COMPLEX SYSTEMS AND EVOLUTIONARY PERSPECTIVES ON ORGANISATIONS:
THE APPLICATION OF COMPLEXITY THEORY TO ORGANISATIONS

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Ten Principles of Complexity & Enabling Infrastructures

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Chapter 2

Introduction

If organisations are seen as complex evolving systems, co-evolving within a social 'ecosystem', then our thinking about strategy and management changes. With the changed perspective comes a different way of acting and relating which could lead to a different way of working. In turn, the new types of relationship and approaches to work could well provide the conditions for the emergence of new organisational forms.

This chapter will offer an *introduction to complexity* by exploring ten *generic principles of complex evolving systems* (CES) and will show how they relate to social systems and organisations. These are not the only principles of CES, but gaining an understanding of these ten principles and how they relate to each other, could provide a useful starting point for working with them and applying them to the management of firms. An example of how a department of an international bank, in one geographic location, changed its way of working from the different dominant culture, will be given at the end to illustrate the proposition that providing the appropriate socio-cultural and technical conditions could facilitate the emergence of new ways of working and relating.

There is no single unified Theory of Complexity, but several theories arising from various natural sciences studying complex systems, such as biology, chemistry, computer simulation, evolution, mathematics, and physics. This includes the work undertaken over the past four decades by scientists associated with the Santa Fe Institute (SFI) in New Mexico, USA, and particularly that of Stuart Kauffman (Kauffman 1993, 1995, 2000) John Holland (Holland 1995, 1998), Chris Langton (Waldrop 1992), and Murray Gell-Mann (1994) on *complex adaptive systems* (CAS), as well as the work of scientists based in Europe such as Peter Allen (1997) and Brian Goodwin (Goodwin 1995, Webster & Goodwin 1996); Axelrod on cooperation (Axelrod 1990, 1997;

Axelrod & Cohen 2000); Casti (1997), Bonabeau et al (1999), Epstein & Axtel (1996) and Ferber (1999) on *modelling* and *computer simulation*; work by Ilya Prigogine (Prigogine & Stengers 1985, Nicolis & Prigogine 1989, Prigogine 1990), Isabelle Stengers (Prigogine & Stengers 1985), Gregoire Nicolis (Nicolis & Prigogine 1989, Nicolis 1994) on *dissipative structures;* work by Humberto Maturana, Francisco Varela (Varela & Maturana 1992) and Niklaus Luhman (1990) on *autopoiesis* (Mingers 1995); as well as the work on *chaos theory* (Gleick 1987) and that on economics and *increasing returns* by Brian Arthur (1990, 1995, 2002).

The above can be summarised as five main areas of research on (a) complex adaptive systems at SFI and Europe; (b) dissipative structures by Ilya Prigogine and his co-authors; (c) autopoiesis based on the work of Maturana in biology and its application to social systems by Luhman; (d) chaos theory; and (e) increasing returns and path dependence by Brian Arthur and other economists (e.g. Hodgson 1993, 2001). Fig.1 shows the five main areas of research that form the background to this chapter and the ten generic principles of complexity that will be discussed. Since the ten principles incorporate more than the work on complex adaptive systems (CAS), the term *complex evolving systems* (CES) will be used (Allen) as more appropriate to this discussion.

By comparison with the natural sciences there was relatively little work on developing a *theory* of complex *social* systems despite the influx of books on complexity and its application to management in the past 6-7 years (an extensive review of such publications is given by Maguire & McKelvey 1999). The notable exceptions are the work of Luhman on autopoiesis, Arthur in economics and the work on strategy by Lane & Maxfield (1997), Parker & Stacey (1994) and Stacey (1995, 1996, 2000, 2001). A theory in this context is interpreted as an *explanatory framework that helps us understand the behaviour of a complex social (human) system*. (The focus of the author's work and hence the focus of this chapter is on human organisations. Other researchers have concentrated on non-human social systems, such as bees, ants, wasps, etc.) Such a theory may provide a different way of thinking about organisations, and could change strategic thinking and our approach to the creation of new organisational forms—that is, the structure, culture, and technology infrastructure of an organisation. It may also facilitate, in a more modest way, the emergence of different *ways of organising* within a limited context such as a single department within a firm. The case study at the end of this chapter describes how a different way of organising emerged in the Information Technology Department in the London office of an international bank.

The chapter will discuss each principle in turn, providing some of the scientific background and describing in what way each principle may be *relevant* and *appropriate* to a human system. Regarding the five areas of research listed on the left hand side of Figure 1, dissipative structures are discussed at length as part of the 'far-from-equilibrium' and 'historicity' principles; complex adaptive systems research underlies most of the other principles and the work of Kauffman is referred to extensively; autopoiesis is not discussed in this chapter but it has played an important role in the thinking underlying the current work (for the implications and applications of autopoiesis see Mingers 1995); chaos theory is given a separate section, but the discussion is not extensive; and Arthur's work on increasing returns is discussed under the 'path-dependence' principle.

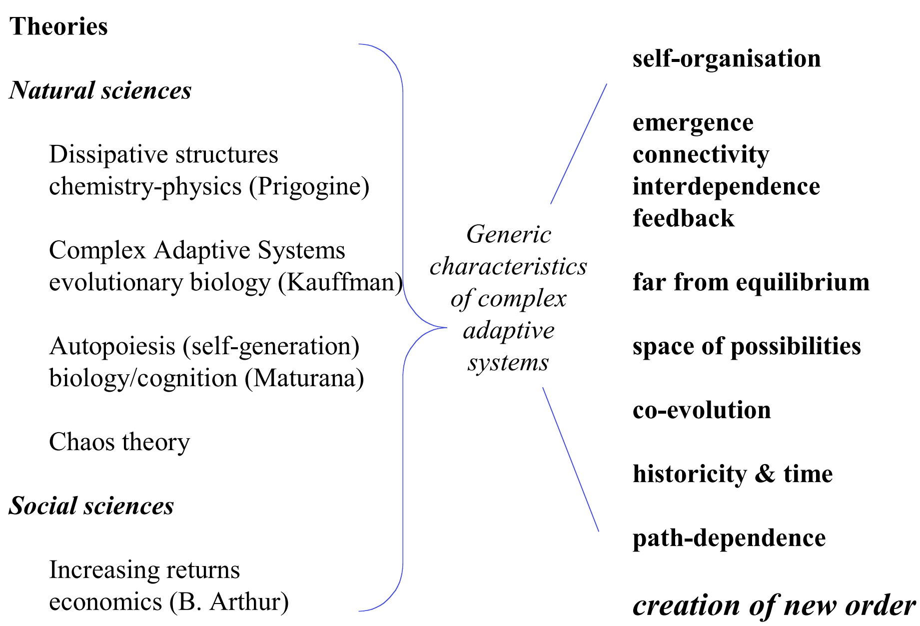

Figure 1

The four principles grouped together in Fig. 1, of emergence, connectivity, interdependence, and feedback are familiar from systems theory. Complexity builds on and enriches systems theory by articulating additional characteristics of complex systems and by emphasising their inter-relationship and interdependence. It is not enough to isolate one principle or characteristic such as self-organisation or emergence and concentrate on it in exclusion of the others. The approach taken by this chapter argues for a deeper understanding of complex systems by looking at several characteristics and by building a rich inter-related picture of a complex social system. It is this deeper insight that will allow strategists to develop better strategies and organisational designers to facilitate the creation of organisational forms that will be sustainable in a constantly changing environment.

The discussion is based on *generic principles*, in the sense that these principles or characteristics are common to all natural complex systems. One way of looking at complex human systems is to examine the generic characteristics of natural complex systems and to consider whether they are *relevant or appropriate to social systems*. But there is one limitation in that approach, which is to understand that such an examination is merely a starting point and not a mapping, and that social systems need to be studied in their own right.

This limitation is emphasised for two reasons: (a) although it is desirable that explanation in one domain is consistent with explanation in another and that these explanations honour the *Principle of Consistency* (Hodgson 2001, p90), characteristics and behaviour cannot be mapped directly from one domain to another, without a rigorous process of testing for appropriateness and relevance. Not only may the unit of analysis be quite different, but scientific and social domains may also have certain fundamental differences that may invalidate direct mapping. For example humans have the capacity to reflect and to make deliberate choices and decisions among alternative paths of actions. This capacity may well distinguish human behaviour from that of biological, physical or chemical entities; (b) a number of researchers consider the principles of complexity only as metaphors or analogies when applied to human systems. But metaphors and analogies are both limiting and limited and do not help us understand the fundamental nature of a system under study. This does not mean that neither metaphor nor analogy may be used. We use them as 'transitional objects' all the time in the sense that they help the transition in our thinking when faced with new or difficult ideas or concepts. The point being emphasised, is that using metaphor and analogy is not the *only* avenue available to us in understanding complexity in an organisational or broader social context. Since organisations are, by their very nature, complex evolving systems, they need to be considered as complex systems in their own right.

