. The 100 or so older models Carley (1995) mentions mostly place intelligence in the agent but they are neither dynamic nor connectionist because agents do not show coevolutionary growth in intelligence. It is important to note that AI models are a long way from being capable of human quality thought (Dreyfus and Dreyfus 1986), though in some activities they are far superior (Johnson 1987). MY use of DI is not subject to this limitation since my "nodes" are human brains. My focus on DI as emergent order informs places most of the emphasis on the emergence of constructive networks. Of course, firms that have constructive networks among geniuses usually will fare better than those having great networks among idiots.

4 COMPLEXITY THEORY

How should CEOs accelerate the rate of DI increase? Complexity theory points the way. Over the past thirty-five years it has become a broad ranging interdisciplinary subject, as demonstrated in the books by Nicolis and Prigogine (1989), Waldrop (1992), Holland (1995), Belew and Mitchell (1996), and Arthur, Durlauf and Lane (1997). The study of "*complex adaptive systems*" (Cowan, Pines and Meltzer 1994) focuses its modeling activities on how *stochastic idiosyncratic agents* (whether particles, molecules, genes, neurons, human agents, or firms), self-organize into emergent aggregate structure. Cowan (1994) says:

> …Complexity…refers to systems with many different parts which, by a rather mysterious process of self-organization, become more ordered and more informed than systems which operate in approximate thermodynamic equilibrium with their surroundings. (p. 1)
>
> …Complex systems contain many relatively independent parts which are highly interconnected and interactive and that a large number of such parts are required to reproduce the functions of truly complex, self-organizing, replicating, learning, and adaptive systems. (p. 2)

I focus on agents and what creates the region of emergent complexity "at the edge of chaos."

Cramer (1993) identifies three levels of complexity—defined in Table 1—depending on how much information is necessary to explain the complexity: *Newtonian complexity*, *emergent complexity*, and *stochastic complexity*. Complexity science (Nicolis and Prigogine 1989) shows that the separation of the region of emergent complexity from the other kinds is a function of the ambient energy impinging on a system of agents. Emergent structures are created and maintained by negentropy and eroded by entropy (Nicolis and Prigogine 1989, Mainzer 1994). Negentropic[6] effects create or maintain order in the face of entropic energy/order destroying effects within any system.

> > > Insert Table 1 about here < < <

Complexity theorists define systems in the emergent complexity category as being in a state "*far from equilibrium*" (Prigogine and Stengers 1984) and "*at the edge of chaos*" (Kauffman 1993). Prigogine and colleagues observe that energy importing, self-organizing, open systems create structures that in the first instance increase negentropy, but nevertheless ever after become sites of energy or order dissipation. Consequently they are labeled "*dissipative structures*." Self-organized—and self-contained[7]—dissipative structures may exhibit persistence and nonlinearity. Complexity caused self-organizing structures are now seen as a ubiquitous natural phenomenon (Cramer 1993, Mainzer 1994, Favre et al. 1995) and presumed broadly applicable to firms (Stacey 1992, 1995, 1996; Zimmerman and Hurst 1993, Goldstein 1994, Levy 1994, Thiétart and Forgues 1995, 1997; Byrne 1998, McKelvey 1997, 1999a, b, c, d; Anderson 1999, Maguire and McKelvey 1999).

The boundaries of emergent complexity in P.12 are defined by "*critical values*" (Cramer 1993, Gell-Mann 1994). Nicolis and Prigogine (1989, Ch. 1) describe the function of critical values in natural science. Nothing is so basic to their definition of complexity science as the Bénard cell—two plates with fluid in between. An *energy* (heat) *differential* between the plates—defined here as '*adaptive tension*', *T*—creates a molecular motion of some velocity, *R*, as hotter molecules move toward the colder plate. The energy-differential in the Bénard cell parallels that between hot surface of the earth and cold upper atmosphere—hotter air molecules move upward and if they move fast enough, create storm cells. Complexity science cannot be understood without appreciating the role that *T* plays in defining the region of complexity "at the edge of chaos." If *T* increases beyond the 2nd critical value, the agent system jumps into the region of chaotic complexity. Here the system is likely to oscillate between different states—centered around different *basins of attraction*—thereby creating chaotic behavior.

[6] Schrödinger (1944) coined negentropy to refer to energy importation.

[7] According to a recent conversation between Mike Lissack and Ilya Prigogine, the latter has long regretted not having originally included "self-contained" along with "self-organized" when defining dissipative structures (personal communication from Mike Lissack, Brussels, June 26th, 1999).

Definitions of *attractors* are given in Table 2. Thus, for molecular agents:

- **Below the 1st critical value** of *T*, agents show minimal response in reducing *T*—molecules vibrate in place but "conduct" energy by colliding with each other.
- **Above the 1st critical value** of *T*, agents show collective action toward reducing *T*. Gas molecules start bulk currents of "convection" movement, as the molecules actually circle around from hot to cold and back to hotter plate, or generate strong bulk currents of air flowing up and down from earth's surface to upper atmosphere—the air turbulence and storm cells that create rough airplane rides.
- **Above the 2nd critical value** of *T*, the molecular movements become chaotic. For example, if *T* between hot lower air and cold upper air increases further, perhaps by the conflation of warm moist air from the south and cold air from the north, say over Kansas, the *2nd critical value* may be exceeded. At this point the storm cell may oscillate between two basins of attraction, tornadic and nontornadic behavior.

