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Complexity Theory Chapter

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This chapter introduces complexity theory as an approach which challenges some of our assumptions – both about organizations and what it means to organize. Complexity theory draws on a diverse range of source literatures including physical chemistry, biology and computing science and is increasingly being used to inform practice in management and organization. For those interested in pursuing a more detailed review of complexity, there are introductions in the form of popular science (Waldrop, 1992), reviews of contemporary contributions (Maguire et al 2011) as well as introductory reviews of organizational applications of complexity theory (MacIntosh et al. 2006).

In essence complexity thinking tends to be organized around a few key concepts. First, is the observation that small events can be amplified to produce large scale outcomes. Researching weather patterns, Lorenz coined the phrase 'the butterfly effect' (1963) which has since passed into widespread usage capturing both sensitivity to initial conditions and the inherent unpredictability of complex systems. A key feature of such systems is that they are **densely interconnected** such that one part of the system can influence many others in ways that are often difficult if not impossible to track in terms of "cause and effect". A second theme in complexity theory is that complex systems tend to exist in **non-equilibrium** states. This is challenging since so many of our organizational concepts, such as supply and demand, assume that equilibrium is the default position. Nobel prize winner, Ilya Prigogine observes that systems in highly unstable states become susceptible to tiny signals and random perturbations that would have had little impact were it still at equilibrium. This introduces a third theme, namely **non-linearity** driven by feedback processes. Positive feedback, which is essentially an amplifying feedback, can turn these tiny changes into "gigantic structure breaking waves." (Prigogine and Stengers, 1984: xvii). Feedback processes are therefore seen as central to the relationship between stability and change; in particular, the balance of negative (i.e. restorative or damping) and positive (i.e. amplifying) feedback influences the extent to which system-wide change occurs. A fourth theme draws attention to **simple rules** or deep structure (Drazin and Sandelands, 1992). In complex systems, order is seen to emerge through the repeated enactment or application of simple rules. For instance, Reynolds managed to simulate the flocking behaviour of birds using only 3 rules[1]. Eisenhardt and Sull (2001, 2012) suggest that organizations in high velocity environments work with simple rules i.e. heuristics or rules of thumb, to determine which products to launch, which markets to operate within, etc. The radical departure from other theoretical perspectives is that complexity theory suggests that order emerges from within a system through a process called self-organization (Kauffman, 1993). As a shorthand summary, self-organization – which can sometimes amount to radical new patterns emerging – occurs when the four themes set out above (a densely interconnected system, non-linear feedback, non-equilibrium conditions, a set of simple rules which are repeatedly applied).

Many of the insights generated in the study of complex adaptive systems arose from studies in the natural sciences (e.g. Prigogine's work on chemical reactions), mechanical or electrical systems (e.g. Kaufmann's studies of electrical circuits) or animals (e.g. Goodwin's studies of ant behaviour). However, a significant further complication is introduced when considering social systems. In complex adaptive social systems, issues such as of voluntary behaviour, participation and reflexivity need to be incorporated (MacLean and MacIntosh, 2003).

To take one example, consider the concept of simple rules. Reynolds produced a computer simulation where each individual "boid" (his term for a simulated bird) follows instructional

[1] In 1986 Reynolds managed to produce a computer simulation which he called Boids. In the simulation each individual boid follows 3 simple rules: (1) steer to avoid crowding and collision (2) align toward the average line of flight of other local boids and (3) head toward the average positional location of other boids in the flock. Using these three rules a whole flock of boids emulate the flocking behaviour of real birds. An internet search for the term "boids" will identify several on-line versions of the simulation that you can experiment with.

statements such as "match the velocity of other boids". A further twist occurs when we consider the case of birds rather than boids. If one accepts that birds are not capable of formulating and following instructional rules, it is inappropriate to argue that individual birds are engaged in rule-following. A more accurate account would be to argue that the instinctive, or perhaps inherent, behaviour of individual birds can be explained via the repeated application of simple rules such as "maintain a safe distance from other birds". The important thing to note here is that it is the explanation that relies on the concept of rules – not necessarily the behaviour itself. Rules may thus simply be a way of ***explaining*** behaviour which emerges from certain patterns of interaction in a way that is not fully understood.