Another way of looking at complexity is that suggested by Nicolis and Prigogine (1989 p8) "It is more natural, or at least less ambiguous, to speak of *complex behavior* rather than complex systems. The study of such behavior will reveal certain common characteristics among different classes of systems and will allow us to arrive at a proper understanding of complexity." This approach both honours the Principle of Consistency and avoids the metaphor debate. It may however upset some sociologists who do not find 'arguments from science' convincing. But this is to miss Nicolis's and Prigogine's point, when they put the emphasis on the behaviour or characteristics of *all* complex systems. Nicolis and Prigogine are not behaviourists; they study the behaviour of complex systems in order to understand their deeper, essential nature.

This provides us with the underlying reason for studying complexity. *It explains and thus helps us to understand the nature of the world—and the organisations—we live in.*

The term *'complexity'* will be used to refer to the *theories of complexity* (in the literature the plural 'theories' is reduced to the singular for ease of reference and this practice will be used here) and *'complex behaviour'* to the behaviour that arises from the interplay of the characteristics or principles of complex systems.

Complexity is not a methodology or a set of tools (although it does provide both). It certainly is not a 'management fad'. The **theories of complexity** provide a conceptual framework, **a way of thinking**, and **a way of seeing the world**.

1. Connectivity & Interdependence

Complex behaviour arises from the inter-relationship, interaction, and inter-connectivity of elements within a system and between a system and its environment.

Murray Gell-Mann (1995/96) traces the meaning to the root of the word. *Plexus* means braided or entwined, from which is derived *complexus* meaning braided together, and the English word "complex" is derived from the Latin. Complex behaviour therefore arises from the *intricate inter-twining or inter-connectivity of elements within a system and between a system and its environment.*

In a human system, connectivity and interdependence means that a decision or action by any individual (group, organisation, institution, or human system) may affect related individuals and systems. That affect will not have equal or uniform impact, and will vary with the 'state' of each related individual and system, at the time. The 'state' of an individual or a system will include its history and its constitution, which in turn will include its organisation and structure. Connectivity applies to the inter-relatedness of individuals *within* a system, as well as to the relatedness *between* human social systems, which include systems of artefacts such as information technology (IT) systems and intellectual systems of ideas.

Complexity theory, however, does not argue for ever-increasing interconnectivity, for high connectivity implies a high degree of interdependence. This means that the greater the interdependence between related systems or entities the wider the 'ripples' of perturbation or disturbance of a move or action by any one entity on all the other related entities. Such high degree of dependence may not always have beneficial effects throughout the ecosystem. When one entity tries to improve its fitness or position, this may result in a worsening condition for others. Each 'improvement' in one entity therefore may impose associated 'costs' on other entities, either within the same system or on other related systems.

Connectivity and *interdependence* is one aspect of how complex behaviour arises. Another important and closely related aspect is that complex systems are *multidimensional*, and all the dimensions interact and influence each other. In a human context the social, cultural, technical, economic and global dimensions may impinge upon and influence each other. The case study at the end of the chapter, illustrates how what on the surface appeared to be a technical problem involving the integration of information systems across Europe, was partially resolved by paying attention to some social and cultural issues.

But the distinguishing characteristic of a CES is that it is able to *adapt* and *evolve* and thus create *new order and coherence*. This creation of new order and coherence is one of the key defining features of complexity. Individuals acting 'at random' or with their own agendas nevertheless can work effectively as a group or an entire organisation—and may create coherence in the absence of any grand design. They can also create new ways of working, new structures, and different relationships, where hierarchies may be reversed or ignored, as in integrated project teams[1] where a senior

[1] Integrated project/product teams (IPTs) are often used in the Aerospace and other industries to bring together representatives from different organisations or functions with the knowledge and skills necessary to design a new project or product.

executive outside the team may not hold a leadership role within the team, while a more junior employee becomes team-leader because he/she has the correct qualifications for leading that particular integrated project team.

Other features include the possibility of entities in a CES to *change their rules of interaction*; to *act on limited local knowledge*, without knowing what the system as a whole is doing; and to be *self-repairing* and *self-maintaining*. Reference to entities as individuals or collections (systems) is deliberately ambiguous, to emphasise the point that complex characteristics tend to be *scale-invariant* and could apply at all scales from an individual to a whole system as well as to systems at different scales (e.g. team, organisation, industry, economy, etc.)

1.1 Degrees of Connectivity

Propagation of influence through an ecosystem depends on the *degree* of connectivity and interdependence. Biological "ecosystems are not totally connected. Typically each species interacts with a subset of the total number of other species, hence the system has some extended web structure." (Kauffman 1993: 255) In human social ecosystems the same is true. There are networks of relationships with different degrees of connectivity. *Degree of connectivity* means strength of coupling and the dependencies known as *epistatic interactions*—i.e. the extent to which the fitness contribution made by one individual depends on related individuals. In biological co-evolutionary processes, the fitness of one organism or species depends upon the characteristics of the other organisms or species with which it interacts, while all simultaneously adapt and change. (Kauffman 1993, 33) In other words a single entity (allele, gene, organism or species) does not contribute to overall fitness independently of all other like entities. The fitness contribution of an individual may depend on all the other individuals in that context. This is a contextual measure of dependency, of direct or indirect influence that each entity has on those it is coupled with.

In a social context, each individual belongs to many groups and different contexts and his/her contribution in each context depends partly on the other individuals within that group and the way they relate to the individual in question. An example is when a new member joins a team. The contribution that individual will be *allowed* to make to that team may depend on the other members of the team and on the space they provide for such a contribution, as much as to the skills, knowledge, expertise, etc brought by the new member.

In human systems, connectivity between individuals or groups is not a constant or uniform relationship, but varies over time, and with the diversity, density, intensity, and quality of interactions between human agents. Connectivity may also be formal or informal, designed or undesigned, implicit with tacit connections or explicit. Furthermore, it is the degree of connectivity, which determines the network of relationships and the transfer of information and knowledge and is an essential element in feedback processes.

2. Co-evolution

Connectivity applies not only to elements within a system but also to related systems within an ecosystem. An **ecosystem** in biology means, "each kind of organism has, as parts of its environment, other organisms of the same and of different kinds ... adaptation by one kind of organism alters both the fitness and the fitness landscape[2] of the other organisms" (Kauffman 1993, p242) The way each element influences and is in turn influenced by all other related elements in an ecosystem is part of the process of co-evolution which Kauffman describes as "a process of coupled, deforming landscapes where the adaptive moves of each entity alter the landscapes of its neighbors." (Kauffman & Macready, 1995)

Another way of describing co-evolution is that *the evolution of one domain or entity is partially dependent on the evolution of other related domains or entities* (Ehrlich & Raven 1964, Pianka 1994, Kauffman 1993 & 1995, McKelvey 1999a & b, Koza & Lewin 1998); or *that one domain or entity changes in the context of the other(s).* The notion of co-evolution places the emphasis on the *evolution of interactions* and on *reciprocal evolution* (Futuyama 1979). In human systems, co-evolution in the sense of the *evolution of interactions* places emphasis on the relationship between the co-evolving entities.

A point emphasised by Kauffman is that **co-evolution takes place within an ecosystem**, and cannot happen in isolation. In a human context a social ecosystem includes the social, cultural, technical, geographic and economic dimensions and co-evolution may affect both the form of *institutions* and the *relationships* and interactions between the co-evolving entities (the term *entity* is used as a generic term which can apply to individuals, teams, organisations, industries, economies, etc.).

A distinction may also be made between *co-evolution <u>with</u>* and *adaptation <u>to</u>* a changing environment. When the emphasis is placed on co-evolution with, it tends to change the perspective and the assumptions that underlie much traditional management and systems theories.

Although we make a conceptual distinction between a 'system' and its 'environment' it is important to note that there is no dichotomy or hard boundary between the two as in Figure 2, in the sense that a system is separate from and always *adapts to* a changing environment. The notion to be explored is rather that of a system *closely linked with* all other related systems within an ecosystem, illustrated by Figure 3.

