Human Systems Management 23 (2004) 71–78
IOS Press

The complexity of the corporation

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Abstract. We discuss the notion of complexity as applied to firms and corporations. We introduce the background to complex adaptive systems, and discuss whether this presents an appropriate model or metaphor to be used within management science. We consider whether a corporation should be thought of as a complex system, and conclude that a firm within an industry can be defined as a complex system within a complex system. Whether we can say that the use of complexity research will fundamentally improve firm performance will depend on the effect on success derived from its application.

Keywords: Complexity, complex adaptive system, emergence, agent-based models

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1. The genesis of complexity science

Organization science has long been constrained by models of industries and competition that are static and linear in nature. Complexity science is a relatively new way of thinking about systems of interacting agents such as firms, a methodology that can be used to create non-linear, dynamic models. Complexity thinking and complexity research have however only recently been applied to management science, and its application in this domain is still in its infancy. The application of the logic of complexity research to organizations is not a straightforward process: one of the reasons for this is that there is no widely accepted definition of what complexity actually *is*. Similar to management science in general, with its parent disciplines of for example economics, sociology, and psychology, complexity science draws on linkages to research in its many parent disciplines: condensed matter physics, social science, politics, evolutionary biology. Some, if not all, of these concepts can be borrowed from or at least be demonstrated using these disciplines in order to give insight into the ways that organizations can and should behave in a complex environment. The research being done in complexity applied to organizations may also have the benefit of repaying its debt to the corpus of research in complexity, thereby reinforcing the building of complexity as a research agenda that transcends traditional boundaries between research disciplines. This transdisciplinary nature of research institutions devoted to complexity has allowed collaborations between researchers from very different research backgrounds, giving fresh insight and potentially novel contributions to management research.

A precursor to the understanding of complexity science was the research into the phenomenon of "chaos". Chaos theory [16] was fundamentally the demonstration of unpredictable behavior from deterministic rules – this differs from complexity science in that complexity science can describe *order* from a system of interconnected agents. One of the indicators of chaotic dynamics is that systems have critical dependence on initial conditions: small perturbations in the starting conditions of the system can cause completely different behaviors into the future; the often-cited metaphor of Lorenz [24] used to illustrate chaos theory is that a butterfly flapping its wings in Brazil may cause a storm in Texas, a perturbation as small as that caused by a butterfly can cause the weather system to change fundamentally. Indeed, the concept of chaos has found its way into the management literature [23]: "chaos theory provides a useful theoretical framework for understanding the dynamic interaction of industries and the complex interactions among industry actors". Treating organizational systems as chaotic systems leads to propositions of how to conceptualize an industry: long term planning is very difficult, industries do not reach a stable equilibrium, dramatic change can occur unexpectedly, and short-term forecasts and predictions of patterns can be made [23]. Little evidence is proposed to state that an organization or an industry *is* a chaotic system, and this stream of research has received relatively little attention in recent years. However, what such an approach does is to present a counter-approach to the pervasive economic-inspired models within management that propose equilibrium, stability, and the benefits from undertaking long-term planning to produce strategies that may provide the panacea of sustainable competitive advantage. The concept of chaos, when treated as a model rather than a metaphor, is of relatively limited value within management science, as regardless of managers' interventions, the system being critically dependent on initial conditions (including perturbations that may not be under the control of managers) will in the long term result in unpredictable and chaotic behavior. The reason that the promise of treating industries as chaotic has not produced tangible results may be due to the difference between chaos theory and complexity: the former is concerned with *un*predictability, whereas the latter is concerned with *order*, which is expected to be within the control of managers.

2. Complex adaptive systems: concepts

Complexity as a concept is a relatively recent study, having been transferred into the organizational domain from research in natural science. There is no universally accepted definition of the concept, partly due to the disparate range of disciplines within which the phenomenon has been investigated. Axelrod and Cohen [1, p. 7] define a system as being *complex* when "there are strong interactions among its elements, so that current events heavily influence the probabilities of many kinds of later events". Holland [17] sees complexity as exhibiting order creation generated from simple specifications.

The concept of *adaptiveness*, the biological definition being "organic modification by which an organism or species becomes adapted to its environment" [28] is defined, according to Axelrod and Cohen, as the outcome of a selection process that leads to an improvement according to some measure of success. Although systems may be complex, and possess adaptive properties, not all complex systems are complex adaptive systems (CASs), for instance, systems can exhibit chaotic behavior but this does not imply that the system is a complex adaptive system.

