Complexity and Management: Moving From Fad To Firm Foundations

Steve Maguire & Bill McKelvey

CEOs have many different complexity approaches to choose from. The books reviewed in this Special Issue more or less define frequently obscure complexity science terms and complexity science theories have been given meanings more relevant to firms. Organization change methods leading toward emergence and empowerment are powerfully set forth. But in the founding issue of *Emergence*, one of us (McKelvey, 1999b) worried that "complexity science applied to management" had all the earmarks of becoming just another management consulting fad, aimed at marketing personal skills and books. It could become just another ingredient in what Micklethwait and Wooldridge (1996) describe as management guru witch-doctoring. The record is clear over the past several decades—management ideas that do not become legitimized by resting on a foundation of quality research are quickly replaced by the next fad coming down the pike.

Are complexity applications to firms vulnerable to or solidly past faddism? The purpose of this Special Issue is to give readers a broad overview of the general quality of complexity applications to CEO problems and to test how vulnerable to faddism they are. In this article, we present an overall summary of the total message that emerges from the reviews.

REVIEWERS' OBSERVATIONS

To summarize parsimoniously the many points made in the books and book reviews assembled here is a significant challenge. The books themselves are all different, as are their reviews. Book reviewers were free to write in their own style, to emphasize what they considered to be of importance or interest, and of course to arrive at their own judgment of books' merits and shortcomings. In addition, our reviewers are a diverse bunch. Each brings a unique expertise and perspective to their task, although we do believe that it is safe to say that they share an appreciation of the potential of the study of complex systems to improve our understanding of organizations and social life. Despite the heterogeneity of reviewers, reviews, authors, and books, some common threads of discussion, that tie together much of the complexity and management discourse aimed at practitioners, emerge from our review of the reviews.

By far the largest subset of the books reviewed is that which initially motivated this special issue: the quickly proliferating set of "popular" books on complexity and management aimed at managers, CEOs, strategists, and businesspeople, which we refer to as "trade" books. A couple of books, while still being "popular" and accessible, are somewhat more narrowly focused, discussing systems design or specific applications aimed at slightly more technical-oriented organizational members, like IS people and BPR analysts (i.e., Dhar & Stein, 1997; Warfield, 1994). There are a few books in our collection aimed at a nonacademic audience that are more broadly focused on entire political and social systems, looking at history and the past (i.e., Herrmann, 1998; Jervis, 1997) or the future (i.e. Kelly, 1994). Finally, a few books are clearly aimed at academics and address the links between complexity and some rather broad topics, like social science (Byrne, 1998), sociology (Eve, Horsfall and Lee, 1997), and postmodernism (Cilliers, 1998). In this section our discussion deals with only that largest set, the trade books.

Reviewers' evaluations: A wide range of evaluations are given to the trade books, varying from "disappointing" to "significant success" or even "a perfect example of how complexity and management thinking can enrich each other." Note also that not all reviews of the same book converge. Most reviews cluster towards evaluations that can only be described as mixed. Authors make "valiant attempts" and have produced works that are "satisfactory" or "worth reading" in that they "made a start" and were a "good light treatment" or a "good introduction." But these same books are typically "not for the familiar" and most provide "few insights for researchers and specialists." With notable exceptions, which readers will discover in the individual book reviews, in general complexity concepts are successfully presented but less successfully applied.

Common structure: The trade books have a more or less standard content, presenting a common argument with a structure as follows:

1. Managers now find themselves in qualitatively different world. It is more "uncertain," "turbulent," "complex," "nonlinear," "unpredictable," "fast-paced," "dynamic," and even "postmodern."
2. The "old" or "traditional" models employed by managers, founded as they are on Newtonian science, are not (or will not be) adequate in this new world. By "old" or "traditional" models are meant: hierarchical command-and-control structures; bureaucratic organizational routines; centralization of power and decision making; planning and forecasting; attempts at the reduction of uncertainty; and the use of machine and mechanical metaphors.
3. Fortunately, science has developed something new and improved, the authors have recognized this, and have undertaken the task of translating it for managers. Most then introduce and describe "New Science"—or, more commonly, a limited and specific set of concepts and terminology from it—that deal with chaos, complexity, complex adaptive systems, self-organization and autopoiesis.
4. From New Science can be derived a new set of managerial tools, models, principles or even entire philosophies that, if applied, will bring organizational success. Once translated into organizational terms, these commonly involve the flattening of hierarchies; decentralization of power, authority and decision making; empowerment of employees; embracing uncertainty; and the use of organic and ecological metaphors. Even just adopting terminology and language from the study of complexity can help CEOs, some authors claim.
5. Finally, most books provide illustrations of the application of these tools, models, concepts, and principles that frequently draw on empirical examples or case studies. Sometimes checklists, procedures, or a series of steps for managers to follow are also furnished, while a few books promote trademarked methodologies.

Complexity concepts used: Besides chaos and complexity themselves, a number of other terms from the study of complex systems frequently appear. That formal models of complex systems can be used to understand agents involved in self-organization, adaptation, coevolution, or evolution is significant, as is the emergence of phenomena that these processes generate, along with instances of punctuated or quantum change, and discontinuities. Attractors, especially of the strange variety, figure prominently in discussions, as do fractals. A few concepts are less frequent, but are addressed nonetheless, like fitness, fitness landscapes, and networks. Time figures less prominently than one might expect, but is not ignored, with a few works focusing on cyclicality and the potential for a viewing systems from a multiplicity of time scales.

Managerial, organizational and/or social phenomena addressed: According to the trade books, the study of complexity and formal models of complex systems helps illuminate a number of areas within organization science. By far the most common, perhaps because authors are reluctant to be more specific, is the vaguely defined phenomena of management itself. It is also claimed that complexity science has implications for organizational design, including organizational structure and hierarchical depth; degree of centralization of power, authority and decision making; degree of routinization and bureaucratization; as well as culture. The obvious connections between adaptation of agents and organizational change, adaptation and learning are also drawn, with a number of authors mentioning the relevance of complexity terminology, concepts, and tools to leadership—leading, managing, and facilitating change, or even organizational transformation. That the application of complexity-inspired tools can improve an organization's creativity and innovation is another popular claim. Addressed, but receiving less attention, are competition and strategy.

What reviewers applauded: Our reviewers like many different things in these books, too numerous to enumerate here. But there are commonalities between reviewers. For instance, the empirical examples, case studies and illustrations of concepts that draw on real organizational experiences are almost universally appreciated. Even reviewers who complain of a lack of rigor in the use of complexity concepts congratulate authors for attempting to apply them and for recounting these case histories. Future research reporting on empirical work will almost certainly be well received. Authors are also applauded for bringing structure and order to the chaotic world that they describe. Indeed, just attempting to order the business world within complexity-inspired frameworks is appreciated, as it stimulates thinking and forces readers to reflect on and perhaps struggle with their own ideas. Authors' use of metaphors is singled out as particularly insightful. If nothing else, the metaphorical and thought-provoking potential of complexity is certainly in the process of being realized. Finally, while this term is not used, reviewers appreciate the humanism implicitly or even explicitly embodied in many of the authors' recommendations.

What reviewers would like improved: Here again, it is difficult to generalize, as many specific criticisms are made and areas for improvement in particular books identified. Nevertheless, some complaints do reappear, especially that of authors' "loose," "less than rigorous," "oversimplified," and even sometimes "incorrect" use of concepts. And while metaphors are applauded, a number of reviewers feel that authors' over-reliance on metaphors contributes to these "superficial" treatments. The absence of at least some mathematics in many books is conspicuous and undesirable for a number of reviewers, as is also the insufficient harnessing of simulations and computer models. In other words, the full toolkit of complexity has not been put on display for practitioners. Finally, although empirical examples are much appreciated, a number of reviewers feel that these are mere retellings of old tales using complexity terminology tacked on retrospectively, gratuitously and, in many cases, quite awkwardly.

Conclusion: The reviews, taken together, paint an interesting and fairly complete picture of what is "out there"—available to practitioners in bookstores—on the applications of complexity science to organizations and managerial problems. Our summary here does not do the reviews justice and is certainly not meant to substitute for a first-hand reading, which we enthusiastically encourage. In some cases the book reviews rival the books when it comes to insights.

OUR OBSERVATIONS

Having summarized the reviews and identified some common themes, we now turn our attention to a discussion of what we did and did not find. Clearly, throughout the books and book reviews, one finds widespread agreement on the existence of a significant potential for the study of complex systems to inform and illuminate the science and management of organizations. And, on balance, a strong start towards developing this potential is evident. Managers reading these books have different approaches from the New Sciences to choose from, and many once obscure complexity science terms and theories have been interpreted and given meaning more relevant to firms. Nevertheless we wish to underline here a point made by reviewers in this issue and which echoes a worry set forth in the founding issue of *Emergence* (McKelvey, 1999b): there is a real risk that complexity science applied to management could become just another management fad.