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[2] Kauffman (1993, p33) borrows the hill-climbing framework with minor modifications, directly from Wright (1931, 1932) who introduced the concept of a space of possible genotypes. Each genotype has a 'fitness', and the distribution of fitness values over the space of genotypes constitutes a *fitness landscape*. Depending upon the distribution of the fitness values, the fitness landscape can be more or less mountainous.

Within such a context change needs to be seen in terms of *co-evolution with* all other related systems, rather than as *adaptation to* a separate and distinct environment. This perspective changes the way strategy may be viewed.

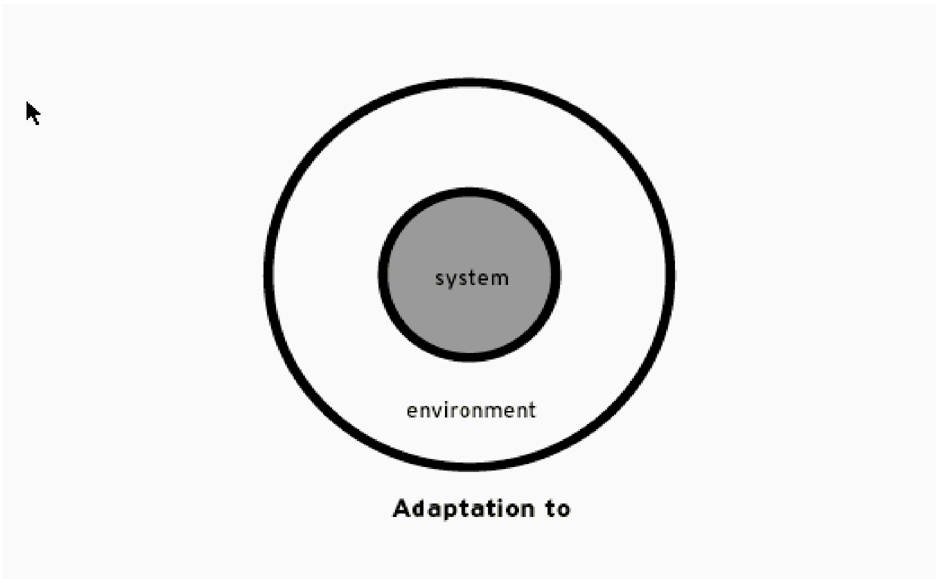

Figure 2

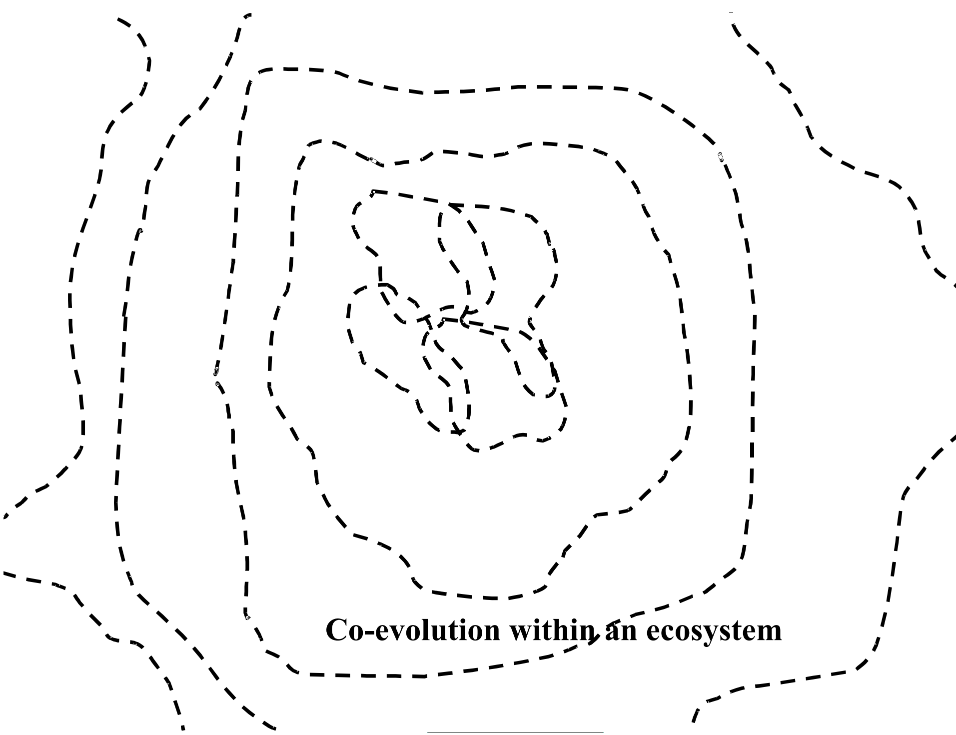

Figure 3

In a social co-evolving ecosystem, each organisation *is a fully participating agent which both influences and is influenced by* the social ecosystem made up of all related businesses, consumers, and suppliers, as well as economic, cultural, and legal institutions. Strategies consequently cannot to be seen simply as a *response to* a changing environment, which is separate from the organisation, but as adaptive moves, which will affect both the initiator of the action and all others influenced by it. The notion of co-evolution is thus one of empowerment, as it suggests that all actions and decisions affect the social ecosystem. No individual or organisation is powerless—as each entity's actions reverberate through the intricate web of inter-relationships and affects the social ecosystem. But co-evolution also invites notions of responsibility, as once the ecosystem is influenced and affected it will in turn affect the entities (individuals, organisations, and institutions) within it. This notion is not the same as pro-active or re-active response. It is a subtler 'sensitivity' and awareness of both changes in the environment and the possible consequences of actions. It argues for a deeper understanding of reciprocal change and the way it affects the totality.

Seen from one perspective, co-evolution takes place when related entities change *at the same time*. But in most observable examples it is more a matter of short-term adaptation and long-term co-evolution. Two examples will be used to illustrate this. The first example was given by Maturana at an Open University workshop (Maturana 1997). When I buy a pair of shoes, both the new shoes and my feet will change to accommodate each other. They co-evolve. What I observe at a macro-level after wearing the shoes several times and suffering from sore feet, may be co-evolution happening at the same time, as both my feet and shoes change to accommodate each other. But at a micro short-term level of minute-to-minute walking, there could well have been short-term adaptation of the one to the other. This reciprocal movement is illustrated more clearly by the second example given by a senior Marks & Spencer executive at an LSE Seminar. Weavers and knitters have influenced each other and produced new materials, which are knitted but look woven, and materials that are woven but look knitted. They have co-evolved over time, with short-term adaptation to each other and the market. Through the process of co-evolution they have produced something new, a new order or coherence; which is, as has been pointed out earlier, the key distinguishing feature of CES.

Co-evolution also happens between entities *within* a system, and the *rate of their co-evolution* (McKelvey 1999b) is worth considering. For example, how can the rate of co-evolution within and between teams be facilitated and improved? Co-evolution in this context is associated with learning and the transfer of information and knowledge. If one individual or one team learns to operate better, how can that knowledge or ability be transferred to other teams to help them evolve? Since co-evolution can only take place within an ecosystem, the notion of social 'ecosystem' also needs to be addressed. An ecosystem is defined by the interdependence of all entities within it. It provides sustenance and support for life. A community is a social ecosystem, if it provides mutual support and sustenance. When firms and institutions cease to function like a community or social ecosystem, they may break down. Some of the most successful organisations nurture their community or social ecosystem. (Lewin & Regine date?) The debate on organisational culture is attempting to address that issue. How can the organisation create the kind of culture that will help it to survive and thrive? Or what are the conditions that will help it co-create a sustainable social ecosystem?

Co-evolution therefore affects both individuals and systems and is operational at different levels, scales, or domains. Co-evolution is taking place at all levels and scales and can be thought of as *endogenous co-evolution* when it applies to individuals and groups *within* the organisation and as *exogenous co-evolution* when the organisation is interacting with the *broader ecosystem.* This however is a simplification—as the endogenous and exogenous processes are necessarily interlinked and the boundaries between the organisation and its 'environment' may not be clear-cut and stable. Furthermore the notion of 'ecosystem' applies both within the organisation and to the broader environment, which *includes* the organisation under study. Hence the notion of a complex co-evolving ecosystem is one of intricate and multiple intertwined interactions and relationships, and of multi-directional influences and links, both direct and many-removed. Connectivity and interdependence propagates the effects of actions, decisions and behaviours throughout the ecosystem, but that propagation or influence is not uniform as it depends on the *degree of connectivity.*

3. Dissipative Structures, Far-from-equilibrium & History

Another key concept in complexity is dissipative structures, which are ways in which open systems exchange energy, matter, or information with their environment and which when pushed 'far-from-equilibrium' create new structures and order.