> > > Insert Table 2 about here < < <

Translating to firms, suppose a large firm acquires another firm needing a turnaround. Suppose *T* stays below the 1st critical value, in which existing management stays in place and little change is imposed by the acquiring firm. There is little reason for people in the acquired firm to create new structures. Instead, there might be only "conduction" type changes in the sense that new turnaround ideas percolate slowly from one person to another person adjacent in a network.

If *T* goes above the 2nd critical value, complexity theory predicts chaos. Suppose the acquiring firm changes several of the acquired firm's top managers and sends in "MBA terrorists" to change the management systems "over-night"—new budgeting and information systems; new personnel procedures, promotion approaches, and benefits packages; new production and marketing systems. And the acquired firm's culture and day-to-day interaction patterns are changed as well. In this circumstance, two basins of attraction could emerge: one basin defined around demands of the MBA terrorists and the other centered around the comfortable pre-acquisition ways of doing business and resistance to change. The activities of the system could oscillate between these two basins, seemingly exhibiting the characteristics of a strange attractor.

Between the 1st and 2nd critical values lies the organizational equivalent of Cramer's emergent complexity—the region of complexity at the edge of chaos that Brown and Eisenhardt (B/E) (1998) aim at. Here, network structures emerge to solve *T* problems. Using the storm cell metaphor, in this region the "heat conduction" of interpersonal dynamics between sporadically communicating individuals is insufficient to reduce the observed *T*. To pick up the adaptive pace, the equivalent of organizational storm cells consisting of "bulk" adaptive work-flows starts. Formal or informal structures emerge, such as new network formations, informal or formal group activities, departments, entrepreneurial ventures, and so on.

Though the *T*s in organization science are unlikely to have the precise values they appear to have in some natural sciences (Johnson and Burton, 1994) it seems likely that a probability distribution of such values will exist for individual firms and each of their subunits. Though precise values of *T* for firms do not exist, we do know about symptoms indicating whether a firm is below the 1st, in between, or above the 2nd critical value (B/E 1998)—some of which are mentioned later on.

5 STEPS TOWARD HIGHER CORPORATE IQ

How can CEOs use adaptive tension and other related activities to speed up the DI appreciation rate and steer it away from the least promising directions without inadvertently creating the negative effects of an emergent command-and-control structure? In this section I focus on nine managerial activities CEOs may pursue to improve corporate IQ.

5.1 DEFINING AND MANAGING ADAPTIVE TENSION

For corporate DI to have its IQ raised, Ashby's definition of order needs to prevail. This means that the constraints, C_i, must be identified and brought to bear on the human "nodes" in the system in addition to fostering emergent networks. Thus, a CEO's first task in improving corporate IQ is to make sure the corporate brain is exposed to the full range of "T_os" "**o**ut there"—that surround the agents—that might energize emergent order. But a T_o that is "out there" but ignored by agents has no impact on agents' behavior. In natural systems, so far as we know, agents—particles, molecules, cells—do not ignore T_os impinging on them. Agents in firms can. Welch uses "*Be #1 or 2 in your industry*," with a very clear **m**otivational valance. Respond to the *T* or your division will be sold! Thus, T_ms—simply *T*s hereafter—need to have an intrinsic or extrinsic motivational valance attached before they can be expected to be felt as tension by agents. *T*s are the root motivation causing agents to import negentropy—from whatever source available—that is the cause of emergent networks aimed at dissipating them.

Definition 1: *T is the product of (1) the difference between a firm's or agent's current state and a different, more desirable state relevant to the firm or agent;* times *(2) the intrinsic or extrinsic motivation of an agent to respond.*

While agents in a Bénard cell face just one *T*, the adaptive tension confronting the many agents within a firm—as receivers—appears as countless *T*s. In addition, there are many *T*s reflecting forces and constraints in the environment, not to mention *T*s created by numerous agents within competing firms—from the CEO down to the people in engineering, production, marketing, sales, and so on. An agent network could emerge virtually anywhere in a firm around an initiative to produce a better part, product, marketing approach, new strategy, and so forth. Consequently, there is danger in *a priori* trying to focus certain kinds of *T*s toward specific kinds of agents. This might preclude the emergence of the most effective new networks. But there is an equal danger in trying to flood every agent with every kind of *T*. It is also clear that "selecting" the nature of the incoming *T*s based on preconceived CEO-level notions, as Roger Smith did at GM for a decade (Hunt and Ropo 1998) puts blinders on the corporate brain. Toyota is well known for its system of increasing the awareness of workers about how well their designs and products compete against the competition—a small set of narrowly defined *T*s. Welch accomplishes the same objective by defining *T*s very broadly as, "Be #1 or 2 in your industry!" This is a perfect example of using a simple piece of information to focus attention on a particular aspect of the competitive environment—everything is boiled down to one *T* that *drives* the lower level systems without the command-and-control structure *defining* them. Strong corporate leadership is shown without setting up a suppressive command-and-control-structure or otherwise inhibiting emergent DI.