We stress that not all books reviewed fall into this category and that we abstain here, in our discussion, from singling out particular authors to be attacked or applauded. This is the job of our reviewers, and one that they have executed with balance and fairness. Instead, we address a collective tendency among the trade books to make claims that are incautiously exuberant, misleading, or unfounded. We choose this last adjective with care: unless management ideas are developed from and built on a solid foundation of quality organizational research, they are quickly replaced—ritually killed, as soon as their novelty has worn off, by management consultants who originally gave them life and nourished them with marketing budgets.

We also develop our discussion with something else in mind: complexity is a phenomena around which scientists are still building a discipline. A unified view or theory has not yet been built. It is one thing for organizational researchers to turn to long-standing, relatively uncontested and "black-boxed" theories from the harder sciences, like for example the Lotka–Volterra equations of population ecology imported by Hannan & Freeman (1977), but it is quite another to borrow ideas, concepts and models from a young and nascent field under development. Complexity science is still, very much, "in action" (Latour, 1987) and fundamental questions, including those of potential limits to knowledge and the role of the observer in models—that lead quickly to those of ontology and epistemology for those willing to go in that direction—are being asked. The implications of this are threefold:

1 First, many opportunities exist for a fruitful exchange between organization and complexity scientists. Yes, we said "exchange." As that field within the social sciences that devotes itself to the study of "organizations" and "organizing," it would be surprising if management and organization studies had nothing to contribute to complexity scholars as they turn their attention to systems composed of human agents. In addition, any natural science theory that arrived in social science with all its ontological and epistemological questions settled would just be ignored by many if not most researchers and would thus present only limited opportunity. The humanity of agents matters. Even our book reviewers recruited from the "harder" sciences reiterated this, stressing that, to make complexity science relevant to managers, tough issues related to "softer" concepts like identity, values, and purpose as well as situated, contextual, contingent knowledge had

to be addressed. In addition, it is far from clear that the development of knowledge relevant to actor-observers inside a complex system would necessarily take the same form as that relevant to observers outside the system (Hendrickx, 1999). That hermeneutic or interpretist may complement more realist approaches to complexity is a possibility to which a number of authors and reviewers point. In addition, near the end of our discussion we suggest that critical approaches may also be the source of, ironically, managerial insights. All of these alternatives merit further exploration.

2 Second, even more than the usual caution that organizational researchers exercise when importing and translating concepts and tools from other disciplines would seem to be required. If complexity researchers themselves have not yet reached a consensus on how to integrate and synthesize all the ideas and concepts they bring together from diverse disciplines, it would appear unwise for organizational researchers to charge ahead with the building of models or entire organization theories and management philosophies, drawing a few concepts from one discipline and a few from another based on whatever is convenient or has a nice metaphorical ring to it.

3 Finally, in building firm foundations of and for research, scholars can either begin from a relatively clean slate or they can attempt to build on solid existing research and literature. The former strategy is one more appropriate or even obligatory, we suggest, to the importing of models from well-developed sciences, as the population ecologists did when they introduced that paradigm and research program to organization science. Given that complexity science is still being constructed and many of its concepts have not yet "hardened" and retain a certain plasticity (but perhaps not as much as some authors assumed, as they, according to our reviewers, bent them past the breaking point in certain cases!), there would appear to be opportunities for seeking integration and synthesis between complexity constructs and those in existing organizational literatures. Many concepts and constructs from complexity and organization science are analogous, but is this still the case once the tough work of rigorous definition and operationalization, drawing on existing research, is attempted? What conceptual revisions must be made to integrate them? Are these justifiable? The invention and proliferation of completely "new and improved" models and paradigms may be a

> profitable marketing strategy for consultants, but it is lazy scholarship. The organizational literature is rich with insights about the particular complex systems that are human organizations, and we encourage scholars and practitioners to draw on it.

Our goal in this section is to suggest how researchers might go about building the solid foundations of research that we argue are necessary to thwart faddism. Obviously, we cannot address all the different approaches taken by all the books, nor even the themes common between them. Many of these point in research directions with significant potential for building on existing organizational research, and these are explicitly or implicitly presented in the book reviews. Certainly, the organization development literature seems ripe for integration! Instead, in the spirit of complementing our collection of book reviews, after a very brief introduction to complexity, we limit ourselves here to a discussion of what surprised us, drawing attention to the absence and presence of what we believe to be significant themes. In our discussions of these, we identify promising research directions and literatures on which could be built firm foundations.

COMPLEX SYSTEMS AND COMPLEXITY

Complex systems and the phenomena of complexity have indeed received much attention from the scientific community recently and together have become a broad-ranging interdisciplinary subject (see, for example, Prigogine & Stengers, 1984; Anderson, Arrow & Pines, 1988; Nicolis & Prigogine, 1989; Lewin, 1992; Waldrop, 1992; Kaye, 1993; Mainzer, 1994; Casti, 1994; Cowan, Pines & Meltzer, 1994; Kauffman, 1993, 1995a; Holland, 1995; Nadel & Stein, 1995; Belew & Mitchell, 1996; Arthur, Durlauf & Lane, 1997; and Bar-Yam, 1997). A complex system is a system (whole) comprised of numerous interacting entities (parts), each of which is behaving in its local context according to some rule(s), law(s) or force(s). In responding to their own particular local contexts, these individual parts can, despite acting in parallel without explicit inter-part coordination or communication, cause the system as a whole to display emergent patterns—orderly phenomena and properties—at the global or collective level. The language of complex systems is useful for describing any system that has these characteristics. In some complex systems, the constituent parts are not themselves complex systems and are governed by unchanging rules. In more complicated complex systems, these parts can themselves be complex systems, governed by rules that evolve. Here it is common to refer to the parts as "adaptive agents" guided by "internal models," giving rise to a whole referred to as a "complex adaptive system" (Holland, 1995). In these systems, it is possible for a mutually consistent ecology of parts—along with the internal models and rules guiding them—to emerge from what is effectively a decentralized bottom-up process of co-design. This process is better described with a terminology of coadaptation, colearning and coevolution rather than adaptation, etc.

"Complexity" arises when complex systems approach "the edge of chaos" (Kauffman, 1995a). This is when emergent system-level phenomena generate patterns in time and space that have neither too much nor too little form, and are neither static nor chaotic but are instead interesting due to the coupling of individual and global behaviors. In highly structured stable things like crystals, nothing new can emerge. But conversely, overly random media like fluids or gases are too formless. If our socioeconomic system was like a crystal (i.e. the perfect equilibria of neoclassical economics or the iron institutional cages of structuralist sociology) or like a gas (i.e., a Hobbesian anarchy), then there would be no need for the study of complexity in social science.

WHAT IS SURPRISINGLY ABSENT

Nothing surprises us in this postmodern world. To admit to surprise is to admit to expectations and the archaic practice of making predictions. It is testimony to a failure to embrace uncertainty and an admission of viewing the world through a retrograde philosophy. Well, okay, we're being a little less than serious and a lot less than truthful. We were surprised by both the absence and presence of certain themes, and the previous sentences playfully point to a theme that is definitely there: the linking of complexity to postmodernism and a new philosophical era.

But before we jump to what many view as "softer" approaches to complexity, which by the way we feel could and should have a significant role to play as complexity-inspired tools are applied in the social sciences, we review "harder" approaches from various natural science disciplines contributing to complexity science and related organizational research areas. These have already received some academic and/or research attention by management researchers and offer promise for building firm foundations, but they were, generally, not reflected in the trade books.

Complexity and dissipative structures: adaptive tension

Complexity science has developed to address open systems phenomena that are poorly described by classical Newtonian deterministic laws dictating the conservation of motion and energy, as represented by the 1st law of thermodynamics. Given the 2nd law of thermodynamics, that all ordered states of closed systems eventually dissipate (via entropy) with the system equilibrating towards more disordered states, complexity science addresses and emphasizes those dissipative dynamical open subsystems created or maintained by negentropy and eroded by entropy (Nicolis and Prigogine, 1989; Mainzer, 1994). Locally, these appear to violate the 2nd law, although strictly speaking this is not the case, as the 2nd law still holds at a more coarse-grained scale defined by the boundaries of some closed system (i.e. the "universe"). Negentropic effects that create or maintain order in the form of new structure, and entropic (energy dissipation) order destroying effects within any structure, form the heart of complexity theory.

"[Newtonian] physics deals with an invented, simplified world. This is how it derives its strength, this is why it works so well" (Cohen and Stewart, 1994, p. 12). In this view, the universe is "algorithmically compressible" into simple-rule explanations (Barrow, 1991, p. 15). Cohen and Stewart devote their entire book to a demonstration of how all the phenomena studied by the core sciences using the reductionist methods of Newtonian science pilloried by most of the books reviewed, in fact, are "generated from chaos and complexity" (p. 2). It is not a case of either Newtonian or complexity science. Rather, phenomena amenable to study via Newtonian science can and do emerge as dissipative structures in the region of complexity—at the edge of chaos.