Yet more complicated is the case of a social system where individuals are both sentient and capable of complying or contravening simple rules. It is possible to get a group of people to reproduce flocking behaviours by asking each individual to act in accordance with the set of simple rules employed in Reynolds' simulation model. Two significant issues are thrown up by this transition to human settings. First, rules can be identified, communicated and made explicit. Second, individuals are capable of making a conscious decision to enact the rules, inadvertently misinterpret them, ignore them or deliberately manipulate them.

Similar concerns arise in relation to the other concepts described above. In human systems, perception affects the extent to which individuals feel connected with others. One person's sense of instability or non-equilibrium conditions may not accord with the views of others. Intentional efforts to amplify particular behaviours, processes or outcomes may inadvertently be interpreted in ways which produce the opposite of the desired effect. Indeed, in complex adaptive social systems, we have argued that each of these complexity concepts act as "interacting gateways" (MacIntosh and MacLean, 2001: 1353) where, for example, non-linear feedback applied to a set of simple rules pushes a system to non-equilibrium conditions when interconnections reach a certain density. Each of these concepts needs to be co-present and each is in some ways, created by and creating the others. When these concepts operate in concert, order is produced over time yet the potential for the spontaneous emergence of radical novelty is ever-present. This is the quintessential feature of complexity.

Complexity is therefore primarily concerned with the ***emergence of order*** in so called ***complex adaptive systems*** which exist in ***far-from-equilibrium conditions*** in an ***irreversible medium***. Such order manifests itself through emergent ***self-organization*** as a ***densely interconnected*** network of interacting elements ***selectively amplifies*** certain events. This propels the system away from its current state toward a ***new order*** in a way which is ***largely unpredictable***. Whilst the detailed form of such emergent structures cannot be predicted, the range of broad possibilities is to some extent contained within a combination of initial conditions, the set of order generating rules, and/or patterns of interconnection that are available.

Debates in the Complexity Literature

Whilst there is broad agreement on these core concepts, the field of complexity theory tends to combine them differently based on two distinct views which are labeled "the edge of chaos" and "dissipative structures". Organizational applications of these concepts mirror the pattern that has occurred in the natural sciences, in that usage of the dissipative structures view pre-dates its edge of chaos counterpart (see Gemmill and Smith, 1985). Dissipative structures have been used to describe regional development (Allen, 1998), organizational change (Gemmill and Smith, 1985; Leifer, 1989; MacIntosh and MacLean, 1999) as well as individual change (Gersick 1991). The original research on dissipative structures was conducted in the fields of physics and physical chemistry (Jantsch 1980; Prigogine & Stengers 1984) and describes qualitative, systems-wide changes which occur episodically, in distinct phase transitions initiated by some external trigger. During these phase transitions, the system concerned imports energy and exports entropy (a measure of disorder). Since dissipative structures consume energy, they tend to stabilize again and return to equilibrium if, or when, the supply of energy stops.

Subsequent research in the field of biology (see Kauffman 1993; Solé et al. 1993) adopted a different perspective claiming that, rather than experiencing periodic punctuations, systems can exist in a zone on the edge of chaos. The edge of chaos perspective is most frequently associated with work in so called living systems (e.g. insect colonies, organizms, the human body, neural networks, etc.). Goodwin, (1994: 169) claims that "complex, non-linear dynamic systems with rich networks of interacting elements (have a zone which) … lies between a region of chaotic behavior and one that is frozen, with little spontaneous activity." Systems on the edge of chaos appear constantly to adapt and self-organizing again and again to create configurations that ensure compatibility with the ever-changing environment. This perpetual fluidity is regarded as the norm in systems on the edge of chaos, as opposed to a periodic feature of systems that undergo dissipative transformations from one stable state to another.