Definition 2: *Adaptive tension is defined by "an effective sampling" of Ts that agents at various levels within the firm can use to define their adaptive state relative to that of competing agents/firms.*

Definition 3: *"An effective sampling" is defined as ranging "adroitly" between (1) a set of Ts (a) not delimited by the CEO's or others' visions; (b) not narrowly defined by the specific responsibilities of a specific agent; and (c) not mindlessly flooding all agents indiscriminately with all kinds of information, on the one hand, and (2) T prioritizations based on (a) indications of value migration and industry, technological, and market trends; (b) the firm's path dependencies, idiosyncratic resources and competencies, and (c) larger groupings of agents (the sampling of Ts relevant to agents in one division may be reasonably different from Ts relevant to another).*

Definition 4: *"Adroitly" is defined as that mix of Ts getting the corporate brain to produce emergent initiatives showing the highest probability of rent generation over time.*

Another aspect of tension is the felt sense of urgency, defined as the rate at which adaptive events take place—a firm's metabolic or energy conversion *rate*. This is the rate at which the DI system seeks to reduce the *T*s. A cursory review of the OD literature (see French, Bell, and Zawacki 1994) suggests that little attention is paid to "rates" at which organizational events happen. An exception is an article by Beatty and Ulrich (1991) in which they talk about "re-energizing" mature firms. They mention in passing Welch's interest in "speed" of event flows at GE, a point noted again by Stewart (1999). Schoonhoven and Jelinek (1990) bear witness to the concern over speed at Hewlett-Packard. More recently Eisenhardt and colleagues (Eisenhardt 1989b, Eisenhardt and Tabrizi 1995, Brown and Eisenhardt 1997, 1998) zero in on the use of "time pacing" strategies for cranking up the metabolic rates of firms.

If a firm is construed as a place where events take place that improve fitness, then, how often do effective events take place—process improvement events in general, bottom-up leadership events, network transaction events, novelty occurrence rates, dysfunctional-event reduction rates, and so forth. CEOs have used "management by walking around" to raise metabolic levels while staying outside the bureaucratic command-and-control structure. Rates at which DI systems check in with top leaders are important and may be speeded up as appropriate. Ashkenas et al. (1995) identify four critical elements that serve to raise or lower metabolic flow rates in the DI system: information, competence, authority, and incentives—they call them leverage points. Information flow rates may be managed, as can rates at which learning, knowledge accumulation, and as a result, competence, improve. The relative mix of point attractors and strange attractors used also may be managed (more on this in Section 6.3). And surely incentives have a tremendous effect on the rate at which events take place in organizations. In the secondary value chain, differentials in rates of new product research and products brought to market, human and social capital accumulation, requisite variety development, and so forth, are important.

Definition 5: *Ts may also be defined as rates of: product introductions, positive and negative bottom-up leadership events, process improvement events, network transaction events, novelty occurrences; rates at which dysfunctional events are reduced; rates of effective coordination events; information flow rates, etc.*

5.2 MANAGING AROUND THE CRITICAL VALUES

Assuming agents are confronted by the appropriate *T*s, managing the critical values aspect of adaptive tension requires three basic activities: (1) checking whether behavioral symptoms of *T*s impinging on one or more agents are below, between, or above the critical values; (2) altering motivational valances to move the *T* levels into the region between the 1st and 2nd critical values; and (3) widening the distance between the critical values. For now I assume *T*s impinging on an agent are averaged, though in real life some *T*s have far more adaptive significance than others and agents may respond to some more than others with heightened intrinsic motivation.

Critical values are not precisely determined in firms—as they are in natural science. Nor does research indicate what levels of *T*s are below, between, or above the critical values. For now we have to rely on behavioral symptoms for evidence about *T* effects. B/E (1998)[8] identify some symptoms. As indications that *T* is *below the 1st critical value*, B/E point to (a) high bureaucratic level: all rules followed, overbearing structure, strictly channeled communication (p. 30); (b) too low alliance coadaptation: fiefdoms, overlapping effort, little coordination or learning, uncoupled strategies (p. 60); (c) too low a regeneration level: no modular structures, little novelty, too much path dependency, too many rules (p. 94); (d) kind of experimentation: little agent vision, reactive, focused on present competition (p. 130). For evidence that *T* is *above the 2nd critical value* B/E point to (a) minimal bureaucracy: rule breaking, loose structure, random communication (p. 30); (b) too high alliance coadaptation: bottlenecked structures, over coordination, politics, poorly adapted products, (c) too high a regeneration level: too much novelty, no building on the past, modular structures disconnected (p. 94); (d) kind of experimentation: intense experimentation but too narrowly focused, sporadic. The B/E symptoms do not identify the full range of *T*s I define earlier, but they make a good start and point the way toward a broader set of symptoms. Some other indications of the system tipping over into the chaotic region could be: Emergent groups that subsequently inhibit intergroup networks—the groups become isolates themselves; emergent structure gone wild; the breaking down of structures—such that individual agents tend toward more isolation; oscillation between individual or network domination; and unstable emergent groups.