But how do phenomena appear, absent the idealized Newtonian world? Cramer (1993) identifies three levels of complexity. For ease of communication, we change Cramer's "subcritical" to Newtonian; "fundamental" to stochastic; and "critical" to emergent:

- ➨ 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 [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. In what follows we mostly 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 stochastically complex. It is here that natural forces ease the investigator's task by offering intervening objects as "simplicity targets," the behavior of which lends itself to simple-rule explanation. Cramer (1993, pp. 215–17) categorizes all kinds of phenomena according to his scheme.

Self-organizing systems may display and be characterized by any of these kinds of complexity.

Complexity theorists define systems in the emergent complexity category as being in a state "far from equilibrium" (Prigogine & Stengers, 1984). The key question becomes: What keeps emergent structures in states of equilibrium far above entropy, that is, in states that violate, locally, the 2nd law? Prigogine & Stengers (1984) 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, thereby accounting to the 2nd law. Consequently they are labeled "dissipative structures," because they are the sites where imported energy is dissipated. In a Bénard cell the temperature difference between two plates causes the emergence of an organized molecular flow structure that efficiently dissipates the energy gradient created and maintained by experimenters' input of energy. Similarly, the temperature gradient established by the relatively hot surface of the earth and the cooler upper atmosphere drives the life cycle of atmospheric storm cells. Some biologists have even gone so far as to characterize ecosystems and the life therein as an emergent dissipative structure that is going about dissipating the energy gradient between the earth and the sun (Schneider & Kay, 1994a and 1994b).

What causes one kind of complexity to appear and not another? In physical and chemical systems it is all based on energy differentials (or "gradients"). For firms, the "gradient" driving events in firms can be usefully conceptualized as adaptive tension (McKelvey, 1999c). If we define the firm as an open system importing energy-matter and information (in the form of labour, capital, raw materials, etc.), then in successive time slices can be seen to occur a large collection of synchronous idiosyncratic microstate events that cause the system to transition to a new state: they are put to use in creating the kind of activities, accomplishments, and competitive positioning that move the firm towards its goals and hence reduce adaptive tension. In a firm, this tension represents the difference between its current state and activities and what it needs to accomplish so as to optimize its performance, which for many analyses can be assumed to be obtaining a competitive advantage—hence adaptive tension. In addition, it could easily be linked to formal fitness landscape models (introduced in more detail later) by equating the adaptive tension to the fitness differential between a firm in its current position and that of the most fit firm or the global optima of the landscape. Indeed, any optimization model of organization could be considered as a candidate for further formalization.

CEOs need both old and New Science: One conclusion for CEOs that can be drawn from this very brief lesson on complexity science is this: CEOs need to be aware that their firm most likely contains all kinds of complexity. It is hard to imagine that a CEO could manage adaptive tension so well as to face only emergent complexity—hard as he or she might try. It is surely unlikely that a CEO can get rid of all random and probabilistic kinds of complexity. And there is considerable advantage to the stability provided by emergent dissipative structures. Not only do some parts of the organization need to be stabilized so that others can "design around" them (indeed, this is complexity—if whatever emerges then immediately dissipates itself on too fast a time scale, this appears as chaos to an observer), but these transient pockets of stability could very likely behave in ways that are amenable to simple-rule explanations and managerial tools based on simple-rule understandings. Ideally, a CEO would want to create regions of emergent complexity, that in turn generate emergent dissipative structures, *and* which then may be managed successfully with known managerial tools. Who would want it any other way? For example, a standard outcome of emergent structure in firms would be self-directed teams, emergent networks, and cross-functional liaison teams. Once these structure have emerged, we organizational scientists know a lot about how to make them more effective (see Galbraith, Lawler & Associates; 1993; Fisher & Fisher 1998; Kelly & Allison, 1999, for examples).

There are times and places when simple-rule management is possible and when it is not—and these times and places are the result of actions taken to develop competitive advantage. They are not God-given; they are created by CEOs and, as it turns out, quite possibly by almost everyone else in the firm! If a properly functioning region of complexity is created and operating, and dissipative structures come to exist—in these places simple-rule management works. But at other times and in other places, what baseball managers call percentage plays work best. For example, if a nice neat and tidy dissipative structure doesn't exist, managerial tools may work "on average" over a long period of time, but not all the time for every situation. This is the spirit in which Pfeffer (1998) proposes the use of the seven human resource principles that he identifies. Of course, there are inherent risks associated with percentage plays, and CEOs should not let themselves be fooled into thinking that percentage-play management always works in firms, any more than a baseball manager thinks that all left-handed pitchers entering in the bottom of the ninth to face Mark McGuire are going to prevent a home run.

CEOs can manage adaptive tension: Another lesson that can be drawn is this: The region of complexity "at the edge of chaos" is not something that is necessarily "there" that managers have to contend with. It is a region that they may create, consciously or inadvertently, as they attempt to develop competitive advantage. Managing adaptive tension focuses on keeping agents/employees in the presence of information, making them aware of their performance levels relative to those of agents in competing firms. Toyota has done this for years—workplaces are surrounded by charts showing how their output compares with that of other plants and competitors. Adaptive tension is a function of fitness differentials in technology, market effectiveness, cost, novelty, direct competitor comparisons, other plant comparisons, and so forth. One of the best known and effective is Jack Welch's simple rule, "Be #1 or 2 in market share." This simple piece of information defines the area of adaptive tension easily, quickly, and without ambiguity. Another aspect of tension is the felt sense of urgency, i.e., its velocity of change-occurring events. This is the rate at which the CEO and others in the firm seek to reduce the adaptive tension. If a firm is construed as a place where events take place that improve fitness, then, how often do effective events take place? "Management by walking around" is one way in which CEOs have raised metabolic levels. Rates at which emergent subordinate networks "check in" with top leaders are important. Information flow rates can be managed. Rates at which knowledge accumulation, learning, and, as a result, competence improve can be managed. Incentives have a tremendous effect on the rate at which events take place in organizations.

CEOs can manage with an eye to "critical values" of adaptive tension: "Critical values" determine when a system shifts from being explainable (1) by the simple rules of Newtonian science to (2) having self-organizing capability, to (3) behaving chaotically (Cramer, 1993). Nicolis & Prigogine (1989, Ch. 1) offer an overview of 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. A heat (energy) differential created between the plates creates a molecular motion of some velocity, R, as hotter molecules move toward the colder plate. Below the 1st critical value of R (the Rayleigh number), the molecules vibrate in place but "conduct" energy by colliding with each other. Above the 1st critical value of R, the molecules start bulk currents of "convection" movement, as the molecules actually circle around from hot to cold and back to hotter plate, and so on. The system's behavior is qualitatively different. Above a 2nd critical value of R and the molecular movements become chaotic as the system transitions to yet another region of behaviour. Using the Rayleigh number, but with fluid flow around a cylinder, Mainzer (1994, p. 67) offers a wonderful depiction of how the 1st and 2nd critical values create a region of complexity consisting of stable dissipative structures. Complexity science cannot be understood without appreciating the role that critical values of R play in defining the region of complexity "at the edge of chaos."

As a more familiar example, consider the life cycle of an atmospheric storm cell. The level of adaptive tension setting up the heat convection dynamics in a weather system is defined by the difference between the relatively hot surface of the earth and the cold upper atmosphere. At a low level of adaptive tension, heat is slowly transferred from air molecule to air molecule via conduction. Energetic (heated) molecules at the surface more rapidly collide with molecules just above the surface and thereby transfer their heat energy collision by collision to the less energetic molecules—but the molecules stay in their local area, just banging around at each other.

If the adaptive tension increases sufficiently, to the 1st critical value, some mass of air molecules, having become collectively "lighter" than other molecules, will start rising toward the upper atmosphere in bulk, thus setting up a convection current. At this critical value clear air turbulence appears and if the rising bulk of air is sufficiently moist, it will appear visible as clouds as it reaches the cooler upper atmosphere. The "bulk air current" is classed as an emergent structure by complexity theorists. If the adaptive tension between surface and upper atmosphere increases still further, the structures quite predictably develop as thunderstorms. Thunderstorms may be treated as isolated physical structures and are scientifically studied via the analytical mechanics of Newtonian science. In Prigogine's terminology (Nicolis & Prigogine, 1989, Ch. 2), the storm cells are dissipative structures occurring as the result of negentropy—they are created by the energy differential between hot and cold air that leads to rapidly moving bulk air currents, and they serve to dissipate the energy of the hot surface air into the cold upper atmosphere. This accomplished, they dissipate to the point of disappearance.

Suppose the adaptive tension between hot lower air and cold upper air increases further, perhaps by the conflation of warm moist air from the Gulf of Mexico and a cold air front coming down from Alaska, say over Kansas. At some point a 2nd critical value is reached that defines "the edge of chaos." At this point, the point attractor of a deterministic system is replaced by either two or more attractors around which the system oscillates periodically, or a strange attractor in which the system is confined to a limited space by forces defining behavioral extremes (limits) rather than by the attraction of a particular states. In a weather system chaotic emergent structures are things like tornadoes—the system oscillates between tornadic and nontornadic behavior.