The definition of complex adaptive systems is a notoriously difficult one. However, it is possible to elucidate certain themes that indicate the concept. The social world around us, and the world that corporations inhabit is essentially a non-linear, non-equilibrium system. However, most economic models of organizations assume solutions based upon the premise of equilibrium (even if it is a dynamic equilibrium) being present in the system. Axelrod and Cohen [1, p. 15] emphasize the difference between a system that is complex and one that is complicated, complicated being defined by them as comprising many elements within the system, complexity indicating that the system "consists of parts which interact in ways that heavily influence the probabilities of later events", often resulting in *emergent properties*.

2.1. Emergence

The existence of emergent systems is an important phenomenon within a certain class of complex adaptive systems [17]. Perhaps Holland makes the most basic and profound definition of emergence: "much coming from little": the concept of patterns in the system as a whole *emerging* from simple rules. Emergence can perhaps most easily be demonstrated by the use of agent-based models, a concept that is discussed below. Central to the notion of emergence is the understanding that global properties of a system emerge from the *local* interaction of the agents within the system.

2.2. Co-evolution

Co-evolution (Fig. 1) is a concept based, as much of complexity research, in the natural sciences, particularly in biological science. The concept of co-evolution among species was introduced by Ehrlich and Raven [11] who observed that certain species of butterflies and plants evolve simultaneously, each adapting to the other species. One of the descrip-

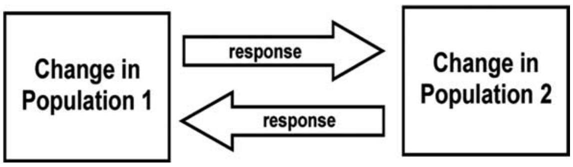

Fig. 1. Schematic representation of co-evolution.

tions of this phenomenon is "stepwise evolutionary responses" [11, p. 606], coevolution defined more recently from an evolutionary biology perspective by Janzen [18, p. 611]:

> "an evolutionary change in a trait of the individuals in one population in response to a trait of the individuals of a second population, followed by an evolutionary response by the second population to the change in the first".

2.3. *Power laws and self-organized criticality*

Bak [5], Bak and Creutz [6], and Bak et al. [7] discuss the concept of self-organized criticality. As an example, if we have a sandpile, and we add sand one grain at a time to the pile, there eventually comes a point where an avalanche occurs, and the system changes from a stable system to an unstable one. Furthermore, if we analyze the size distribution of these avalanches, we observe that the sizes of the avalanches obey a power law distribution (of the form $y = \beta x^a$), these power laws are exhibited in many self-organized systems, leading to the metaphor of the system being "on the edge of chaos". Importantly, chaos *does not* explain the behavior of such systems – and hence the manifestation of complexity as a research stream separate from research into chaotic behavior. Power law distributions have been observed in management, for example Axtell's [4] empirical observation, using data from the entire population of US tax-paying firms, that the size distribution of firms follows a power law. The empirical data are supported by an agent-based model [3] that recreates the power law distribution of firm sizes.