B/E focus on symptoms showing when a system is *outside* the region of emergence. There are also direct symptoms of emergence. In general *T* between the critical values produces emergent dissipative structures, which then start reducing *T*, at which point they dissipate. Examples are:

1. Emergent social networks such as dyadic or triadic communication channels, informal or formal teams, groups, or other network configurations;
2. More effective networks within or across groups, more structural equivalence, better proportions of strong and weak ties, increased numbers of structural holes (Burt 1992), more networks emerging between hostile groups—marketing with engineering, or with production, with suppliers, with customers, and so forth;
3. Emergent networks of any kind, networks that produce novel outcomes, new strategies, new product ideas, new directions of knowledge accumulation; and
4. Networks that speed up metabolic rates of event occurrence.

Recall that a "*T*" is really $T_o \times T_m$, the degree of adaptive tension × motivation. Thus, the "felt" impact of a *T* on an agent could be altered by changing T_o or T_m, or both. An agent's behavioral symptoms, therefore, can be altered relative to the critical values by operating on T_o or T_m, or both.

Not only does the level of an imposed *T* fall below, between, or above the critical values, the *felt adaptive tension* and the consequent behavioral symptoms could be a function of the number and nature of *T*s hitting any given agent. One *T* per agent, even though significant may not get the agent's behavior above the 1st critical value and too many may shoot it over the 2nd value. This augments the definition of "adroitly" mentioned in Definition 4.

In addition to the B/E material, symptoms showing the agent system oscillating from below the 1st to above the 2nd critical value, and vice versa—thereby missing the region of emergence—are worth noting. Oscillation could be a sign that either:

1. An agent system is above the 2nd value and subject to a strange attractor in which the two basins of attraction are agents' oscillating attempts to (a) respond to the more extreme values of the impinging *T*s; or (b) respond by retreating to the region below the 1st value;
2. The region between the two values is so narrow that the only responses possible are (a) or (b) above; and
3. The *T*s themselves are fluctuating to the point where the agent system does not stay in the emergence region long enough for emergent structure to form coherently or with stability.

Leaders can deal with (1) above simply by reducing *T* to the point where it falls below the 2nd value. A better strategy is to widen the region of emergent structures as much as possible—the larger the region of emergence the easier it is for the system to avoid oscillating or bifurcating.

Widening the region of emergence requires operating on the location of the critical values themselves—lowering the 1st, raising the 2nd—rather than only trying to adjust the *T*s to fall in between. Much of OD is aimed at getting employees to communicate more—"Increased interaction and communication…underlies almost all OD interventions. The rule of thumb is: Get people talking and interacting in new, constructive ways and good things will result" (French and Bell 1995, p. 161).

[8] Though the B/E book offers useful advice to practicing managers the impression they give of complexity theory could be misleading to naïve readers. They argue that managers should balance their firms between too much rigid bureaucratic structure and chaos—as if these are God-given and etched in stone. Instead, complexity science shows that a complex adaptive system is caused to exist below, between, or above the 1st and 2nd critical values by an adaptive tension (energy-differential) acting on the system as an exogenous variable, that naturally (as in the weather) or artificially (as with a Bénard cell) is subject to change and/or manipulation. Put simply, CEOs don't respond to complex adaptive systems as fixed entities—they can inadvertently or purposefully create all three kinds of them!

Anything that gets networks to form more easily is essentially lowering the 1st critical value. Raising the 2nd critical value requires training agents to develop (1) more effective emergent structures—so tension stops rising and starts dissipating; and (2) higher 'tension tolerance' to handle higher tension levels before "going chaotic." For example, employees in high-velocity firms in Silicon Valley work routinely in an atmosphere of adaptive tension far higher than might ever appear in large dinosauric firms or government agencies. What seems above the 2nd value in Detroit or Washington may be below the 1st value in Silicon Valley. What seems chaotic to agents with little experience at managing adaptation and forming new networks may seem well below the 2nd critical value to agents experienced in adapting to high-velocity environments. Many OD methods also respond to this issue as well. In fact, most of the 34 "complexity-theory-applied-to-management" books apply elements of OD to these issues.

5.3 MANAGING THE ATTRACTORS

Speeding up the corporate brain's search for new initiatives, could easily lead to lots of newly empowered agents running around out of control wasting funds on silly projects. The previous two sections work on the "fostering-and-speeding-up-emergence" part. Now I turn to the problem of "steering" without inadvertently fostering the emergence of a suppressive command-and-control-bureaucracy. Recall the definitions of *point* and *strange attractors* in Table 2.

Bureaucratic negative feedback systems center around point attractors. A visionary CEO operates as one—the vision is the goal, which becomes the equilibrium point toward which negative feedback, managerial control processes define the system. Since firms do need strong leaders, and since some people like being strong leaders and behave like strong leaders, it is pointless to think of avoiding point attractors. The trick is to aim these "strong leader types" toward using point attractors that "*drive*" the system toward reducing the *T*s but do not "*define*" it in the command-and-control ways that inhibit emergence. *T*s *are* point attractors. Activities that serve to reduce *T*s, thus, are point attractors. These should become the focus of strong leaders' attentions. In managing DI it is essential to have point attractors mostly limited to the *T* symptoms relevant to agents in the DI system. Any other use of point attractors by strong charismatic leaders seems most likely to start defining lower level behaviors, thus working against constructive emergence (McKelvey 1999c).