It has been noted that “the edge of chaos is a good place to be in a constantly changing world because from there you can always explore the patterns of order that are available and try them out … you should avoid becoming stuck in one state of order which is bound to become obsolete sooner or later.” (Brian Goodwin quoted in Coveney and Highfield, 1996: 273).

Table 1 offers a comparison of the dissipative structures and edge of chaos views of change processes.

Whilst a full discussion of the relationship between these two views of complexity theory is beyond the scope of this chapter, it is perhaps worth noting that one view, dissipative structures, arose in fields of study concerned with systems of molecules and other such assemblies, whilst the edge of chaos view focuses mainly on living organizms or organs. The extent to which organizations are continuously fluid or episodic in their change patterns may thus boil down to whether they are primarily seen, or designed, as mechanical or living systems, i.e. whether they are fundamentally geared towards control or evolution.

	Edge of Chaos	Dissipative Structures
Temporal Characteriztics of Change	Change is seen as an on-going, evolutionary process	Change occurs episodically
Espoused attitude to equilibrium states	Disequilibrium is the norm and is associated with a healthy vibrant system. "Equilibrium is the precursor to death" (Pascale, 1999:85)	Equilibrium represents the normal state of systems, this is interrupted periodically by epidodes of disequilibrium but the system will strive to return to equilibrium
Evidence of Self-organization	Self-organizing processes both create order and maintain the system's position on the edge of chaos.	Self-organizing processes create order out of the far from equilibrium conditions.
Emergent Properties	Arise through the connectivity between parts of the systems and are the result of local coupling (Solé et al., 1993: 344). For a more general discussion of connectionist views see Cilliers (1998)	Order emerges through the repeated application of simple rules (Prigogine and Stengers, 1984) and over time, the system will settle into some new configuration
Drivers for Change	The internal dynamics of the self-organizing processes trigger change on an on-going basis	Change is triggered by the action of some external force on the system (e.g. the input of energy into the system)

Table 1: Comparing the Edge of Chaos and Dissipative Structures

Illustrating Complexity in Action

The Conditioned Emergence framework (MacIntosh and MacLean, 1999) is located in the dissipative structures view of complexity offers one way of operationalizing complexity thinking in relation to organizational settings. The organization must reconfigure its simple rules (sometimes referred to as order generating rules or deep structure), ensure that the organization experiences sufficient instability and make explicit efforts to encourage positive feedback (since most organizations are dominated by processes which engender negative feedback). Pascale, (1999: 85) notes that "one cannot direct a living system, only disturb it," and Stacey's extensive work in this area (e.g. 2001) centres on the assertion that for complex systems we cannot accurately predict (or control) what happens in the future. Nevertheless, the Conditioned Emergence framework suggests that managerial influence, if not control, can be exerted on complex adaptive social systems.

We have used this framework extensively when working with organizations to develop strategy. One such case involved working with a manufacturer of complex mechanical engineered products. The company had been performing poorly for a number of years and had experienced significant headcount reduction over a series of redundancy and restructuring exercises. We worked with the management team of the organization and our first task was to try and explain recurrent patterns within the organization by using the concept of simple rules. The constant pressure to reduce operating costs meant that organizational changes were seen as inextricably linked to costs. One of the rules operating within the firm was phrased as "don't innovate unless it leads to cost reduction". Using this one rule as an example, with the management team we seeded an alternative new framing of this rule which was that all innovations had to result in outcomes, products or processes which were "better, faster and cheaper". Notably, the new rule contained echoes of the old rule in that there was still some emphasis on reducing costs but this was set in a new context which emphasised improvement for customers and/or existing staff.

To create the conditions in which this new rule could be operationalized, we needed to work with the other main concepts set out earlier in this chapter. Over time we encouraged new processes, organizational structures and physical configurations of work spaces to create a sense of non-equilibrium conditions. Further, we encouraged new working practices which drew individuals from different parts of the organization into closer contact with each other, thereby increasing interconnectivity. Finally, we encouraged the explicit management of feedback processes and in particular positive feedback, to amplify and to encourage small signals consistent with new ways of working. It would be over-simplifying a multi-faceted organizational change narrative to imply that this was all that happened in the 12 months that we worked with the company or indeed that there was a neat start and end point to the project in the reality of a continuous flow of the company's own narrative. However, the management team found it helpful to conceptualize the challenges they faced from a complexity perspective.