Now let's return to our idealized model of the firm as an open system subjected to adaptive tension. Consider a small firm recently acquired by a larger firm. With a low level of adaptive tension created—below the 1st critical value—existing management stays in place and little change pressure is imposed by the acquiring firm. Thus, there might be "conduction" type change events in the sense that new ideas from the acquiring firm percolate slowly from one person to another person adjacent in a network. There would be little tension causing people in the acquired firm to create new structures to speed up change.

Above the 2nd critical value chaotic behavior occurs. Suppose the acquiring firm changes several of the acquired firm's top managers and sends in "MBA terrorists" who have radically different notions of what constitutes satisfactory performance and who attempt to change the management systems "overnight"—new budgeting approaches, information systems, personnel procedures, promotion approaches and benefits packages, new production and marketing systems—along with disruption of the acquired firm's culture and interaction patterns. The sudden increase to a very high tension level is intended to set up a high velocity rate of change so as to reduce the adaptive tension. Lots of change does occur, but given interdependencies of the organization, it leads to chaos: contingencies between changes and their marginal impact on performance mean that positive change events are cancelled by negative change events. No coherent structures for reducing adaptive tension emerge.

In between the 1st and 2nd critical values is the region of Cramer's emergent complexity field. It is also the region where Cohen and Stewart's emergent simplicity concept prevails. Here, structures can emerge to solve a firm's increased adaptive tension problems. In this region, the "energy conduction" of interpersonal dynamics between communicating individuals in a value chain network does not change events at a high enough velocity to reduce the observed adaptive tension quickly enough. As a result, the organizational "storm cells" consisting of "bulk" higher-velocity change events emerge in the form of formal or informal structures—new network formations, new informal or formal group activities, new departments, new entrepreneurial ventures, importation of new technologies and competencies then embedded within the new social or formal organizational structures, and so forth. Their emergence is caused by the contextual dynamics of adaptive response to changing environmental conditions. Having emerged, they generate change event flows of a probabilistically predictable nature.

Brown & Eisenhardt's (1998) discussion is a clever presentation of symptoms for which a CEOs could look so as to see whether the adaptive tension that he or she creates produces regions between the 1st and 2nd critical values. In effect, they begin the tough work of dimensionalizing adaptive tension and organizational R. This is important since critical values are not explicitly determined—as they are in natural science applications of deterministic chaos theory.

Depending on what CEOs observe, they could then turn to managing the adaptive tension level so as to create the region of complexity. That's right! CEOs *create* the region of complexity—they do not just go around looking for it or looking for balancing points between no change and chaos. Emergence in complexity science is due to energy differentials, not environmental chaos. Assuming that the state of the environment figures into how a firm defines performance (the most obvious component of this are competitors' performance levels), then in a truly chaotic environment the adaptive tension "felt" by members of a firm—the agents—would not generate a consistent change velocity lying within a stable complexity region. That is, a chaotic environment means chaotically fluctuating adaptive tension. Emergent dissipative structures cannot solve the chaotic environment problem. Fortunately, complexity scientists suspect that few economic environments are actually chaotic: it is much more likely that they are complex (see, for example, Bak & Chen, 1991; Kauffman, 1995a, 1995b; Bak, 1994).

A key part of managing adaptive tension is checking it against symptoms that indicate that the system is below the 1st critical value or above the 2nd critical value. In addition to those outlined in Brown & Eisenhardt (1998), other symptoms, such as frequent oscillation back and forth across the region of emergence—meaning that agents do not land in the region long enough for emergence to occur—are worth noting. 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. And in addition to focusing on symptoms suggesting when a system is outside the region of emergence, there are also symptoms of emergence itself worth noting. In general, a desired level of adaptive tension produces emergent dissipative structures—structures emerging to resolve adaptive tension, at which point they dissipate. Examples are emergent social networks such as dyadic or triadic communication channels, informal or formal teams, groups, or other network configurations of individuals; at a higher level, more effective networks within or across groups, more networks emerging between hostile groups—marketing with engineering, or with production, with suppliers, with customers, and so forth. They can be emergent networks of any kind—networks that produce novel outcomes, new strategies, new product ideas, new directions of knowledge accumulation, and other positive change events.

Complexity and fitness landscapes: adaptation

The diversity of scientific disciplines within which examples of complex systems can be found means that a rich and diverse range of frameworks, tools and modeling approaches are available. Besides models of dissipative structures presented above, others include spin glass models from statistical mechanics; classifier systems, genetic algorithms, neural network and cellular automata models from computer science; lambda calculus from theoretical chemistry; as well as fitness landscape models based on the mathematics of combinatorial optimization from evolutionary biology. This last tool in particular has a number of interesting conceptual connections to organization science that gives it much potential as a basis for model-building. Metaphorically, firms have long been viewed as organisms, gathering resources from, and adapting to the exigencies of, some environment (Morgan, 1997), and more recently organizational ecologists have imported formal models from biology to explain the forces and variables underlying organizational founding, change and mortality (Singh and Lumsden, 1990). As a result, the notion of organizational fitness is well accepted (Hannan and Freeman, 1977). Though typically associated with selectionist arguments and what is referred to as the environmental school of strategy (Mintzberg, 1990), where it is argued that it is the environment that optimizes the design of key organizational features, the notion of "fit"ness can also be linked to the design school of strategy (Mintzberg, 1990), which makes adaptationist arguments emphasizing strategic choice (Child, 1972) and views firms as actively seeking strategic fit (Andrews, 1971). The opposition of these two arguments is, in many authors' views, artificial (Levinthal, 1991). We draw attention to these connections in the spirit of conceptual integration and synthesis, perhaps achievable to some extent around the notion of fitness, certainly one that has received some academic and/or research attention. This work addresses organizational strategy, adaptation and competition and frequently draws on Kauffman's NK model to explore the managerial issues related to adaptation and strategizing on rugged fitness landscapes.

The metaphor: When thinking about combinatorial optimization, the fitness landscape framework is very powerful, but can appear daunting. Consider the following example which, despite being a bit contrived, neatly captures the essence of the metaphor and helps us point to fitness questions that CEOs can ask and computational experiments with which to search for answers.

Imagine an x–y grid of size 1000 meters by 1000 meters by letting x vary from 0 to 1000 along the west–east axis and let y vary from 0 to 1000 along the north–south axis. Now imagine a landscape—a mountain range for instance—placed on top of this x–y grid, with elevation given by the third dimension, z, rising vertically out of the grid. Now imagine a strategist-mountaineer who is attempting to get to the highest point of the mountain range—to navigate the mountain range—as part of some contest that rewards him with higher payoffs the higher he gets (i.e., in this example, elevation, the value for z, would map into "fitness"), and who starts from a point (x, y, z) on the mountain range landscape chosen at random. Our strategist can move one step at a time west, east, north or south, in one-meter steps, to neighboring positions on the grid. Now, if our mountaineer was an omniscient rational actor—your neoclassical Economic Man—and hence could "see" the entire mountain range, he would head off towards the highest peak (i.e. the point (x,y, z) with the highest value of z), no doubt taking the shortest route in order to minimize his travel time and costs. There is little room for strategy in this case.

But now imagine a situation that better describes that of the strategists in real firms, which is decision making under uncertainty, ignorance and ambiguity, combined with finite temporal and cognitive resources. Imagine that our mountaineer has never visited this particular mountain range before, and, to make things even more difficult, is out on a very foggy day such that his visibility is limited to only one meter away, that he is able to accurately judge, by comparison with his current position, to be either uphill or downhill. Now that his "rationality" is "bounded" and his search confined to being "local," strategy comes into play.

Taking a series of one-unit steps and always moving uphill—a sort of "logical" incrementalism (Quinn, 1980)—might appear to be a sound policy, but in and of itself, is it? If the mountain range you have overlaid onto the x–y grid is a very simple one such that it has only one single high peak flanked by smooth sides (think of Mount Fuji), then eventually, by only moving uphill, our mountaineer would certainly find the highest point. But what if you had imagined a more complex or rugged terrain, with many peaks and valleys (think of the Rockies)? In some movements uphill, our "near-sighted" mountaineer could conceivably be moving away from the highest peak (i.e., the global maximum). If our mountaineer only moved uphill and never downhill, then he might find and get stuck on a peak that is not the highest in the mountain range (i.e., he would have found one of the many local maxima on his fitness function but not the global maximum). His problem gets more complicated if looking (i.e., search or sampling), moving (i.e., adaptation) and remembering (i.e., memory or map building) are costly in terms of resources.

The important strategic questions addressed: There are many strategic options on competitive landscapes. Are all kinds of adaptive moves valuable? Maybe CEOs should just stay put, and exploit their current position. How much exploration of the landscape should one invest in? Is there an optimal exploration/exploitation ratio? Does this change after playing the game for some time? On landscapes with different characteristics? Do the payoffs for steps uphill outweigh their costs? And if CEOs could find a way to overcome the "near-sightedness" imposed by the fog through some remote sampling technique, how far away should they sample? And in which direction should the search occur? Should CEOs attempt to remember the results of their sampling activity and develop a topographic map of the landscape as it is explored? If yes, how much detail should be retained? Answering these questions by playing around with a firm and employee activities is risky and costly. Computational experiments offer a cheap and safe alternative.