Remaining strong leader activities are best redefined to be strange attractors. This is probably the best way in which to view Bennis's "herding cats" metaphor—the "cage" effect of the rabbit and dog metaphor in Table 2. We may use what Morgan (1997, p. 98) refers to as "*cybernetic reference points*" and "*avoidance of noxiants*" to define the reflective cage of a strange attractor without defining goals that act as point attractors. Strange attractor "definitions of the cage" must be created without determining specific or repeating paths—characteristics of point attractors and opposite the definition of novelty. Core values, core ideologies (Collins and Porras 1994), and Hewlett-Packard style strong cultures (Schoonhoven and Jelinek 1990), that keep agent systems from falling off the track of seeking emergent networks and novel approaches to rent generation, can be particularly effective in defining limits without setting up point attractors.

Incentives should encourage the proper delineation, separation, and development of point and strange attractors. It is easy to define point attractor incentives—"Here is the goal and I will pay more if you achieve it." Saying "No" is all too easy in firms and seldom needs to be encouraged. Setting up "inexpensive experiment" strange attractor systems seems more risky and learning when to say "No" to continuing an experimental product development activity is problematic. Strange attractors also need to be made attractive for agents "inside the cage." Entrepreneurial incentive systems and strange attractor champions seem relevant, following the new product champion idea (Clark and Wheelwright 1993). Selection processes seem relevant since goal-setting theory (Locke and Latham 1990) indicates that some people thrive better in basins created by point attractors than by strange attractors. As Stacey (1996) discusses at great length, operating in a strange attractor organization could raise anxiety to dysfunctional levels and, thus, needs to be managed carefully, a point I discuss in the following section. For a general review of managing incentives and innovation, see Tushman and Anderson (1997).

5.4 MANAGING DYSFUNCTIONAL STRESS

In his book, *Complexity and Creativity in Organizations* (1996), Stacey sets up anxiety felt by employees in firms facing changing environments in the same framework of Lorenz energy-differentials and critical values that I use here and refer to as the critical values of adaptive tension. In my framework CEOs aim to adjust adaptive tension to be within the critical values, by identifying the adaptive tension *T*s and coupling them with incentives. If a particular *T* is too high and the incentive too draconian then the anxiety felt by the targeted employees could tip over the "edge of chaos" into the region where chaotic behavior results and, thus, produce dysfunctional kinds of behavior. This section will elaborate this important consequence.

Psychoanalytic Theory
Creativity Subject to Critical Values
Managing Anxiety--too little, too much, moderate
Depressive State (holding ambiguity & paradox without being overcome by anxiety)
Transitional Objects for Adults
Neurotic Organizational Forms
Critical Values Applied to Creativity in Groups
Leadership as Containing Anxiety
Capacity to Contain Anxiety in Others
Double-Loop Learning
Heroic Power/Vision vs. Anxiety Management

5.5 MANAGING THE COACHING (AUTO)CATALYTIC PROCESS

The (auto)catalytic process is discussed as the "coaching" process in the OD literature and in the complexity-theory-applied-to-management books such as those by Goldstein (1994) and Kelly and Allison (1998). OD researchers and consultants (French and Bell 1995) have known for decades that one cannot simply assume that all employees know how to foster empowerment, the formation of autonomous work groups, creation of teams, and so forth. Often first-line supervisors are trained as coaches to help the emergence process along. The coaching process is not unlike the autocatalytic process complexity theorists observe taking place in the emergence of dissipative structures in natural systems. This section will elaborate on the use of the coaching process in fostering emergent order.

Definition of a Catalytic Agent
Boundary Managers
Inspiration & Motivation
Role Model, Coach
Interpreting Adaptive Issues
Breaking Down Barriers
Facilitating SDWT Efforts
Maintaining Customer Links

5.6 MANAGING THE DISSENT REGIME

Argyres and Mui (1999) elaborate the various conditions in firms by which internal "dissent regimes" can either help or hinder the organizational learning and development of novel rent generating strategies. Clearly, emergent order structures occur in the context of favorable or unfavorable dissent regimes. A CEO needs to be able to diagnose the nature of his/her firm's dissent regime and then, if necessary, how to alter it so as to foster the kinds of discussions among employees and subsequent network development that catalyze emergent order. This section will elaborate these points.

5.7 MANAGING COMPLEXITY CATASTROPHE

Elsewhere (McKelvey 1999a, d) I have applied Kauffman's concept of "*complexity catastrophe*," to firms, as have Levinthal (1997, 1998), Baum (1999), Levinthal and Warglien 1999, and Rivkin (1999). Kauffman argues that complexity catastrophe arises under some conditions and acts to arrest the blind-variation-selection-retention process in firms (Campbell 1965, Baum and McKelvey 1999). Emergent order structures in firms are, in essence, blind variations that are also subject to the variation-selection-retention process of natural selection theory (Darwin 1859, Depew and Weber 1995). The complexity-based forces identified in this section set up the need for the modular design approach outlined in the following section.