The Bénard cell is an example of a physico-chemical dissipative structure. It is made up of two parallel plates and a horizontal liquid layer, such as water. The dimensions of the plates are much larger than the width of the layer of water. When the temperature of the liquid is the same as that of the environment, the cell is at equilibrium and the fluid will tend to a homogeneous state in which all its parts are identical (Nicolis & Prigogine1989, Prigogine & Stengers 1985). If heat is applied to the bottom plate, and the temperature of the water is greater at the bottom than at the upper surface, at a threshold temperature the fluid becomes unstable. "By applying an *external constraint* we do not permit the system to remain at equilibrium." (Nicolis & Prigogine 1989, p10) If we remove the system farther and farther from equilibrium by increasing the temperature differential, suddenly at a critical temperature the liquid performs a bulk movement which is far from random: the fluid is structured in a series of small convection 'cells' known as Bénard cells.

Several things have happened in this process: (a) the water molecules have spontaneously organised themselves into right-handed and left-handed cells. This kind of spontaneous movement is called *self-organisation* and is one of the key characteristics of complex systems; (b) from molecular chaos the system has emerged as a higher-level system with *order* and *structure;* (c) the system was pushed far-from-equilibrium by an *external constraint or perturbation*; (d) although we know that the cells will appear, “the direction of rotation of the cells is unpredictable and uncontrollable. Only chance in the form of the particular perturbation that may have prevailed at the moment of the experiment, will decide whether a given cell is right- or left-handed.” (Nicolis & Prigogine 1989, p14); (e) when a constraint is sufficiently strong, the system can adjust to its environment in several different ways, that is *several solutions* are possible for the *same parameter values*; (f) the fact that only one among many possibilities occurred gives the system “a *historical dimension*, some sort of “memory” of a past event that took place at a critical moment and which will affect its further evolution.” (Nicolis & Prigogine 1989, p14); (g) the homogeneity of the molecules at equilibrium was disturbed and their *symmetry was broken*[3]; (h) the particles behaved in a *coherent* manner, despite the random thermal motion of each of them. This coherence at a macro level characterises *emergent* behaviour, which arises from micro-level interactions of individual elements.

In the Bénard cell heat transfer has ***created new order***. It is this property of complex systems to create new order and coherence that is their distinctive feature. The Bénard cell process in thermal convection is the basis of several important phenomena, such as the circulation of the atmosphere and oceans that determines weather changes. (Nicolis & Prigogine1989, p8)

Ilya Prigogine was awarded the 1977 Nobel Prize for chemistry for his work on dissipative structures and his contributions to nonequilibrium thermodynamics. Prigogine has reinterpreted the Second Law of Thermodynamics. Dissolution into entropy is not an absolute condition, but “under certain conditions, entropy itself becomes the progenitor of order.” To be more specific, “... under non-equilibrium conditions, at least, entropy may produce, rather than degrade, order (and) organisation ... If this is so, then entropy, too, loses its either/or character. While certain systems run down, other systems simultaneously evolve and grow more coherent.” (Prigogine & Stengers 1985: xxi)

Symmetry breaking in complexity means that the homogeneity of a current order is broken and new patterns emerge. Symmetry breaking may be understood as a generator of information, in the sense that when a pattern of homogeneous data is broken by differentiated patterns, the new patterns can be read as ‘information’. This phenomenon applies to and can be interpreted at different levels, from undifferentiated code (homogeneous data) to exception reporting, when different or unexpected patterns appear to deviate from the expected norms.

In dissipative structures the tendency to split into alternative solutions is called ***bifurcation***, but the term is misleading in that it means a separation into *two* paths, when there may be several possible solutions. However, as it is easier to explain the splitting of possibilities into two alternative paths, this simplified meaning will be used, with the proviso that multiple solutions are also possible. In the Bénard cell, a unique solution is

[3] “The emergence of the concept of space in a system in which space could not previously be perceived in an intrinsic manner is called *symmetry breaking*.” Nicolis & Prigogine, 1989 p12

present until the heat differential reaches a critical value. At that point the molecules self-organise themselves and become right- or left-handed cells. The two possibilities are present simultaneously. Figure 4 is borrowed from Nicolis and Prigogine (1989 p72) and illustrates bifurcation.

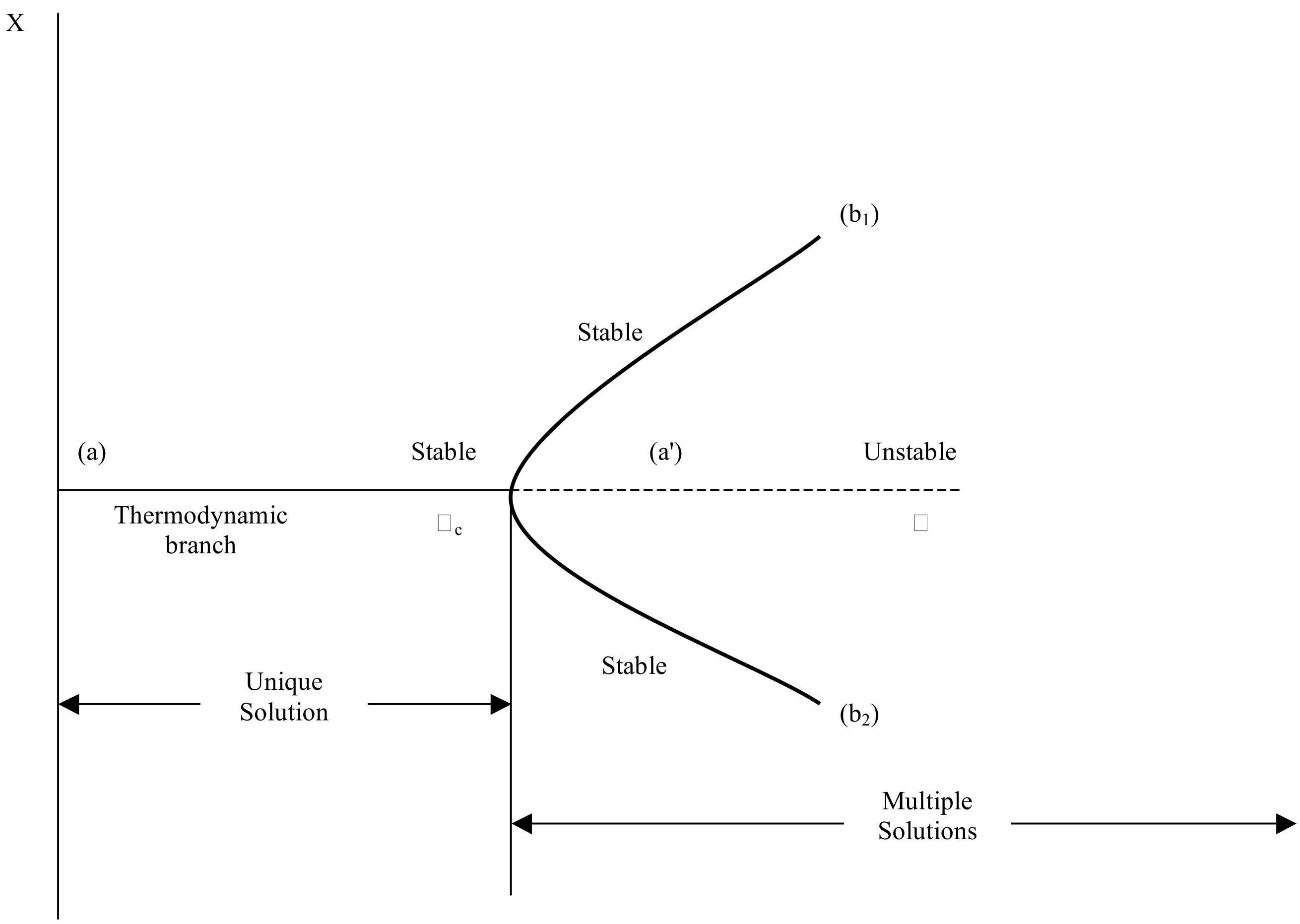

Figure 4
(from Nicolis & Prigogine, 1989, p72)
Bifurcation diagram showing how a state variable X is affected when the control parameter □ varies. a unique solution *(a)*, the thermodynamic branch, loses its stability at $□_c$. At this value of the control parameter new branches of solutions *(b_1, b_2)*, which are stable at the example shown, are generated.