Now let's complicate the game a bit more to make it more closely resemble the game being played by real-world strategists who, besides playing a game against "nature" (i.e. the topology) are also competing with industry rivals. Imagine other strategist-mountaineers in the mountain range who are playing the same game and to whom our original strategist's performance will be compared before payoffs are handed out according to relative elevations achieved. Now what to do? And what if every now and again the worst performers are eliminated and new entrants to the game are dropped on to the mountain range and into the competition? And what if while playing the game there is some exogenous shock like an earthquake that shifts the location of the peaks and valleys? Or what if our mountain range is not solidly fixed but is an artificial rubber spongy game surface, such that the endogenous activity of our mountaineer and his rivals walking around it causes it to deform, shifting the location of peaks and valleys?

It is on these phenomena and types of questions that research using fitness landscapes can (and already has begun to) shed some light using formalized models. Firms can be seen to be confronted by a highly dimensional technological fitness landscape (or, more generally, a space defining possibilities for firms' strategic "design" decisions) that they may or may not "know" (i.e., have a map, or causal understanding, linking positions and fitness outcomes), that may or may not be rugged or deforming (i.e., complex). They must devise strategies that place them high on the landscape, relative to their rivals and potential new entrants.

The model: Within biology, a formalized notion of fitness landscapes over a space of discrete objects has been used since the 1930s. Biologists frequently characterize adaptive evolution as the search of a combinatorial space of all possible genotypes for points that map to higher fitness on the landscape using mathematical and computational models of combinatorial optimization (Kauffman, 1993, 1995a). Genotypes (i.e., technologies, or firms) are modeled as "strings" or "chains" of a particular number of genes (i.e., component technological parts, or strategic decisions/value chain competencies), with each link in the chain able to take on one of a finite number of states. A whole made up of *N* parts, for each of which there are *A* possible alternatives, gives rise to a space of *AN* possible wholes—genotypes or technologies—each of which will have a particular fitness in a given environment, with *K* interdependencies between the *N* parts.

Fitness landscapes can vary in their ruggedness (tuned with *K*—more *K* means more peaks and valleys) that captures the number of peaks present (a peak is a point where all neighbors are of lower fitness) as well as the relative fitness of neighboring points (on more rugged landscapes, moves of just a tiny distance in the space can result in dramatic increases or decreases in fitness). Increasing the ruggedness of a landscape is roughly equivalent to increasing the complexity of the optimization problem facing adaptive agents on it. It has been suggested that complex systems—like the technological system that is an economy—self-organize themselves into states of intermediate complexity (Bak & Chen, 1991; Kauffman, 1995a, 1995b; Bak, 1994).

For example, suppose that a notebook computer firm and an opponent exist in a coevolutionary pocket (Porter, 1990) and that they coevolve in terms of a number of technologies (departments), *N*, in charge of, for example, processor and bus speed, motherboard, hard-drive capacity and speed, weight, battery life, display, multimedia capability, upgradability, reliability, and service—each in treated as an agent. Each firm has a level of interdependency, *K*, among its *N* agents. Within a firm, each agent could be a source of a good idea (a fitness improvement) or an impediment (for example, yield on processor speed could be inhibited by a slow bus and poor heat sink).

Recently, the tunable fitness landscape framework has been used to explain a number of important organizational phenomena: learning curves, dominant designs and eras of ferment in technology evolution (Kauffman, 1995b; Kauffman & Macready, 1995); organizational adaptation (Levinthal, 1997a, 1997b; Levinthal & Warglien, 1997); the likelihood of selection forces "optimizing" in an industry and the potential for complexity catastrophes given the interdependencies of firms' value chains (Sorenson, 1997; McKelvey, 1999a, 1999d); the appropriate level of firm complexity to render imitation by others more difficult and less profitable than self-replication (Rivkin, 1998, 1999), whole–part competition within organizations (Baum, 1999), and the "fit" of different archetypal configurations of organizational structure, strategy and leadership with different industry environments (Maguire, 1999). Other questions that consultants, CEOs and researchers may be able to fruitfully explore using such computational approaches are:

- ➨ What is the impact of varying degrees of centralization (modeled as parallelism and decentralization of fitness tests in optimization algorithms) vs the complexity of firms' resource, product and value chain (modeled as landscape ruggedness), or vs firms' environmental stability and dynamism (modeled as landscape deformations), or vs the stage of life cycle (modeled as number of iterations of optimization algorithm already completed)?
- ➨ What is the impact of "error taking" (modeled as the acceptance of changes to a solution string that move the solution "downhill" to lower

fitness) vs the complexity of firms' resource, product and value chain; or vs firms' environmental dynamism (modeled as landscape deformations); or vs the stage of life cycle (modeled as number of iterations of the optimization algorithm already completed)?

- ➨ Are there critical thresholds of firms' "complexity" (modeled as landscape ruggedness) where "adhocracies" gain competitive advantage over machine bureaucracies (modeled with "adhocracies" as decentralized, error-making, optimization algorithms with high allocation of resources to search that continues even after numerous unsuccessful iterations (i.e., with tougher halting rules for search), and with "bureaucracies" as centralized, error-free optimization algorithms with low search)
- ➨ Can too much complexity in a firm's value chain competencies inhibit competitive advantage?
- ➨ Can trying to compete on too many value chain elements all at the same time inhibit its competitive advantage?
- ➨ Do complexity effects suggest an optimal industry size?
- ➨ Are there levels of internal and external complexity that are good for both individual firm and its industry as well?
- ➨ How can managers avoid situations where too much complexity acts to severely limit the adaptive success of his or her firm or the entire industry?

You may see that (1) the enthusiasm of the authors of the reviewed books could run into trouble, if in fact they are successful in inducing emergence—too much complexity could slow down adaptive moves; and (2) they are ignoring all the advantages of adaptive landscape-oriented computational experiments that could save CEOs the danger of taking false adaptive steps. Certainly, the fitness landscape framework offers possibilities for building firm foundations.

Complexity and information: adaptation in ambiguity

Perhaps specifically because the field has attracted researchers from a wide diversity of home disciplines, there is no consensus as to how to define, measure, describe, or interpret "complexity." "It is perhaps well at this time not to define complexity too narrowly, although, in general, we recognize it when we see it." (Morowitz, 1995, p. 4). That there are multiple meanings and uses of this term even among researchers of complex systems is important for organizational scientists venturing into the complexity literature to note. Some lists of distinct definitions include more than 30 entries (Horgan, 1995), although these can grouped into two general clusters.

Information: First, some formal definitions of complexity are pure "information" measures. For instance, one might estimate complexity by the length of the shortest possible description of a system. Note here just how quickly the observer gets tangled up with the phenomena: any description or account of a complex system must occur from a particular perspective, with a particular purpose, and by drawing on particular concepts or variables. To different observers, different aspects of the system will be relevant. For computer scientists, what is relevant may be describing a phenomena (like a sequence of characters or bit string) in order to recreate it, as when printing a bit string for instance, the complexity of which is the bit string's "algorithmic information content." For scientists and engineers, what is relevant about a system may not be its entire description, *per se*, but a description of just the system's regularities, the shortest of which is termed "effective complexity" (Gell-Mann, 1994, 1995). If we consider entities that are seeking to survive, then those regularities that matter to them are those in themselves and in their environment that, once described, can be used for prediction and, with luck, control such that the entity can generate "behavior conforming more or less to the selection pressures in the real world." (Gell-Mann, 1995, p. 17). This is how "adaptive agents" are understood within the discourse of complexity. Be they organisms, humans, or firms, each of these can be seen to be surviving by compressing data and signals into "internal models" or "schema" of themselves, of their environment, and of the interaction between the two, and then "exploiting" these to make predictions and to guide their behavior. Because models are never perfect nor complete, all behavior also has an "exploring" dimension to it as well: it generates more information that can be incorporated into and improve their schema. Selection is multilevel, occurring on the level of internal models and behavior (i.e., learning as selection between competing schema), on the level of the agent (i.e., evolution as selection between competing agents), and perhaps on higher-level "organizations" that have emerged out of the interactions of agents.

Second, other measures of complexity are "time" or "space" measures in that they capture the amount of these required to generate, manipulate or exploit representations of the system. For computer scientists, the "computational complexity" of a task measures the amount of computing time or the computing capacity or the number of computing steps required to execute it. Measures like "crypticity" and "logical depth," on the other hand, capture the effort required to generate knowledge and then to exploit it. "In the human scientific enterprise, we can identify crypticity roughly with the difficulty of constructing a good theory from a set of data, while logical depth is a crude measure of the difficulty of making predictions from that theory." (Gell-Mann, 1995, p. 18) Though they are not, strictly speaking, "information" measures, these time and space measures do clearly refer to activities that involve "information processing" and so also underline the intimate connections between notions of information and complexity.