5.8 MANAGING MODULAR ARCHITECTURE

Starting with the classic work at the Tavistock Institute on socio-technical systems and self-directed autonomous work groups (Herbst 1974)—brought up to date by Galbraith *et al*. (1993) and Fisher and Fisher (1998)—coupled with work on modular structures (Sanchez and Mahoney 1996, Sanchez 1995, 1997, 1998; Schilling 2000, Schilling and Steensma 2000) there is now a literature on the use of modular designs to slow down the development of what Kauffman calls complexity catastrophe or, more generally, interdependency bottle-necks. The idea is that designing systems as collections of loosely coupled (Weick 1976) subunits wins out over globally optimized systems under conditions of environmental change. That is, the emergence of DI in subunits happens more rapidly if the subunits are loosely coupled and therefore emergent order in the global system also happens more rapidly. Global optimization, like visionary leadership at the top of firms (McKelvey 1999c), can operate to inhibit emergent order, and thus, emergent DI structures.

Managing the Modular Process Architecture Problem
Optimization Architecture
Optimal integrated Design of Multiple Components
Limited Product Alteration Flexibility
Modular Architecture, Interface Definition
Module by Module Flexibility
Product Alteration via Module Flexibility
Distributed Intelligence & Modular Architecture
Mutually Supportive
Coevolutionary
Flexible, Bottom-Up, & Rapid Product Response
Modular Architecture Thwarts Complexity Catastrophe
The Ultimate Modular Design?
Is There a "Selfish Module" Problem?

5.9 MANAGING THE AGENCY PROBLEM

Economists define the agency problem as the likelihood that managers, as agents of shareholders, will substitute their own personal interests for those of shareholders (Jensen and Meckling 1976, Eisenhardt 1989a, Besanko, Dranove and Shanley 1996). They say that stock options offer the best defense against the agency problem. Absent this, the DI system will tend to seek the missions of its own agents rather than shareholder wealth. However, if sustainable competitive advantage and rent generation lies within the DI system, adhering to strong visions held by leaders at the top—even if they have stock options—surely works against shareholder interests—witness Smith's decade of isolated strong vision at GM (Hunt and Ropo 1998). Strong visions that create conditions of emergent DI can work for shareholders—as in the shareholder wealth resulting from Welch's approach toward "workouts," the empowerment of lower participants (Tichy and Sherman 1993), the emphasis on boundary-suppression (Ashkenas et al. 1995) and the almost ruthless insistence of rapid "best practice" flows throughout the GE system (Kerr 2000), and in the Hewlett-Packard vision (Schoonhoven and Jelinek 1990). Even so, if responsibility for strategy lies within the DI system, then the agency problem is relevant. Human and social capital holders could choose to put their own interests ahead of shareholder interests.

If slack resources (March and Simon 1958) are made available for DI development, then there is the possibility that the slack could be used against shareholder interests. Agency theorists define slack as resources used for nonowner purposes. But slack may be seen constructively as resources available for importation into an emergent system as negentropy, thereby creating dissipative structures. So viewed, slack is another means, in addition to managing the *T*s, to tune agents' symptoms toward the emergent complexity region. High *T*s that would produce symptoms above the 2nd value without slack—because developing emergent structures without negentropy is more difficult—could produce symptoms between the values if more slack was available.

Slack targeted for DI development should be managed by strange attractors rather than allocated to point attractors. Slack imported into basic research parks is adaptive, but the tension is low as the agents are disconnected from market defined *T*s. Connecting slack with specific *T*s, but still steering the DI system by strange rather than point attractors seems optimal. The more market-connected *T*s are used to create the conditions leading to emergent order, the more likely networks will emerge in response to market related adaptive problems rather than in response to the interests of individual agents. In most organizations, lack of effective strange attractors—leader activities that define the "cage" without creating an emergent command-and-control bureaucracy, coupled with strong bureaucratically driven point attractors, are the forces giving rise to the classic anti-management informal groups and pursuit of aberrant individual interests (McKelvey 1999c). *Random* agent interests—lacking a unity of response toward *T*s—are not likely to give rise to emergent networks absent oppressive command-and-control point attractors uniformly seen as undesirable by the agents. In short, *T*s serving to heighten and steer the adaptive tension felt by agents, if designed properly—meaning an adroit mix of point and strange attractors—also mitigate the agency problem.

In light of my goal of finding ways that CEOs can produce sustainable rents, CEO activities that inhibit DI appreciation actually contribute to the agency problem. DI appreciation depends on staying in the region between the critical values, which in turn depends on "pointing" agents' attention toward the *T*s (defined to include incentives). Failure to do this leaves more leeway for agents to pursue their own interests. Furthermore, energetic agent campaigns of experimentation, novelty generation, and new product initiations are less likely to deviate from shareholder interests if they are "caged" within a strange attractor framework.

6 THE GE "BEST-PRACTICE-FLOW" EXAMPLE

Since GE developed their "boundaryless organization" approach (Ashkenas et al. 1995), GE has moved to elaborate a system whereby best-practices discovered in one section are quickly spread to other parts of what is now a vast (partially related) diversified firm (Kerr 2000). It accomplishes this by developing "*simple rules*" and fairly draconian incentives to make sure the flow of best-practice discoveries throughout the GE network is speed up as fast as possible. GE is a particularly important example, as the following bullet points make clear.