An observer could not predict which state will emerge; “only chance will decide, through the dynamics of fluctuations. The system will in effect scan the territory and will make a few attempts, perhaps unsuccessful at first, to stabilize. Then a particular fluctuation will take over. By stabilizing it the system becomes a *historical object* in the sense that its subsequent evolution depends on this critical choice." (Nicolis & Prigogine, 1989 p72) At a totally different scale, the notions of chance and *history* are used by Kauffman to describe a view of evolutionary biology that sees "… organisms as ultimately accidental and evolution as an essentially historical science. In this view, the order in organisms results from selection sifting unexpected useful accidents and marshalling them into improbable forms. In this view, the great universals of biology—the genetic code, the structure of metabolism and others—are to be seen as frozen accidents, present in all organisms only by virtue of shared descent." (Kauffman 1993, pxv)

In a social context, it is the series of critical decisions each individual takes from several possible alternatives that may determine a particular life path for that individual. The alternatives available, however, are constrained by the person's current state and the state of the landscape the person occupies. Thus the emergent behaviour of the person is not a matter of 'chance' but is the result of a person's selection among a finite set of perceived choices; as well as the past choices made (the history) that have shaped that person's life path. Once the decision is made, there is a historical dimension and subsequent evolution may depend on that critical choice; but *before* the decision is finalised, the alternatives are sources of *innovation* and *diversification*, since the opening up of possibilities endows the individual and the system with new solutions. When a social entity (individual, group, organisation, industry, economy, country, etc) is faced with a constraint, it finds new ways of operating, because away-from-equilibrium (established norms) systems are forced to experiment and explore their *space of possibilities*, and this exploration helps them discover and create new patterns of relationships and different structures.

Non-equilibrium may allow a system to avoid thermal disorder and to transform part of the energy communicated from the environment into an ordered behaviour of a new type, a new *dissipative structure* that is characterised by symmetry breaking and multiple choices. In chemistry, ***autocatalysis*** (the presence of a substance may increase the rate of its own production) shows similar behaviours, and the Belousov-Zhabotinski (BZ) reaction, under certain non-equilibrium conditions shows symmetry breaking, self-organisation, multiple possible solutions, and hysteresis (the specific path of states that can be followed depends on the system's past *history*). (Nicolis & Prigogine 1989, Kauffman 1993, 1995) Furthermore, *self-reproduction*, a fundamental property of biological life, is "the result of an autocatalytic cycle in which the genetic material is replicated by the intervention of specific proteins, themselves synthesized through the instructions contained in the genetic material." (Nicolis & Prigogine 1989, p 18) In one sense, complexity is concerned with systems in which evolution—and hence history—plays or has played an important role, whether biological, physical, or chemical systems.

Similarly in a social context, when an organisation moves away from equilibrium (i.e. from established patterns of work and behaviour) new ways of working are created and new forms of organisation may emerge. These may be quite innovative if choice is allowed and the symmetry of established homogeneous patterns is broken. There is however a fundamental difference between natural and social human systems. The latter can deliberately create constraints and perturbations that consciously push a human institution far-from-equilibrium. In addition, humans can also provide help and support for a new order to be established. If the new order is 'designed' in detail, then the support needed will be greater, because those involved have their self-organising abilities curtailed, and may thus become dependent on the designers to provide a new framework to facilitate and support new relationships and connectivities. Although the intention of change management interventions is to create new ways of working, they may block or constrain emergent patterns of behaviour if they attempt to excessively design and control outcomes. However, if organisation re-design were to concentrate on the provision of *enabling infrastructures* (the socio-cultural and technical conditions that facilitate the emergence of new ways of organising), allowing the new patterns of relationships and ways of working to emerge, new forms of organisation may arise that would be unique and perhaps not susceptible to copying. These new organisational forms may be more robust and sustainable in competitive environments.

4. Exploration-of-the-space-of- possibilities

Complexity suggests that to survive and thrive an entity needs to explore its space of possibilities and to generate variety. Complexity also suggests that the search for a single 'optimum' strategy may neither be possible nor desirable. Any strategy can only be optimum under certain conditions, and when those conditions change, the strategy may no longer be optimal. To survive an organisation needs to be constantly scanning the landscape and trying different strategies. An organisation may need to have in place several micro-strategies that are allowed to evolve before major resources are committed to a single strategy. This reduces the risk of backing a single strategy too early, which may turn out not to be the best one, and supports sensitive co-evolution with a changing ecosystem. In essence, unstable environments and rapidly changing markets require flexible approaches based on requisite variety. (Ashby 1969)

Flexible adaptation also requires new connections or new ways of *seeing* things. *Seeing* a novel function for a part of an existing entity is called '***exaptation***'[4]. A small example might help explain the concept. While on holiday, I was using my laptop computer in the garden. The computer was on a garden table, with a hole in the middle for an umbrella. The laptop was connected to a mobile telephone, which enabled me to send and receive emails and faxes. Both the computer and the mobile were attached to power leads, which were passed through a window into the house. The plethora of leads was both ugly and fragile, as people passing by could trip over them. They also took up a lot of space on the table. My son Daniel then used the hole in the middle of the table to keep the leads tidy and out of sight. The umbrella hole therefore gained a novel function,

[4] *'Exaptation'* is the term used by Stephen J.Gould and Stuart Kauffman. Darwin used the term *'preadaptation'*. "Darwin noted that in an appropriate environment a causal consequence of a part of an organism that had not been of selective significance might come to be of selective significance and hence be selected. Thereupon, that newly important causal consequence would be a new function available to the organism." Evolutionary adaptations "by such preadaptations, or exaptations, are not rare; they are the grist of adaptive evolution. Thus arose the lung, the ear, flight." (Kauffman, 2000, p130)

in keeping the leads tidy and safe. That simple solution was an example of an exaptation. Daniel 'saw' the different function for the umbrella hole, while no one else had even considered it.

When searching the space of possibilities, whether for a new product or a different way of doing things, it is not possible to explore all possibilities. It may, however, be possible to consider change one step away from what already exists. In this sense, exaptation may be considered an exploration of what is sometimes called the ***'adjacent possible'***. (Kauffman 2000) That is exploring one step away, using 'building blocks' already available, but put together in a novel way. According to Kauffman (2000, p22) the push into novelty in the molecular, morphological, behavioural, technological and organisational spheres, is persistent and happens through exploration of the adjacent possible. The *rate* of discovery or mutation, however, is restricted by selection to avoid possible catastrophes that could destroy a community. Bacteria and higher cells have a mutation rate well below the error-catastrophe, which is the phase transition that renders a population unsustainable. There seems to be a balance between discovery and what the ecosystem can effectively sustain. Both the biosphere and the econosphere seem to have "endogenous mechanisms that gate the exploration of the adjacent possible such that, on average, such explorations do successfully find new ways of making a living." (Kauffman 2000, p156) In the biosphere adaptations are selected by natural selection and in the econosphere by economic success or failure, at a *rate* that is sustainable. The current slowing down in the mobile telephone market, could well be an indicator of intolerance to the rate of innovation, which cannot be assimilated by the market.

Although the rate at which novelty can be introduced is restricted, the adjacent possible is indefinitely expandable. (Kauffman 2000, p142) Once discoveries have been realised in the current adjacent possible, a new adjacent possible, accessible from the enlarged actual that includes the novel discoveries from the former adjacent possible, becomes available. The constant opening up of niche markets in areas and products that only a few years earlier had not even been thought of, is an example of the ever expanding possibilities of the adjacent possible.

5. Feedback

Feedback is traditionally seen in terms of positive and negative feedback mechanisms, which are also described as "reinforcing (i.e. amplifying) and balancing." (Kahen & Lehman, http://www-dse.doc.ic.ac.uk/~mml/). Putting it another way, positive (reinforcing) feedback drives change, and negative (balancing, moderating, or dampening) feedback maintains stability in a system. A familiar example of negative feedback is provided in a central heating system. A thermostat monitors the temperature in the room, and when the temperature drops below a specified level, an adjusting mechanism is set in motion, which turns the heating on until the desired temperature is attained. Similarly, when the temperature rises above a set norm, the heating is switched off until the temperature falls below the desired level. The gap between the desired and the actual temperature is thus closed. Positive feedback, on the other hand, would progressively widen the gap. Instead of reducing or cancelling out the deviation, positive feedback would amplify it.