This "information-processing" view is certainly one that has links to existing organizational and economic research, especially in models built on or derived from rational actor assumptions. This begins with the classic view of hierarchies put forth by Simon (1945) as rational responses to problems of bounded rationality, which is another way of saying that computational complexity exceeds the resources available in one human being over a given time period. The work of Schoemaker (1990), arguing that the potential for rents is maximized at intermediate levels of complexity of strategic problems, implicitly adopts a computational definition of complexity. Research appearing in the journal *Computational and Mathematical Organization Theory* frequently adopts an information-processing view of organizations.

Ambiguity and interpretation: Things are as complex as actors/observers see and make them. This is because any and all measures of complexity are subjective and context dependent. Though absent when it comes to a specific definition, there is consensus on this point: before assessing the complexity of a system, the level of coarse graining and scale of observation must be determined; a certain amount of previous knowledge and understanding about the world must be assumed; and the language used in descriptions of the system under consideration must be agreed (Gell-Mann, 1994, 1995; Bar-Yam, 1997). Hence, defining and understanding what constitutes complexity inevitably involves defining and understanding what constitutes information within, and about, a system: "Since it is impossible to find all regularities of an entity, the question arises as to who or what determines the class of regularities to be identified." (Gell-Mann, 1995, p, 17).

As stated above, those regularities that matter to adaptive agents are those that help the agent to survive: those that can be exploited to increase fitness in the face of the particular selection pressures acting on it. Now, in biological systems, selection occurs in and through the material realm as organisms compete for physical resources that they harness in order to physically reproduce themselves. The process, along with its outcome, is relatively unambiguous.

The situation is quite different in social systems where agents can consciously communicate in order to coordinate their behaviors into structures in time and space, and hence where questions of meaning and interpretation are central to determining "the class of regularities to be identified" and the survival prospects of agents, their artifacts and their behaviors. Survival (or, more generally, the pursuit, defense, and promotion of "interests") in such a system involves discursive struggle (Phillips & Hardy, 1997) over facts, values, meanings, interpretations, and appreciations along—and very entangled—with material struggles over resources. In other words, in social systems, selection processes are not entirely material. They occur at least partly in and through, or are mediated by, the realm of ideas.

Even hard scientists do not escape issues of interpretation, as the challenge of arriving at an appropriate scale of observation and of integrating knowledge across different levels of analysis when describing complex systems is one of the most fundamental facing researchers of complexity (Holling, 1989; Gell-Mann, 1995; Bar-Yam, 1997). Note how the problem of scale opens the door for competing appreciations (Checkland, 1994) of a complex system that differ in terms of coarseness of grain used for observations the system, as well as for time. All of these appreciations can be "true," so truthfulness and appeals to Nature cannot be the standard used to distinguish between them and to allow one to dominate over others. Another standard is required, and the determination of this standard is arbitrary or contingent in the sense that it comes from Society, not Nature. Which appreciation is better will always depend on the observer's purpose and perspective. It is also important to note that, given emergent phenomena, an observer's choice of scale is simultaneously a choice of which variables and concepts to be used in descriptions and representations of the system.

Another important source of ambiguity is revealed by reexamining the definitions of complexity above. It is far from clear whether complexity is a property of the observed system or of the observer's representation of the system, with the latter impossible to disentangle from the observer's purpose. In some sense, complexity may come into existence as particular representational frames are brought to bear on phenomena. This contingency of even "hard" complexity on how a system is known, characterized, and conceived of—on what is treated as, or defined to be, "information" when a system is observed and studied—is not trivial. One suspects that this is especially so for those seeking to model and to explain social phenomena, and who therefore must contend with the representations of other human agents in their models. How complex are these representations? It is also especially relevant to managers, who find themselves within the very social phenomena or complex system that they are seeking to know and to influence.

Power: Organizational researchers do understand the implications of ambiguity. In situations for which multiple competing and contested appreciations of a system, with different actors making knowledge claims, offering evidence, doing analysis, and offering prescriptions, the differential power of actors—social structure—necessarily comes into play in the process by which one perspective emerges as dominant. Decisions and actions are not the outcome of "calculation" nor "computation" but rather of "negotiation" and "judgment" (Thompson, 1967). "Rational" processes are replaced by "political" ones.

That power is being exercised as competing appreciations are filtered or reconciled when goals or ends are contested is relatively obvious, observable and overt. Such a situation leads to negotiation, bargaining and compromise, the outcomes of which favor more powerful actors with control over material resources, almost by definition. But even if there is agreement on goals, competing cause–effect assertions also leads to decision making that can be described as political. When beliefs about means and cause–effect relations conflict, judgment is exercised and, like negotiation, this also inevitably involves power, of a more more covert sort certainly, but discernable nonetheless by investigating such questions as: Who is at the table representing which beliefs? Who has a right to speak and put forward their perspective? Who has discursive legitimacy? Who chooses the concepts and language? Who is viewed as authoritative and deferred to? What are the standards of evidence for knowledge claims? Who is credible and why? Whose interests are served by the acceptance of particular knowledge claims? How are issues framed and what does this imply for potential outcomes? etc. Control over symbolic resources matters here. Critical theorists, sociologists of science, and researchers of organizational politics have been especially successful at identifying, explicating, and coming to grips with this more subtle form of power by researching "ideology," "unobtrusive power" and the "management of meaning" (see, for example, Luke, 1974; Pettigrew, 1979; Hardy, 1985; Alvesson & Willmott, 1992; Hardy & Clegg, 1996). Not everyone is equal when it comes to the construction—or, when appreciations conflict, the negotiation—of reality.

We suspect that much of the complexity experienced rather than observed and measured by most managers today is of a qualitatively different nature than the "hard" complexity that has to date preoccupied complexity theorists and informed most of the theorizing about social phenomena that draws on formal models of complex systems. CEOs can ask themselves this: Are describing, predicting and calculating a course of action to achieve goals their biggest challenges, *per se*, or are they related to generating descriptions and goals that are agreed on, motivating, and actively supported? Similar to the distinction between soft and hard systems that led to the genesis of soft systems methodologies from their systems engineering origins (Checkland, 1994), a distinction may need to be drawn between "soft" or embedded complexity and hard or abstracted complexity, with the former characterizing systems subject to conflicting appreciations by actors with different beliefs, values, goals and interests. Knowledge developed from participants' view inside the system may be more relevant for coping with soft or embedded complexity than that developed from a God's eye view (Hendrickx, 1999). This is because, no matter how sophisticated and advanced formal techniques for problem solving or navigating complex situations become, this still leaves managers with the social and political task of problem defining or negotiating them.

But how should CEOs cope in the face of such complexity? In complex situations of diverse competing values and perspectives, an important job of the managers is conceptual and discursive—to conceive of, frame, and promote certain options by invoking reasons that satisfy those in a position to support and/or block their efforts. Managing within the complexity of human systems requires *reasonable* actors, and not necessarily rational actors. Reasons confer legitimacy and increase the chances that actions, artifacts and firms will persist not because they are in any objective sense "right" or "rational," but because they are deemed legitimate by the group in question. When absolute right and wrong do not exist—or are too complex to be calculated—that which is perceived as right is frequently that which receives the largest amount of support by powerful and credible actors. The challenge to management in situations of "soft" complexity is then to select appropriate evaluation criteria and to secure or enroll visible support (Hardy, 1994). Recalling our fitness landscape discussion, one might say that firms seek to survive in social systems not only via an "adaptive walk," but also via "adaptive talk."

Note also that even if observers of a complex system can agree on an uncontested technical definition of "complexity," can recognize it and hence may feel that they can offer managers "objective" prescriptions, complexity by its very nature may nevertheless lead to "political" as opposed to "rational" decision making. It may not be in everyone's interest to defer to and stop contesting appreciations of complex systems. We suggest that, just as it is in the interests of "rational" actors acting "strategically" to increase complexity (Schoemaker, 1990; Rivkin, 1999) it may also be in the interests of "political" actors acting "strategically" to do so as well.

When an enacted reality bites, so to speak, it is time for managers to at least try to enact another one, and the de- and reconstruction of reality begins with the manufacture of ambiguity. "Crystallized" or "blackboxed" understandings need to be called into question, problematized, and "melted" into some degree of ambiguity, alternatives presented, then the ambiguity resolved via crystallization around an alternative that advances the actor's interests.

Our discussion of power in complex systems, with its emphasis on discursive struggle and representation, makes a good transition point to our final section, where we address themes present in the reviews that surprised us, the first of which is postmodernism.

WHAT IS SURPRISINGLY PRESENT

Having underlined the importance of what is construed to be information in and about a complex system, the potential for ambiguity and the differences between "harder" and "softer" views of complexity, we now turn our attention to certain recurring themes in the books and reviews that surprised us. The first is clearly connected to our discussion of complexity, information, ambiguity, and power. Once again, throughout we attempt to identify promising research directions and literatures that could be tapped in the building of firm foundations.