Complexity thinking and the analytic process

When attempting to understand any organizational setting from a complexity perspective, there are two aspects to the analytical process. The first is to apply the four core concepts set out in this chapter to the setting. Look for examples of interconnections in the setting, perhaps by looking for who or what is interacting in the situation. Assess whether the setting under consideration is relatively stable or unstable and how this appears to be changing over time. Sometimes it is easiest to begin by looking for patterns that appear to be stuck. Try to identify anything that appears to be behaving or responding in either a stagnant or, alternatively, a non-linear fashion, and perhaps most importantly of all, ask whether you could explain the dynamics of the situation by using a handful of simple rules. Having looked for instances of the four core concepts, the second stage of the analytical process is to examine the ways in which the examples you have chosen are co-producing each other.

In Simon's story (see chapter x), many of the core concepts presented in this chapter are embedded in both the situation and in Simon's account of events. The various musicians, organized into sub-groups within the structure of the orchestra, represent one set of interconnected elements. Guest soloists or conductors become part of the system on a temporary basis, though others like Sir Simon Rattle reappear in the story. Doubtless, at various points in the orchestra's existence it has experienced periods of instability. These are not immediately obvious in Simon's account but a further exploration of the setting would likely throw up episodes of far-from-equilibrium conditions and these are hinted at. Periods where funding crises occur may be one form of instability. Another may be periods of artistic uncertainty and political unrest over the direction, nature or identity of the orchestra. Simon does mention the tension between being a business, being a civic organization and having to cater to but challenge audience expectations. Each of these issues introduces uncertainty at least for periods in the organization's story.

Non-linearity is harder to see in this particular glimpse of life within City of Birmingham Symphony Orchestra. Perhaps by looking over time, it would be possible to see non-linear changes in for example, the number of associated organizations. The account mentions the youth orchestra, five choruses, etc. There is also reference to the fact that particular types of performance are repeated on the basis of positive outcomes e.g. "it has worked before, we will do it again". A more careful analysis of the data may suggest that one such performance happened by chance, was successful and has now grown to form a regular and substantial part of the orchestra's activities. If so, this is exactly the kind of amplification of small signals that complexity thinking helps to explain.

Finally, there are some aspects of Simon's account which could be interpreted as simple rules. Some of these are formal (e.g. the service level agreements with funders). Some rules however, are implicit and those within the setting may not even be conscious of their operation. One such example is hidden in the explanation of the failed Christmas concert. A previously successful formula was re-enacted with disappointing results which are partially explained by external factors (the weather was poor, etc.). The disappointing outcome led to a fundamental review of the Christmas event which is described as going "right back to the bare bones of what these concerts are." Embedded in the next part of the same sentence is the observation that "(had it been more successful) we certainly would not be reconsidering it at the level we are". Though this is an isolated example, it may be that the orchestra operates with a simple rule which is "only review failures" which is highly characteristic of organizations orientated towards negative feedback and trying to make everything just as it "ought to be". If by examining further examples it transpired that significant perceived failures led to reorganizations, changes in personnel or other similar outcomes a pattern may become apparent. For a moment, assume that this rule does operate within the orchestra. If so, it may generate a particularly reactive dynamic where strategic change is driven by external events or the perception of failure. A subtle but significant shift may occur if the rule was reframed as "review good and bad outcomes".

Having examined the individual concepts thus far, it would also be useful to consider the ways in which these concepts are interacting. Again, Simon's account offers insufficient data for a compelling analysis but one can see how the repeated application of the "review failures" rule could be subject to positive feedback which (re)creates the sense of turbulence, change and instability which complexity theorists would characterize as non-equilibrium conditions.

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