3. The corporation as a complex adaptive system?

Axtell [3] provides a model consisting of a population of heterogeneous agents with preferences for income and leisure, increasing returns to cooperation, where the agents select effort levels that maximize their individual welfare. These agents may migrate between firms or start up new firms. The dynamics of this model produce a distribution of firm sizes consistent with the empirical data of US firm size and it is therefore proposed as a model of the emergence of firms. The corporation as as a complex adaptive system is proposed by authors such as Boisot and Child [9] who consider organizations to be "adaptive systems that have to match the complexity of their environments". Stacey [36, pp. 23–50] states boldly "organizations are complex adaptive systems", when referring to the interaction of human networks within organizations. Stacey views individuals as agents within an organization, emphasizing that the *internal* aspects of the firm are important. However, the organization does not act in isolation independent of its competitors and its environment. In order to clarify whether corporations are complex adaptive systems, we can go back to the basic definitions of complex adaptive systems. If we consider a corporation to be a single entity, then a firm fails the first criterion of being a complex system: there being only one element, it is impossible to define a singular corporation as complex. We may however go deeper into the organization and consider individual agents to be managers and staff, decisions and rules, products and production: only then may we consider the corporation to be complex. However, viewing a corporation merely as a single entity (albeit comprised of a complex system of agents) ignores one of the fundamental properties of firms – their competition with other firms. As for whether the corporation is adaptive, this is dependent upon the organization that we are considering: if the firm succeeds, then it is possible that the organization that we are considering has adapted to its environment. Should the organization fail however, it is unlikely that the firm that we are considering has adapted to its environment. We can further consider whether the organization is a *system*: and once again we find that if we use a macro-level approach and consider the corporation as being a single entity, then this fails the notion of a system in that one single entity cannot interact and therefore does not form a system. We have therefore to be thoughtful of our definition of the firm. If we focus too narrowly on an individual firm without consideration of the environment, then the application of complexity to a single unitary firm may be misguided. To define a corporation simply as a complex adaptive system is rather a crude approach: we need to be careful with such sweeping definitions and rather *specify the level of analysis* at which we consider our system: what are the agents that make up our system? We may be interested in the interaction of individual members of a firm: in which case, we may be looking, as a sociologist might, at the politics within a firm; we may be looking at the macroscopic properties of an industry or an economy as a whole, rather in the way an economist would view the problem. If however we are looking at the competition of firms, we need to consider that to be our system. This is not to say that we cannot look at the emergent properties of an organization: individual actors within a firm may make decisions generated from a decision making process. Individual decisions of employees may contribute to an overall decision of the strategy of a firm. In Bak's [5, p. 60] analysis of sand pile avalanches, he comments "in the critical state, the sand pile is the functional unit, not the grain of sand". This is an important point in whether we consider the firm or the organizational environment to be a complex adaptive system. If we are to observe criticality in firms (analogous in this case to grains of sand that *comprise* the system), the functional unit becomes the industry, or more generally the organization's environment. If we are to consider a firm in isolation, then, there being only one "agent" in the analysis, it is impossible for the organization to be a complex adaptive system. If however we are to consider organizational systems as being complex adaptive systems, it may be more appropriate to consider the firm's *environment* as a complex adaptive system, rather than the firm itself.

4. The corporation as an agent *within* a complex adaptive system

The notion that corporations may be agents *within* a complex adaptive system – the industry or environment within which a corporation operates – may be a better way of thinking about the corporation. This does not exclude the fact that we may have agents (such as employees) within other agents (firms) within our system, making up a nested hierarchy of agents. Let us first review the concept of complex adaptive systems within the context of a number of firms creating a system. We can investigate this proposition by referring to the base definitions of a complex adaptive system. Firstly, is the system complex? Using Axelrod and Cohen's definition of a complex system, where there are strong interactions amongst a system's elements, we can see that this will apply only in certain circumstances. If we consider the elements of a system to be organizations, strong interactions between firms occur only in certain situations. In a monopoly, for example, there are no interactions between competing firms within the industry, and therefore, on an inter-organizational level, one cannot define the system as complex. However, if we broaden our definition of this system in which an organization operates to include regulators, consumers, other markets and industries, then it is possible that the system is complex. However, in a strict analysis of a monopoly, there are no interactions between firms and therefore the proposition fails.

Secondly, we can return to Axelrod and Cohen's definition of adaptation: where a selection process leads to improvement. This definition will also only apply to certain firms. If a firm reduces its profits or market share or fails, then such firms will not meet the definition of adaptation. However, for successful firms, we would expect that these firms adapt to their environment (the environment being the system of competing firms) and thereby increase their profits, market share, or other measure of success. So, we cannot produce a general definition of all firms being adaptive: if we consider a market to have a constant level of profit to be divided by a constant number of firms, then by certain firms adapting to their environment necessarily means that some competitors will not have adapted to their environment. Unsuccessful firms may however be selected out of the system.

Axelrod and Cohen's definition of Complex Adaptive System, where "a system contains agents or populations that *seek* to adapt" (emphasis in original) applies to firms with a profit-maximizing motive, in that they define their measure of success to be increasing profits.

But not all corporations *do* adapt to their environment – and without such firms there would be no adverse selection, a central tenet of complexity. What is important for managers is to ensure that, if the environment is indeed a complex adaptive system, they are the managers of firms that do adapt to their environment and that they are not the firms that are selected out of the environment and fail.