Complexity, postmodernism and language

A number of authors and reviewers drew connections between complexity and postmodernism. Certainly among the more "academic" books reviewed, all take very, very seriously the connections between complexity and postmodernism, although they do not all reach the same conclusions. In the very first article of the collection assembled by Eve, Horsfall and Lee (1997), Price (1997) presents "The Myth of Postmodern Science," in which he affirms:

> A common misconception about theories of chaos and complexity is that they are in some sense "postmodern science." But the constellation of ideas that falls under the general heading of "postmodern" is typically not positivistic, not empirical—not what we generally conceive as scientific lines of inquiry. Meanwhile, theories of chaos and complexity (hereafter abbreviated "complexity"), while recognizing the need for a modification of the reductionist classical model of science, remain grounded within the "scientific" tradition … Postmodernists want to deconstruct science; complexity theorists want to reconstruct it. (pp. 3, 14)

Similarly, Byrne (1998) dedicates his entire second chapter to addressing "the reality of the complex: the complexity of the real," and endorses the view that:

> Bhaskar's scientific realism provides a philosophical ontology which fits pretty well exactly with the scientific ontology underpinning the complexity programme … Complex accounts are foundationalist, although they are absolutely not reductionist and positivist. It is intended here to argue that they are surely part of the modernist programme, and really always have been throughout the history of that programme. An understanding of this will certainly put the kibosh on postmodernism and post-structuralism. (p. 35)

On the other hand, Cilliers (1998) sees postmodernism and post-structuralism in a much more positive light. Indeed, nearly missed in our selection of books because it does not specifically address management, this book is devoted entirely to the theme of complexity and postmodernism. It turns out to be an especially relevant choice. It certainly stimulated its reviewers!

Cilliers claims that postmodernism, for which he accepts the definition of Lyotard (1984) as "incredulity towards metanarratives," has much to offer the science of complexity, especially in the latter's application to social systems:

> As far as postmodernism is concerned, the argument is simply that a number of theoretical approaches, loosely (or even incorrectly) bundled together under the term "postmodern" (e.g. those of Derrida and Lyotard), have an implicit sensitivity for the complexity of the phenomena they deal with. Instead of trying to analyse complex phenomena in terms of single or essential principles, these approaches acknowledge that it is not possible to tell a single and exclusive story about something that is really complex. (Cilliers, 1998, p viii)

Given these very different views, what is the place of postmodernism in building the firm foundations of research that we argue are necessary? That New Science flows from, will give rise to or—perhaps more appropriately causally indeterminate—coevolves with new philosophies is certainly plausible. There is no debate that complexity scientists work with new methodologies, with computer-based simulations perhaps the most clear examples. But what of ontology and epistemology? Does complexity imply changes to these as well? And if so, is it to the ontology and epistemology of postmodernism that complexity researchers should turn?

Skeptical about skeptical postmodernism: We invoke a valid claim by postmodernists that meaning is multiple, ambiguous, and plastic: the answers to these questions depend on what is meant by postmodernism, a term that has become so popular and variously used as to be almost meaningless, with some suggesting that there may be as many postmodernisms as there are postmodernists (Featherstone, 1988). Nevertheless, two distinct styles or ideal types are frequently distinguished: the skeptical and the affirmative (Rosenau, 1992; Kilduff & Mehra, 1997). The first is relativistic and ontologically nihilistic. This strand of postmodernism is one from which Cilliers specifically disidentifies himself and is surely part of what Price and Byrne have in mind when they argue that postmodernism has little to offer complexity science. "The acknowledgement of complexity, however, certainly does *not* lead to the conclusion that anything goes." (Cilliers, 1998, p. viii, his emphasis). As Cilliers sees it, this version of postmodernism derives from a severely limited understanding of Derrida (1973, 1976, 1978). As we see it, authors argue correctly against this postmodernism: it has little to inform scholars trying to connect complexity and management. The relativist postmodernists claim they want all discourses to flourish, although why they should care is not clear, as each is as valid as the next. As Putnam (1997, p. 114) notes, relativist or skeptical postmodernism is self-refuting. If all views are relative and equal holders of "truth," prioritizing relativist discourse over others violates their own rules!

Affirming affirmative postmodernism: Cilliers (1998) advocates a less nihilistic and more affirmative strand of postmodern thought: he is not seeking to undermine science and to replace it with a patchwork of narrative knowledge. Describing the connections he makes between connectionist approaches to complexity and his version of postmodernism, he underlines:

> [T]he focus will be on the affinities between complexity theory and post-structural theory. The reason for this is that I wish to steer clear of those postmodern approaches that may be interpreted as relativistic. The central arguments will come from (mainly the early) work of Jacques Derrida (1973, 1976, 1978)—a position that can only be termed 'relativistic' by the ignorant … My argument is that post-structuralism is not merely a subversive form of discourse analysis, but a style of thinking that is sensitive to the complexity of the phenomena under consideration. Since science can benefit from such an approach, the relevant ideas must be made accessible to scientists. (p. 21–2)

> Post-structuralism has a more "playful" approach, but this attitude has nothing childish or frivolous about it. When dealing with complex phenomena, no single method will yield the whole truth. Approaching a complex system playfully allows for different avenues of advance, different viewpoints, and, perhaps, a better understanding of its characteristics. (p. 23)

Cilliers argues that (1) for scientists, poststructuralism generates variations or novel ideas that can only complement the selection process of falsification; (2) for philosophers of science, poststructuralism focuses their efforts on practical results and their implications rather than the generation of an abstract metanarrative that has to legitimate scientific knowledge; and (3) for both of these groups, poststructuralism draws attention to important issues too often ignored by normal science that are linked to the unavoidable contingencies of choices of methods and, once chosen, interpretation of results generated through them (see p. 23). At a minimum, we believe that Cilliers' book, along with other postmodern work that is not ontologically nihilistic, should be interpreted using the principle of charity that is recommended by those adopting hermeneutic approaches (Hendrickx, 1999). We make no pretense to having answers, but we do feel that, so early in a new research program, scholarly discussion, and not dismissal, should be encouraged.

Indeed, it is in this spirit that we have developed our discussion. The easy route would have been for us to ignore the strong postmodern theme in the trade books and call for more formal models, mathematical analysis and computer simulations. But to ignore surprise is to destroy information. Reflecting on this postmodern theme helped us to develop our ideas on the intimate connections between complexity, information and ambiguity.

In strong contrast to the academic books of Eve, Horsfall and Lee (1997) and Byrne (1998), the trade books celebrate postmodernism. Among them, Sherman & Schultz (1998) go the furthest in making the connection between complexity and postmodernism, stating that "Developments in the sciences of complexity and relevant disciplines (such as mathematics, logic, epistemology, ontology and information theory) tend to supplant the foundational belief systems of traditional science and the methodologies derived from them" (p. 207). They advocate the "integrating beliefs and methodologies" of "postmodern management." They adapt Einstein's views on the reciprocal relationship between science and epistemology to conclude that "Business without epistemology is—insofar as it is thinkable at all—primitive and muddled" (p. 28). The main prescription that flows from this is that an organization should challenge what it holds sacrosanct, that is, its metanarratives. And "when an idea is obsolete, the organization must have the courage to discard it, even if it has been successful in the past" (p. 28). Ideas are foundational; a firm's behaviors rarely go beyond what the ideas/models held by its members make possible, but their ideas can and do go beyond prevailing firm behaviors. In their appendix on postmodern management, Sherman and Schultz claim that innovative behavior in organizations can be characterized as a shift in thinking from modern beliefs and methodologies to postmodern beliefs and methodologies. For them, success and failure have cognitive roots. To change your fate, change your mind!

Excellent advice, if interpreted using the principle of charity in an ontologically non-nihilistic manner. Sherman and Schultz, like Cilliers, are not claiming that "anything goes," but they are raising the possibilities that "something else might go" and "it might go even better!" Scientists, when "in action" (Latour, 1987) put this principle into practice all the time. Nor are they claiming that nothing but language, metaphor and discourse forms the organizational world. Complexity scientists would appear to hold a very similar view: agents' internal models matter (they are real in their outcomes, as social scientists are fond of saying). Kauffman (1996) refers to plans and forward planning horizons as "part of the real furniture of the universe" (p. 132). They affect its unfolding into the "adjacent possible."

Sherman and Schultz and others writing on complexity and management (e.g. McMaster, 1996) also emphasize language and representations, another theme that has emerged in this special issue. This view implicitly accepts that local narratives—and not grand scientific theory—spurs human agents to action. Language and narrative are very much managerial tools. They can be harnessed for effecting action through agents' existing internal models, or for manipulating those internal models and direct their evolution. This is indeed a line of research that is promising and should be encouraged. Note, though, that it is not new and that there are foundations to build on.