- Capitalization:
  Average Diversified Firm: PE Ratio ~ 19
  GE's PE Ratio ~ 44
  Difference is ~ $270 billion in Capitalization
- Growth:
  Three Major Acquisitions per week
  # 1 in Many Business Areas
  Faster Than Any Other Major Firm Since 1980 (except possibly for Microsoft)

I outline the combination of simple rules and incentives they use as follows:

- Defeat Barriers to Information Sharing
  Hoarding vs. "Not Invented Here"
  Boasting vs. "Not Generalizable"
  The "Core" of Most Ideas Mostly *IS* Generalizable
  Learning Opportunities
  Put People in Positions Where They Might Fail
  "Popcorn Stands"
  Reject Only After Trying to Make it Work
  Make Expertise Readily Available

- Strong Incentives
  You Can Get Rich
  You Can Get Fired
- No Secrets Allowed

GE argues that they have an approach that is not new or complicated. It is just a few simple rules focusing on getting good ideas to be shared around the GE system. They are, however, rather strongly focused on how they attach strong incentives aimed at producing a rapid flow of newly discovered best-practices. This section elaborates the GE approach briefly.

7 CONCLUSION

Narrowly, I suggest that CEOs wishing to generate sustainable rents in a changing world would be more successful if they focused on human and social capital appreciation, distributed intelligence, and managerial activities for improving the adaptive competence of firms. These activities stem from complexity theory. Put simply, my approach is aimed at improving corporate IQ. I make the following main points:

1. Economic rents and competitive advantage depend on human and social capital.
2. High-velocity and hypercompetitive contexts require rapid development of human and social capital.
3. In firms, the "critical values" of adaptive tension—most likely identified by behavioral symptoms—define the complexity region that stimulates the emergent social capital networks necessary for improving DI.
4. Several activities are identified for CEOs to use in speeding up DI appreciation rates for the purpose of producing rents and shareholder wealth, and thereby improving corporate IQ.

I use complexity theory and adaptive tension to show how CEOs could speed up the rate of DI appreciation while at the same time suppressing the emergence of bureaucracy—a point elaborated in McKelvey (1999c). Complexity science recognizes that kinds of complexity are not immutable; they are the result of adaptive tension. Knowing this, if leaders alter the adaptive tension imposed on a system, its kind of complexity and emergent order changes. Specifically, tuning adaptive tension to between the 1st and 2nd critical values produces emergent network structures. Complexity science, thus, not only offers a more comprehensive means of explaining social phenomena but also offers explicit methods by which CEOs may create fundamental changes in the intrafirm order networks for which they are responsible.

Theories of bureaucracy and organization (Scott 1998) put intelligence *in the positions* and in the people holding them, and emphasize human capital appreciation as the basis of competitive advantage. Parallel-processing distributed computer systems put intelligence mostly in the agents with primitive emergent connectionism possible. In contrast, theories of the brain and human intelligence say intelligence *is the network*, a view taken up by Burt (1992) with his emphasis of social capital appreciation as the basis of competitive advantage. None of these views is correct by itself. Combined brain and computer-based distributed systems place intelligence both in the agents and in the network. My view of DI in firms, therefore, builds on both brain and computer analogies.

Most present-day computer models of firms and people in firms also are at odds with the distributed systems literature. They usually assume intelligence in the people and positions, as indicated in most of the models Carley (1995) reviews; *or* they have little if any intelligence in the agents as is typical of agent-based models. However, the latter are dynamic in that agents incrementally increase attributes such as fitness or IQ and/or network connectivity. Consequently, they allow a dynamic approach toward discovering the optimal development of corporate IQ as distributed intelligence—IQ in the agents vs. IQ in the network—given specific development costs.

The GE example I present shows that it is possible to get large organizations to behave more or less like adaptive-learning models. Meaning that most employee/agents operate with incentives to be constantly on the lookout for new learning opportunities. They do this by developing both new network connections and moving new best-practice ideas around on them. They also act like model agents in that they are under incentive pressure to adopt new best-practice concepts, that via networking, they come in contact with.

A key part of this paper is the recognition that the use of knowledge in rapidly changing competitive contexts depends on high levels of corporate IQ. Just as IQ in people is a function of neurons and synaptic links, I argue that human and social capital in firms are the basic building blocks of corporate IQ. Since people are spatially distributed throughout a firm, we are necessarily talking about distributed intelligence. Given this, networks are critical. I also draw on a classic article by Ashby (1962) to argue that emergent distributed intelligence in firms is in reality a function of emergent networks among people, with the added Ashby proviso that "order" and self-organization result only in the context of environmental constraints. I note in passing that intelligence is also defined by the Latin root, *intelligere*, which also puts intelligence in the context of choice—among environmental constraints. Thus, it is foolish to attempt to improve distributed intelligence (and corporate IQ) except by driving it with the use of adaptive tension, the so-called Lorenz energy-difference mechanism in complexity theory.