One point needs to be made. First, feedback *'mechanisms'* are related to engineering and other machine-type systems, as indicated by the language used (e.g. 'adjustment mechanism'). When feedback is applied to human systems, the term feedback *process* will be used, in an attempt to avoid the machine metaphor and to distinguish human from other complex systems.

In far-from-equilibrium conditions, non-linear relationships prevail, and a system becomes "inordinately sensitive to external influences. Small inputs yield huge, startling effects" (Prigogine & Stengers 1985: xvi) that cause a whole system to reorganise itself. Part of that process is likely to be the result of *positive or reinforcing feedback*. "In far-from-equilibrium conditions we find that very small perturbations or fluctuations can become amplified into gigantic, structure-breaking waves." (Prigogine & Stengers 1985: xvii)

In human systems, far-from-equilibrium conditions operate when a system is perturbed well away from its established norms, or away from its usual ways of working and relating. When an organisation as a system is thus disturbed (e.g. after restructuring or a merger), it may reach a critical point and either degrade into disorder (loss of morale, loss of productivity, etc.) or create some new order and organisation—i.e. find new ways of working and relating—and thus create a new *coherence*. Positive or reinforcing feedback processes underlie such transformation and they provide a starting point for understanding the constant movement between change and stability in complex systems.

One reason for interventions that create far-from-equilibrium conditions may be that the current feedback processes no longer work. This may be the case when negative or balancing feedback processes that once were able to adjust or influence the behaviour of the organisation can no longer produce the desired outcome. When efforts to improve behaviour in order to improve performance and market position continually fail, and when incremental changes are no longer effective, then managers of organisations may resort to major interventions in an effort to produce radical change. These interventions may also fail, however, and an organisation may become locked in a constant cycle of ineffective restructuring. One reason for such failures is over-reliance on 'adjustment mechanisms' based on negative feedback loops that have worked in the past. But in a turbulent environment, the entire ecosystem may be changing, and we cannot always extrapolate successfully from past experience. New patterns of behaviour and new structures may need to emerge, and these may depend on or become established through new positive feedback processes.

In human systems, the degree of connectivity (dependency or epistatic interaction) often determines the strength of feedback. Feedback when applied to human interactions means influence that changes potential action and behaviour. Furthermore, in human interactions feedback is rarely a straightforward input–process–output procedure with perfectly predictable and determined outputs. Actions and behaviours may vary according to the degree of connectivity between different individuals, as well as with time and context.

Co-evolution may also depend on reciprocal feedback influences between entities. An important question is therefore, *how does degree of connectivity and feedback influence co-evolution?* A related question is, *how does the structure of an ecosystem affect co-evolution?* Kauffman makes the bold statement that "We have found evidence ... that the structure of an ecosystem governs co-evolution." (Kauffman 1993: 279) This statement is based on computer simulations, but it is intuitively appealing and there is evidence that this finding may apply to social ecosystems (LSE Complexity Programme). Feedback processes may therefore have a bearing on degree of connectivity (at all levels), hence on ecosystem structure, and hence on co-evolution.

Furthermore, the two simple concepts of positive and negative feedback need to be elaborated in order to describe the multiple interacting feedback processes in complex systems, and we need to rethink the nature of feedback in this context to recognise multi-level, multi-process, non-linear influences.

5.1 Path Dependence & Increasing Returns

Brian Arthur argues that conventional economic theory is based on the implicit assumption of negative feedback loops in the economy, which lead to *diminishing returns*, which in turn lead to (predictable) equilibrium outcomes. Negative feedback has a stabilising effect, and implies a single equilibrium point, as "any major changes are offset by the very reactions they generate" (Brian Arthur, 1990 p92). The example given by Arthur is the high oil prices of the 1970s, which encouraged energy conservation and increased oil exploration, precipitating a predictable increase in supply and resulting drop in prices by the early 1980s. But, Arthur argues, such stabilising forces do not always operate or dominate. "Instead positive feedback *magnifies* the effects of small economic shifts", and *increasing returns* from *positive feedback makes for many possible equilibrium points*, depending on the negative feedback loops that may also operate in a system (Arthur 1990).

The possibility that a system may have more than one possible equilibrium points has also been described in section 3 under dissipative structures. In physico-chemical systems "two (or sometimes several) simultaneously stable states could coexist under the same boundary conditions." Nicolis and Prigogine call this phenomenon '**bistability**' and describe it as "the possibility to evolve, for given parameter values, to more than one stable state" (Nicolis & Prigogine, 1989, p24). Furthermore, the specific paths that a system may follow depend on its past history. The point here is that past history affects future development, and there may be several possible paths or patterns that a system may follow. This explains why the *precise* behaviour of a complex system may be very difficult to predict, even while keeping the system within certain bounds.

The classic example illustrating Arthur's argument of increasing returns (Arthur 1990, 1995) resulting from a virtuous circle of self-reinforcing growth is the videocassette recorder. "The VCR market started out with two competing formats selling at about the same price: VHS and Beta. Each format could realise increasing returns as its market share increased: large numbers of VHS recorders would encourage video outlets to stock more pre-recorded tapes in VHS format, thereby enhancing the value of owning a VHS recorder and leading more people to buy one. (The same would, of course, be true for Beta-format players.) In this way, a small gain in market share would improve the competitive position of one system and help it further increase its lead. ... Increasing returns on early gains eventually tilted the competition toward VHS: it accumulated enough of an advantage to take virtually the entire VCR market." (Arthur, 1990) This process is what Arthur calls 'path dependence' - the increasing pull of a new technology in attracting or enabling further developments. The more associated products (e.g. pre-recorded tapes) and support services (shops selling tapes in VHS format; selling VHS recorders; engineers becoming available to service the recorders, etc) proliferated, the stronger the position of the VHS format became, until it dominated the market.

Other technical standards or conventions established by positive feedback, increasing returns and path dependence, are the gauge of railway tracks, the English language becoming established as the standard language of air navigation and a particular screw thread, which often "cannot be changed even if alternative techniques or conventions may be better" (Mainzer, 1996, p271).

The story however is not as simple as it may appear and the process leading to increasing returns and path dependence is not straightforward. Positive feedback is not the only process in operation in the examples given above. Apart from reinforcing feedback loops, there are negative feedback or stabilising loops also in operation. The two processes may be present simultaneously or they may follow each other as the market progresses through various economic cycles. Markets and economies are complex systems that co-evolve, are dissipative (in the sense that they are irreversible and have a history), show self-organisation and emergence, and explore their space of possibilities. As all these characteristics play out, the progression of any technology or market is not smooth.

Arthur in later studies (Arthur 2002) looks closely at the development of technology clusters (e.g. with electrification come dynamos, generators, transformers, switchgear, power distribution systems; with mass production and the automobile come production lines, modern assembly methods, 'scientific management' road systems, oil refineries, traffic control), which have defined "an era, an epoch, a revolution" (Arthur 2002). He shows how they eventually change the way business is done, and that they may even change the way society is conducted. The process starts with one or more technologies that 'enable' the new cluster (Perez 2002). The new technology cluster may at first attract little notice, but then starts to achieve successes in early demonstrations and small companies may be set up based on the new ideas. These compete intensely at this early turbulent phase and as successes increase, and Government regulation is mainly absent, the promise of large profits becomes apparent and the public may start to speculate. In certain cases this first exuberant phase is marked by a crash, and Arthur cites three examples, the railway industry crash in the UK in 1847; the Canal Mania of the 1790s with the shares crashing in 1793; and the recent Internet crash. In the past, the crash was followed by a sustained build-out or golden age of the technology, which influenced growth in the economy and the period was one of confidence and prosperity, like the period after 1850 in the UK when the railways became "the engine of the economy in Britain" (Arthur 2002). The last phase is one of maturity.

The point that Arthur is trying to make in this study is to show that if we take a historical perspective and compare the railways to the Internet then the real benefits are yet to come. While building his argument, however, he also shows the constant interplay between positive and negative feedback loops moving the markets between periods of expansion and stability. The story also illustrates co-evolution in the economy, exploration, the adjacent possible, and the emergence of new order.

6. Self-organisation, Emergence and the Creation of New Order

Self-organisation, emergence and the creation of new order are three of the key characteristics of complex systems. Kauffman in the 'Origins of Order: Self-Organization and Selection' (1993) focuses on self-organisation and describes his argument in the title. He calls Darwinian natural selection a "single singular force" and argues that "It is this single-force view which I believe to be inadequate, for it fails to notice, fails to stress, fails to incorporate the possibility that simple and complex systems exhibit order spontaneously." (Kauffman, 1993: xiii) That spontaneous order is *self-organisation;* he brings all three characteristics together when he refers to "the spontaneous emergence of order, the occurrence of self-organisation". He argues that natural selection is not the sole source of order in organisms and suggests that both natural selection and self-organisation are necessary for evolution; he then proceeds to expand evolutionary theory to incorporate both evolutionary forces.