5. Metaphor

Several authors have made the use of complexity metaphors and analogies to provide a basis for bringing such thinking into organizational research and practice. Stacey [36] and Stacey et al. [37] give a general overview of complexity approaches within a managerial context; Shaw [33] discusses a complexity approach to organizational change; while Kelly and Allison [20] use complexity thinking as a metaphor for businesses to "achieve peak performance". However, the notion of using complexity theory purely as metaphor has been challenged by authors such as Fuller and Moran [14] who criticize the use of complexity metaphors without the notions being grounded within organizational research.

Brown and Eisenhardt [10] use the metaphors such as the "edge of chaos" and "continuously deforming landscapes" to propose rules for managers where strategy is seen as "structured chaos". Whilst there is scope for using metaphors of complexity science, to rely on metaphor alone can mean that some of the insights of complexity science are not demonstrated. Whilst metaphors may make complexity notions more accessible, there is no substitute for investigating models that demonstrate complex behavior – models that themselves are complex adaptive systems – in order to understand the notions of complexity science more comprehensively. Metaphors may also be applied incorrectly, where for example a firm being described as being adaptive is not related to the underlying relationships between the firm and its environment – for example where the firm has been successful purely as a result of good fortune. If we rely too heavily on using metaphor where it is inappropriate, we run the risk that managers may take decisions based on their understanding of their environment based on metaphorical representations of their business environments whereas their actual environment may be benign (for example in a monopoly situation) and not in fact a complex adaptive system at all. Here, the concepts such as adaptation may be inappropriate and may actually produce a result that is detrimental to the firm.

5.1. Co-evolution

The concept of coevolution occurring within an organizational framework has been discussed by authors such as Van den Bosch et al. [38] who describe the coevolution of firm absorptive capacity and knowledge environment. Such work builds on the introduction of the metaphor of coevolution into the parlance of management scholars by authors such as McKelvey [26]. Eisenhardt and Galunic [12] use the metaphor of coevolution and apply it to synergies between different internal divisions of a firm, applying the metaphor to the case of a Walt Disney film that provided spin-offs to merchandising, theme park attractions, and musicals without the need of central planning function within the firms fostering these intra-firm collaborations.

5.2. Adaptation

Boisot and Child [9] view organizations as "adaptive systems that have to match the complexity of their environment". Morel and Ramanujam [27] consider organizations to be "adaptive and evolving systems". We must however not consider firms in isolation from other firms – the organizational environment is that comprised of competitors, it is insufficient for organizations to consider adapting without reference to the other agents in the system. If this is not done, this may cause negative selection pressures and the subsequent removal of that firm from the system, if indeed the system be complex and adaptive or otherwise.

6. Models of complexity within business: agent-based models for management theory

Conceptual models of competition between firms have been developed to provide new insights methodology of how inter-firm competition is perceived [30]. The advantage of using agent-based models over "traditional" models of strategy (such as those from economics) is that each "agent" (for example a firm) within the model can be autonomous: there is no requirement for such simplifications as the "representative firm". There is also no requirement for equilibrium to be present within the model; dynamic models are also easily presented within the agent-based framework.

Rivkin [29] has used agent-based modeling to introduce a theory where the interconnectedness of organizational decisions within the firm is explored. Rivkin makes use of the *NK* model, a model introduced into management science by Levinthal [21] that builds on a model of evolutionary biology introduced by Kauffman [19]. Much of the research that has been done on complexity and management has been focused on such "landscape" models: in a 1999 special issue of *Organization Science*, nearly one quarter of the submissions to the issue referred to Kauffman's *NK* model [2]. The *NK* model is such that it generates a complex model, where *N* represents the number of elements within the system, and *K* represents the level of interrelatedness within an entity. However, these models are not the only way to generate rugged landscapes, Levinthal and Warglien [22] review landscapes in general: particularly, they advocate tuning the interactions between actors to influence the landscape on which firms are situated. They use Kauffman's *NK(C)* model, which introduces linkages across entities in order to introduce a level of co-evolution between organizations. McKelvey [25] discusses some of the weaknesses of the *NK* model, particularly that the "fitness" of the system is defined as the average of the fitness of the components of the system; the assumption in Kauffman's model that every node within the network has the same number of inputs is also criticized.

The import of such an evolutionary biology model into management is an example of where complexity science is transdisciplinary – models introduced to explain concepts within other sciences, natural or social, can transcend traditional disciplinary boundaries, and can provide new insights for investigating problems within management science.