Using this strict constructionist interpretation of complexity theory, I develop several activities that CEOs can set in motion to improve corporate IQ by using adaptive tension and incentives to foster emergent order. They are:

Defining and managing adaptive tension
Managing around the critical values
Managing the attractors
Managing dysfunctional stress
Managing the coaching (autocatalytic) process
Managing the dissent regime
Managing complexity catastrophe
Managing modular architecture
Managing the agency problem

Seven of these define ways that CEOs can stimulate the emergent order/intelligence process without introducing the kind of strong command-and-control structure that tends to shut down emergent networks and the creation of new ideas. One of them focuses on what happens if there is too much complexity. The last one argues that the adaptive tension focus also mitigates the agency problem.

My analysis elsewhere shows that strong, visionary, charismatic CEO-level leadership may produce levels of group cohesion inhibiting the production of emergent order/intelligence (McKelvey 1999c). Many of the "complexity-theory-applied-to-management" books reviewed in Maguire and McKelvey (1999) argue that strong command-and-control structures often created by strong visionary CEO leaders also inhibit emergent order/intelligence. In this paper I show that complexity theory offers guidelines for designing aggressive CEO activities aimed at improving corporate IQ that obviate these well known down-side effects of strong leadership at the top.

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Table 1 Definitions of Kinds of Complexity by Cramer (1993)*

‘***Newtonian complexity***’ exists when the amount of information necessary to describe the system is less complex than the system itself. Thus a rule, such as $F = ma = md^2s/dt^2$ is much simpler in information terms than trying to describe the myriad states, velocities, and acceleration rates pursuant to understanding the force of a falling object. “Systems exhibiting subcritical [Newtonian] complexity are strictly deterministic and allow for exact prediction” (1993, p. 213) They are also “reversible” (allowing retrodiction as well as prediction thus making the ‘arrow of time’ irrelevant (Eddington 1930, Prigogine and Stengers 1984).

At the opposite extreme is ‘***stochastic complexity***’ where the description of a system is as complex as the system itself—the minimum number of information bits necessary to describe the states is equal to the complexity of the system. Cramer lumps chaotic and stochastic systems into this category, although deterministic chaos is recognized as fundamentally different from stochastic complexity (Morrison 1991, Gell-Mann 1994), since the former is ‘simple rule’ driven, and stochastic systems are random, though varying in their stochasticity. Thus, three kinds of stochastic complexity are recognized: ***purely random***, ***probabilistic***, and ***deterministic chaos***. For this essay I narrow stochastic complexity to deterministic chaos, at the risk of oversimplification.

In between Cramer puts ‘***emergent complexity***’. The defining aspect of this category is the possibility of emergent simple deterministic structures fitting Newtonian complexity criteria, even though the underlying phenomena remain in the stochastically complex category. It is here that natural forces ease the investigator’s problem by offering intervening objects as ‘simplicity targets’ the behavior of which lends itself to simple rule explanation. Cramer (1993, p. 215–217) has a long table categorizing all kinds of phenomena according to his scheme.

* For mnemonic purposes I use ‘Newtonian’ instead of Cramer’s “subcritical,” ‘stochastic’ instead of “fundamental,” and ‘emergent’ instead of “critical” complexity.

Table 2 Definitions of Attractors by Gleick (1987)

“***Point attractors***” act as equilibrium points. A system, even though oscillating or perturbed, eventually returns to repetitious behavior centered around the point attractor—traditional control style management decision structures may act in this manner (appearing as Newtonian complexity);

“***Periodic attractors***” or “*limit cycles*” (pendulum behavior) foster oscillation predictably from one extreme to another—recurrent shifts in the centralization and decentralization of decision making, or functional specialization vs. cross-functional integration fit here (also appearing as Newtonian complexity);

If adaptive tension is raised beyond some critical value, systems may be subject to “***strange attractors***” in that, if plotted, they show never intersecting, stable, low-dimensional, nonperiodic spirals and loops, that are not attracted by some central equilibrium point, but nevertheless appear constrained not to breach the confines of what might appear as an imaginary bottle. If they intersected, the system would be in equilibrium (Gleick 1987, p. 140) following a point attractor. The attractor is “strange” because it “looks” like the system is oscillating around a central equilibrium point, but it isn’t. Instead, as an energy importing and dissipating structure, it is responding with unpredictable self-organized structure to tensions created by imposed external conditions, such as tension between different heat gradients in the atmosphere caught between a hot surface of the earth and a cold upper atmosphere, or constraints in a fluid flow at the junction of two pipes, or tension created by newly created dissipative structures, such as eddies in a turbulent fluid flow in a canyon below a waterfall, or “MBA terrorist” structural changes imposed in an attempt to turnaround an acquired firm.

As a metaphor, think of a point attractor as a rabbit on an elastic tether—the rabbit moves in all directions but as it tires it is drawn toward the middle where it lies down to rest. Think of a strange attractor as a rabbit in a pen with a dog on the outside—the rabbit keeps running to the side of the pen opposite from the dog but as it tires it comes to rest in the middle of the pen. The rabbit ends up in the “middle” in either case. With the tether the cause is the *pull* of the elastic. In the pen the cause is *repulsion* from the dog unsystematically attacking from all sides.