Emergent properties, qualities, patterns, or structures, arise from the interaction of individual elements; they are greater than the sum of the parts and may be difficult to predict by studying the individual elements. Emergence is the *process* that creates new order together with self-organisation.

In systems theory, emergence is related to the concept of the 'whole'—i.e. that a system may need to be studied as a complete and *interacting whole* rather than as an assembly of distinct and separate elements. Checkland defines emergent properties as those exhibited by a human activity system "as a whole entity, which derives from its component activities and their structure, but cannot be reduced to them." (Checkland 1981, p314) The emphasis is on the *interacting whole* and the *non-reduction* of those properties to individual parts.

Francisco Varela (Varela & Maturana 1992, Varela 1995) in his study of the human brain sees emergence as the *transition* from *local* rules or principles of interaction between individual components or agents, to *global* principles or states encompassing the entire collection of agents. Varela sees the transition from local to global rules of interaction occurring as a result of explicit principles such as *coherence* and *resonance*, which provide the local and global levels of analysis, (Varela 1995) but adds that to understand emergence fully, we also need to understand the *process that enables a transition*. The emergence of mental states for example, such as pattern recognition, feelings and thoughts may be explained by the evolution of (macroscopic) (Varela's *global* principles or states) "order parameters of cerebral assemblies which are caused by non-linear (microscopic)" (Varela's *local* rules or principles) "interactions of neural cells in learning strategies far from thermal equilibrium." (Mainzer, 1996 p7). Another area where the transition process is still not fully understood is that of human consciousness. There is an ongoing debate between neuroscientists and philosophers as to whether consciousness can be described as an emergent property of the neural activity of the brain.

The relationship between the micro-events and macro-structures is not always in one direction and there is *reciprocal influence* when *feedback* is in operation "One of the most important problems in evolutionary theory is the eventual feedback between *macroscopic structures* and *microscopic events*: macroscopic structures emerging from microscopic events would in turn lead to a modification of the microscopic mechanisms" (Prigogine & Stengers 1989). This is a *co-evolutionary* process whereby the individual entities and the macro-structures they create through their interaction, influence each other in an ongoing iterative process.

Modern thermodynamics describes the emergence of order by the mathematical concepts of statistical mechanics (Mainzer, 1996 p4). Two kinds of phase transition (self-organisation) for order states are distinguished: conservative and dissipative. *Conservative* self-organisation means the phase transition of *reversible* structures in thermal equilibrium, such as the growth of snow crystals, which can revert to water or steam if the temperature is increased. *Dissipative* self-organisation is the phase transition of *irreversible* structures far from thermal equilibrium. Macroscopic patterns emerge from the complex non-linear cooperation of microscopic elements when the energetic interaction of the dissipative ('open') system with its environment reaches some critical value (Mainzer, 1996 p4). Nicolis (1994) adds "non-linear dynamics and the presence of *constraints* maintaining the system far from equilibrium" are "the basic mechanisms involved in the emergence of ... (self-organising) phenomena".

In an organisational context, self-organisation may be described as the spontaneous coming together of a group to perform a task (or for some other purpose); the group decides what to do, how and when to do it; and no one outside the group directs those activities. An example is what happened in an Integrated Project Team (IPT) in the Aerospace industry. The team was brought together to create a new project. The members of the team represented firms, which outside the IPT were competitors, but within the team had to cooperate and to create an environment of trust to ensure that sensitive information, necessary for the creation of the new product, could be freely exchanged. The team had to prepare a six-monthly report for its various stakeholders.

This report was on hard copy and was usually several inches thick. Some members within the team decided that they would try an alternative presentation. They found that they had the requisite skills among them and they put in extra time to produce the next report on a CD. The coming together of the sub-team to create the new format for the report illustrates the principle of self-organisation. No one told them to do it or even suggested it. They decided what to do, how and when to do it.

Emergence in a human system tends to create irreversible structures or ideas, relationships and organisational forms, which become part of the history of individuals and institutions and in turn affect the evolution of those entities: e.g. the generation of knowledge and of innovative ideas when a team is working together could be described as an emergent property in the sense that it arises from the interaction of individuals and is not just the sum of existing ideas, but could well be something quite new and possibly unexpected. Once the ideas are articulated they form part of the history of each individual and part of the shared history of the team - the process is not reversible - and these new ideas and new knowledge can be built upon to generate further new ideas and knowledge. In the same way organisational learning is an emergent property - it is not just reification (giving objective existence to a concept) but a process based on the interaction of individuals creating new patterns of thought at the macro or organisational level. When learning leads to new behaviours, then the organisation can be said to have adapted and evolved. In that sense, learning is a prerequisite for organisational evolution. If that is the case, then firms need to facilitate learning and the generation of new knowledge - learning here does not mean just training or the acquisition of new skills, but the gaining of insight and understanding which leads to new knowledge.

Continuing with this line of argument, the new knowledge needs to be shared, to generate further new learning and knowledge. There are many reasons why this process is severely limited in most organisations; one of those reasons may be that learning is often seen exclusively as the provision of individual training and another is that the generation and sharing of knowledge is identified with the capturing of data and information in a database. This is not what the current argument is about. It is about understanding *connectivity, interdependence, emergence* and *self-organisation*. It is about how these characteristics of a human organisation, seen as a complex evolving system, work together to create new order and coherence, to sustain the organisation and to ensure its survival, particularly when its environment or social ecosystem is changing fast.

Furthermore, the logic of complexity suggests that learning and the generation and sharing of knowledge need to be facilitated by providing the appropriate socio-cultural and technical *conditions* to support connectivity and interdependence and to facilitate emergence and self-organisation. The latter two characteristics in particular are often blocked or restricted even in what are considered to be liberal organisational cultures by complicated authorisation procedures. It is not however the case that all emergent properties and all self-organisation are necessarily desirable or efficacious. McKelvey (Chapter 10, current volume) eloquently argues that under certain conditions emergence could be “compromised, biased, fragile, sterile or maladaptive.” A negative side also applies to connectivity. Again complexity theory does not argue for ever-increasing connectivity, as there are limits to the viable connections that can be sustained and to the information that any individual can handle, that arises from these connections.

To summarise, the main points are: (a) if we see organisations as complex evolving systems and if we understand their characteristics as CES, we can work with those characteristics rather than block them; (b) those characteristics are closely related and we need to understand their interrelationship to gain maximum benefit from the application of the theory; for example, looking at emergence or self-organisation in isolation does not provide that deeper understanding; (c) to introduce the idea of *enabling environments* based on socio-cultural and technical conditions that facilitate rather than inhibit learning and the generation and sharing of knowledge; (d) to sound a warning that connectivity cannot be increased indefinitely without breakdown and that emergence is not always efficacious but can also become maladaptive.

7. Chaos and Complexity

Chaos Theory (Gleick 1987) is concerned with those forms of complexity in which emergent order co-exists with disorder at the *edge of chaos*, a term coined by Chris Langton (Waldrop 1992 - Penguin 1994: 230). When a system moves from a state of order toward increasing disorder, it may go through a transition phase in which new patterns of order emerge among the disorder, giving rise to the paradox of order co-existing with disorder.

But Chaos Theory is not identical with complexity, and the two concepts need to be distinguished in their application to social systems. Chaos theory describes non-linear dynamics based on the *iteration* either of a mathematical algorithm or a set of simple rules of interaction, both of which can give rise to extraordinarily intricate behaviour such as the intricate beauty of fractals or the turbulence of a river. Brian Goodwin (1997) describes such emergent patterns as the "emergent order (which) arises through cycles of iteration in which a pattern of activity, defined by rules or regularities, is repeated over and over again, giving rise to coherent order." Therein lies the key difference, because in chaos theory the iterated formula remains constant, while *complex systems may be capable of adapting and evolving,* of changing their 'rules' of interaction. Furthermore, "chaos by itself doesn't explain the structure, the coherence, the self-organizing cohesiveness of complex systems" (Waldrop 1992 - Penguin 1994: 12). Applying chaos theory to human systems therefore may not always be appropriate, because human behaviour does not always mimic mathematical algorithms. Humans have cognitive faculties that may enable them to change their rules of interaction.