On the importance of new ideas and challenging assumptions, much work has been done, including March's (1991) work on exploitation and exploration that studies the effects of mental models of heterogeneous agents in a firm, or Miller's (1990, 1993, 1994) on how success may breed homogeneity and eventually the Icarus Paradox. With respect to communication and narrative, Simon (1945), Cyert & March (1963) and many others have for a long time described management's job as involving the bounding of employee's rationalities, although this work has tended to work with more objectivist notions of "information," "information flows," and "information processing" instead of the more subjectivist notions of "texts," "communication," and "interpretation," "sense making" or "production of meaning," as does more recent work adopting a postmodern stance (Reed & Hughes, 1992; Hassard & Parker, 1993; Chia 1996; Calas & Smircich, 1997; Barry & Elmes, 1997).

Behind the unease that even affirmative postmodernism causes in many scientists who hold on to the ideal of a consensual Truth lie a couple of issues. One important one is representation, along with the related phenomena of language, discourse and meaning, and its relationship to reality. Scientific knowledge, constituted by and through language, can be described as a complex, robust system that helps humans to cope with the world. But unfortunately, "There is no place outside of language from where meaning can be generated. Where there is meaning, there is already language" (Cilliers, 1998, p. 43). Generated from the complete system of differences that is language, scientific knowledge does not—indeed, cannot—isolate itself from political and social traces. Observation is interpretation. Another divisive issue is consensus, an "outmoded and suspect value" (Cilliers, 1998, p 137) according to postmodernists who embrace diversity and see value in competing discourses. But whereas the relativists among them cannot care which interpretations flourish, affirmative postmodernists and poststructuralists who adopt a less nihilistic stance do care and care very much. If "hard" complexity scientists interpret affirmative postmodern work using the principle of charity, they may very well conclude that the authors are sincere and serious human scholars who just happen to be highly sensitized to the inseparability of Knowledge and Power. It is not so much claims to Truth that make many social scientists suspicious of natural scientists' program, it is claims to a singular and neutral Truth. A God's eye view may be a desirable ideal but it is unattained and unattainable. And there are alternatives to the extremes of absolutist objectivism and unfettered relativism. For example, Harding (1992) argues for science that aims at "strong objectivity," an approach to knowledge that has explicit strategies for gaining causal critical accounts of what is dominant.

Perhaps the plasticity of meaning can help to transcend the gap. Explaining language without invoking a metaposition does not lead Derrida to the conclusion that talk is all there is to reality, nor that anything goes. Meaning is plastic, but it is certainly not random nor arbitrary: it is a phenomena that is local in time and space. Never totally anchored, it can and does demonstrate pockets of stability. Meaning can be stretched, but only so far.

Complexity, humanism and ethics

Finally, there appears to be a significant coalition forming among both authors and reviewers within the "complexity and management" community emphasizing and promoting "humanist" organization development. Several authors invoke complexity science to authorize and legitimate increased worker freedom, tolerance, the acceptance of dissent, increased communication, sharing of information, and such things as the building of emotional involvement, personal commitment, community, etc. In addition, the phenomena of trust and social capital reappear in books and reviews. Whether complexity science, in fact, supports these claims is moot at this juncture. We enthusiastically encourage empirical investigations corroborating or refuting these claims. Otherwise, they risk being dismissed as a wish list of well-meaning New Science consultants.

The connections between complexity science and ethics certainly merit attention. One basic question appears to be: If control is distributed, where is the locus of responsibility? Prevailing notions of responsibility seem inextricably bound up in linear notions of causality—although the symbolic role of management has been noted and addressed in the literature for some time (Pfeffer, 1981; Hardy and Clegg, 1996). In addition, the management of meaning that comes with harnessing language, discussed above, cannot be undertaken lightly. If, as some authors and reviewers suggest, such things as fundamental as agent and system identity are to be manipulated and managed, care must be taken. Power must be exercised responsibly. The end of Cilliers' book includes a brief discussion of how New Sciences require new ethical reflections for human systems.

CONCLUSION

Our discussion in this paper is no substitute for reading the reviews in this Special Issue, an activity that we strongly encourage. They are fun to read, very informative, have insightful conclusions, and portray a vision of how complexity science, as applied to managerial activities, might best go forward. It is a tall order to attempt to conclude in a few lines all their insights.

The books generally aim to help CEOs cope with rapidly changing, nonlinear, chaotic environments. They rail against Newtonian deterministic science and command-and-control styles of running organizations. A rash of new terms are presented from New Science, that is, chaos theory and complexity science. The books focus mainly on deterministic chaos, complex adaptive systems, self-organization and emergence, autopoiesis. Hierarchies are flattened, power decentralized, empowerment encouraged, and ecological and organic metaphors abound. Most books are described as excellent in their use of illustrations from real organizations. Many offer various techniques and methodologies—many drawing on ideas from the organization development literature (French, Bell & Zawacki, 1989) for actually changing organizations to make them more humane as well as adaptive to chaotic environments.

Not unexpectedly, the complexity gurus are most upset with how complexity science terms are loosely, if not metaphorically, defined and tossed into our managerial discourse—one goes so far as to suggest that the book offers many insights for managers but one should simply black out all references to complexity science. They some other reviewers worry about "loose definitions" and applications, "oversimplification," "incorrect use of concepts," "superficial" treatments, lack of research, and missing the computational modeling underlay of complexity science. On the other hand, many reviewers think the authors handle the application with deftness, insight, and front-line accessibility to CEOs. Descriptors like "disappointing," "valiant attempt," "satisfactory," "worth reading," "good light treatment," "and few insights for researchers," are used to characterize the books. Reviewers applaud the use of empirical illustrations, case histories, and front-line experience of many authors. Attempts to characterize the business world in complexity science terms, use insightful metaphors, all with an emphasis on humanism, are greatly appreciated.

After studying all of the books and reviews ourselves, we can identify some fundamental aspects of complexity science that did not receive the attention that we felt they deserve. What should CEOs know about New Science applications to firms that seems missing from the books? There are actually multiple kinds of complexity—random, probabilistic, deterministic chaos, emergent complexity, and Newtonian dissipative structures. The books zero in on the "edge of chaos"—one side being the region of emergent complexity; the other being deterministic chaos. All types exist in firms. While it is possible that the region of emergent complexity can appear unbeknownst to CEOs, more telling is the realization that CEOs actually can do much to alter the adaptive tension that is the engine producing the region of complexity between the 1st and 2nd critical values of R—the Rayleigh number. Though the books are fairly good at telling CEOs how to identify some of the symptoms of the kinds of complexity they face, they lose sight of the fact that CEOs can actually create emergent complexity by going to work on managing the adaptive tension engine. We mention some tools that CEOs might consider using.

Complexity science and computational modeling go hand in hand. This is because the platform assumption of stochastically idiosyncratic agents (conversation elements, people, departments, etc.) and nonlinearity are more easily tolerated in computational models, and the preferred larger number of variables makes math intractable. Consequently, complex adaptive systems have come to be studied using computational models of adaptation on fitness landscapes. There are many of these, with Kauffman's (1993) NK model becoming the most prominent application to firms. Asking CEOs to try to introduce and work with complexity concepts in their firms without the experimental opportunities afforded by computational models is like asking people to climb Mt. Everest without oxygen—it's possible, but just barely. CEOs are expected to come up with adaptive solutions to rapidly changing, nonlinear, and complex environments at considerable risk and cost if the solution fails. Surely scientists, consultants, and authors should take the lead in adding computational based experimental approaches to the CEO toolbox.

Saying that there are five kinds of complexity is easy. Complexity science is a nascent, fluid, rapidly development discipline. There is disagreement on how best to define complexity. There are information—bit string—approaches from computer science and time and space measures that focus on the effort or time required to unravel the crypticity or hidden complexities and form a conception and/or "theory" about a system's complex character and functioning. And whether a hard social reality exists or not, there is also the question of individuals' subjective interpretations of complexity and complex systems, the social construction of same and, within complex systems comprised of humans—including scientific communities—how the relative power of different players can affect these. We feel that the books tend to lead CEOs to believe, mistakenly, that complexity is easily discerned and interpreted, that this unfolds in social systems where beliefs and values are not contested, and that those people with the most power, such as CEOs, also have the most correct insights and interpretations of the complexity indicators—surely an unlikely prospect.

Intellectual fads ride the tide of exuberant application of new ideas, mostly by consultants, and soon sink into oblivion, absent quality research. Consulting applications based on nothing but the hottest, most recent intellectual novelties suffer quick fates once a new marketing tool appears on the horizon—unless research findings corroborate the lasting efficacy of the older idea. From what the reviews indicate, as well as our own reading of the trade books, New Science is well on its way toward short-lived faddism unless serious research shows there is more than metaphor to chaos theory and complexity science applications and that CEOs using New Science produce more competitively advantaged firms than CEOs who do not. We need computational experiments showing that interventions inspired by New Science improve performance, and clarifying under what conditions. We also need real-world empirical tests that show that the computational models pass the ontological test—model behavior fits real-world behavior. Other, noncomputational applications need also to be supported by empirical research. And we do not need to start from a clean slate: we need integration and synthesis of the complexity-inspired constructs with solid existing organizational research. Absent all this, and New Science seems unlikely to get past faddism.

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