The discussion of agent-based models has been widely discussed, and other models presented from other social science disciplines by authors such as Epstein and Axtell [13] and Gilbert and Troitzsch [15]. Robertson [31] provides an analysis of how agent-based models can be used in the specific discipline of management science. Agent-based models are perhaps one of the best ways of demonstrating the phenomenon of emergence. For instance, Schelling's [32] early model of segregation of a population according to the tolerance of the color of agents around them, a model of emergent behavior described by Schelling as "micromotives and macrobehavior", demonstrates that segregation – a property of the system as a whole – arises out of the purely local interaction between agents within the system without a central regulator implementing a segregation policy.

7. Models of complexity for businesses: agent-based models in practice

One of the most immediately applicable areas where complexity research has had impact within organizations, and potentially has the ability to provide results that provide an immediate increase in operational effectiveness, is in the use of agent-based models to provide insight into real problems of organizations. Agent based models are not restricted to theoretical models of the corporation. Consultancies such as BiosGroup have introduced agent-based models to provide complexity-inspired answers to practical management problems. Where agent based models can improve over traditional simulation approaches that have traditionally been applied to modeling business processes is that they allow individual agents within the system to be tracked and investigated, and changes in configurations can be investigated without the need for investment in changing the firm's business operations with the associated business risk. Examples where such agent-based models have been used are presented in order to provide indications of where such models may be used.

Southwest Airlines used an agent-based model within their cargo routing operations to improve efficiency of their movement of cargo [35]. An agent-based model of cargo routing was developed, whereby "agents" within the cargo moving system such freight handlers and ramp agents were modeled. Using historical data of cargo movements, the model was calibrated with real historical data. The results reported by Seibel and Thomas indicate improvements in operational efficiency and shipments arriving earlier. Ben Said et al. [8] discuss how researchers at France Télécom have used agent-based models to provide new marketing approaches to model the behavior of customers. The goal of the simulation is to create a virtual population of customers that present realistic behavior in order that this may be used as a model from which artificial experiments may be made to investigate different marketing techniques with the potential advantage of using the simulation before the requirement to commit real sums to marketing. Siebel and Kellam [34] recount the situation of Proctor & Gamble who suffered from a combination of large excess inventories (tying up working capital) and high levels of items that were out of stock. An agent-based model was devised that allowed the firm to visualize the flow of stocks. A supply chain was modeled, and changes in parameters in the model were investigated to identify the location of inventories.

While metaphors from complexity research may influence managers' thinking, agent-based models provide methods to model the individual components within a firm, such as pieces of baggage, customers, or items of inventory, and can provide managers with "hands on" models. Such models can influence their understanding of the way firms' businesses operate and therefore potentially provide deeper insights from complexity.

8. Conclusions

Whether the corporation is indeed a complex adaptive system depends very much on how we consider a corporation – whether we consider it to be the internal components of the firm, or the firm as a component within the wider environmental system. In the absence of monopoly or oligopoly conditions, a firm's environment is certainly *complicated*; whether the firm adapts to its environment may make the difference between success or failure. Complexity methods can be used both to produce agent-based models of organizations or as a metaphor to change our thinking from the linear models that have dominated the management literature. However, in order for real benefits to come from complexity science, models of complex organizations should be built – using agent based models – and from these there is the possibility of real organizational improvement. What is clear is that the insights of complexity thinking will at the very least augment the traditional approaches. Whether organizations should be considered as complex adaptive systems depends on the scale of interaction that we are considering. We can think of a new definition of a firm as a complex system within a complex system, and design management processes with this in mind. Whether the use of complexity thinking can fundamentally change the way that corporations operate will ultimately be reflected by whether their performance is improved – whether corporations adapt to their environment by using strategies and operational models derived from complexity approaches. A complex adaptive system has strong selection pressures – the use of complexity theory within organizations can only be of use to individual firms if the selection pressure within such an environment leads to positive selection – success and increases in performance from using such approaches. Deriving strategies for organizations to adapt to their environment and produce increases in profitability is an elusive aim within management science. The challenge remains to ensure that managers and employees within firms (at all levels) are in companies that adapt to the environment, rather than being in the firms that are selected out and removed from that environment. This is not a new challenge, but the tools of complexity science have the potential to help us interpret and understand our environment and potentially ensure that our firms adapt to their environment rather than being the ones that fail.

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