7.1 Self-similarity

One of the features of complex systems is that similar characteristics may apply at different levels and scales. In an organisational context, the generic characteristics of complex systems may apply *within* a firm at different levels (individual, team, corporate), as well as *between* related businesses and institutions, including direct and indirect competitors, suppliers, and customers, as well as legal and economic systems. *Fractal* is the term often used to describe the repetition of *self-similar* patterns across levels or scale.

The concept of fractals is related to but distinct from the notion of *'hierarchy'* in systems theory. Hierarchy in the systems context does not refer to vertical relationships of organisational structure or power, but rather to the notion of *nested subsystems.* It is the interpretation of 'subsystem' that differs between the two theories. A fractal element reflects and represents the characteristics of the whole, in the sense that similar patterns of behaviour are found at different levels, while in systems theory, a subsystem is a *part* of the whole, as well as being a whole in its own right. It is "equivalent to system, but contained within a larger system" (Checkland 1981, p317). As Checkland (1981) notes, hierarchy is "the principle according to which entities meaningfully treated as wholes are built up of smaller entities which are themselves wholes … and so on. In a hierarchy, *emergent properties* denote the levels" (Checkland 1981, p314). In fractals, repeated properties denote the multiple levels of a system.

8. Managing Organisations as Complex Evolving Systems

If organisations were managed as complex evolving systems, co-evolving within a social ecosystem, emergence would be facilitated rather than inhibited, and self-organisation would be encouraged, as would exploration of the space of possibilities available to an organisation. Managers would understand that an organisation is an entity capable of creating new order, capable of re-creating itself. Management would focus on the creation of conditions that facilitate constant co-evolution within a changing environment, and would encourage the *co-creation* of new organisational form with those directly affected.

We next consider one case study that describes efforts to implement such complexity theory-based management approaches.

The Bank Case Study[5]

The European operation of an international bank needed to upgrade all its European information systems to handle the common European currency by a rigid deadline that could not be changed. The project was completed successfully and on time. One of the main drivers was the pressure of legal and regulatory requirements that needed to be met before the bank was ready to convert to the common European currency. However, although the exogenous pressure was a necessary condition, it was not sufficient for

[5] The Bank case study was written by Mitleton-Kelly and Papaefthimiou for the international workshop on Feedback and Evolution in Software and Business Processes (FEAST) London, July 10-12 2000, (Mitleton-Kelly and Papaefthimiou 2000, 2001)

success. Many other conditions needed to be created internally to provide a *socio-technical enabling infrastructure.*

The project introduced new technologies, and because of its high profile imported an international team of technical experts. What facilitated technical success were certain social conditions initiated by the Project Manager in charge of the project. One of the most important aspects was creating a closer working relationship between business and information systems professionals than had been the norm in that particular organisation. Previously, the system developers, business managers, and operations personnel simply did not talk to each other unless absolutely necessary.

One of the project managers initiated a series of monthly meetings at which all three constituencies had to be present and had to discuss their part of the project in a language that was accessible to the others. The monthly meetings, supported by weekly information updates, enabled the three managers of technology, business, and operations to talk together regularly. Initially the meetings were not welcomed, but in time, the various stakeholders involved in the projects began to identify cross-dependencies in the business project relationships, which led to new insights and ideas for new ways of working. Once conditions for new forms of communication were provided, the individuals involved were able to self-organise, to make necessary decisions and take appropriate actions. Communication enabled micro-agent interaction that was neither managed nor controlled from the top. Once inhibitors were removed and enablers put in place, new behaviours and ways of working emerged, making the business fitter and more competitive.

Research identified some of the conditions that enabled the new way of working and relating, as well as some of the conditions that could have restrained it.

Some of the enabling conditions were:

a) New procedures introducing regular monthly meetings, which supported *networking* and the building of *trust*, as well as a *common language* leading to mutual *understanding*.

b) *Autonomy*: the project manager was empowered to introduce new procedures.

c) A *senior manager* supported the changes, but did not interfere with the process.

d) *Stability*: sufficient *continuity* was assured to see the project through, in an environment where constant change of personnel was a given.

e) An *interpreter* mediated the dialogue between the domains of expertise represented at the meetings. This ensured understanding on both sides, but also helped to protect the technologists from constant minor changes in requirements.

The potential inhibitors were:

a) Charging for system changes

b) Management discontinuity, resulting in projects not completed

c) Differing perceptions—e.g. improving legacy infrastructure could have been seen as a cost by business managers, without understanding its compensating benefits.

d) Loss of system expertise during the project, through restructuring, downsizing, outsourcing, etc.

e) Lack of adequate documentation

f) Inaction when systems were seen as '*old but reliable'*

Another important element in this project was the articulation of business requirements as an iterative process through regular face-to-face meetings. The business requirements meetings in the Bank were at a senior management level with (a) a vice president who owned the product, was responsible for the P&L (profit & loss) and determined the business requirements, (b) a senior and experienced business project manager who was a seasoned banker, with a good knowledge of the bank, and (c) a senior technology project manager who defined the IS platform(s) and the technical development of the project. This constant dialogue created a willingness to communicate and a growing level of trust, both of which were essential enablers of co-evolution. These social processes can also be seen as positive *feedback or reinforcing processes.* For example, trust facilitates better communication, which in turn enables the building of IT systems that facilitate both better communication and the evolution of the business.

What was achieved in this case involved a project manager, supported by his senior manager, who created conditions that enabled dialogue, understanding, and a good articulation of requirements. He created the initial conditions that improved the relationships between the domains, but he could not exactly foresee how the process would work, or indeed whether it would work. As it happened, it did work, and substantial *network rapport* was established between the domains based on trust, a common language, and mutual understanding. They worked well together because the contextual conditions were right and they were prepared to *self organise* and work in a different way. The new relationships that emerged were not designed beforehand. They happened 'spontaneously' in the sense that they were enabled, but not stipulated.

The achievement in this case, however, could be a one-off event. Unless the new procedures and ways of working used in this project become embedded in the culture of the organisation, they may be forgotten over time. Once the project initiator moves on to another position or organisation, dissipation or reversion to the dominant mode of working may assert itself. In this case there has been some embedding to achieve continuity, but the process is fragile. Much of the embedding is the networking rapport that has been established, but the network rapport is implicit and informal, and is therefore under threat if there are too many and too frequent changes. The Bank's culture is one of constant change in management positions, and if the rate and degree of change is too great, then the networking and its ability to support emergent adaptations may be lost.

Summary and Conclusions

This chapter introduces some of the principles of complexity based on the generic characteristics of all complex systems. It uses the logic of complexity to argue for a different approach to managing organisations through the identification, development, and implementation of an *enabling infrastructure*, which includes the cultural, social, and technical conditions that facilitate the day-to-day running of an organisation or the creation of a new organisational form.

Enabling conditions are suggested using the principles of complexity. Complex systems are not 'designed' in great detail. They are made up of interacting agents, whose interactions create emergent properties, qualities, and patterns of behaviour. It is the actions of individual agents and the immense variety of those actions that constantly influence and create emergent macro patterns or structures. In turn the macro structure of a complex ecosystem influences individual entities, and the evolutionary process moves constantly between micro behaviours and emergent structures, each influencing and recreating each other.

The complexity approach to managing is one of fostering, of creating enabling conditions, of recognising that excessive control and intervention can be counterproductive. When enabling conditions permit an organisation to explore its space of possibilities, the organisation can take risks and try new ideas. Risk taking is meant to help find new solutions, alternative ways to do business, to keep evolving through established connectivities while establishing new ways of connecting (Mitleton-Kelly 2000).

This approach implies that all involved take responsibility for the decisions and actions they carry out on behalf of the organisation. They should not take unnecessary risks, nor are they blamed if the exploration of possibilities does not work. It is in the nature of exploration that some solutions will work and some will not.

Thus, another aspect of an enabling infrastructure is the provision of space, both in the metaphorical and actual senses. A good leader provides psychological space for others to learn, but also physical space and resources for that learning to take place. Individual and group learning is a prerequisite for adaptation, and the conditions for learning and for the sharing of knowledge need to be provided.

Complexity's great strength is that it crosses the boundaries of disciplines in both the natural and social sciences. It may one day provide us with a unified approach capable of linking those disciplines, because understanding the behaviour of complex systems in other subjects helps one gain deeper insights into phenomena in one's own field. Much work now being done on complexity in a variety of fields, from anthropology and psychology to economics and organisational science, will in due course change the way we see organisations, will help us understand their nature as complex systems, and ultimately will change the way that we manage organisations.

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