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

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Chapter 2

The Principles of Complexity and Enabling Infrastructures

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 and this inevitably results in different ways of working. In turn, the new types of relationship and approaches to work will provide the conditions for the emergence of new organisational forms.

This chapter will offer an *introduction to complexity* by exploring some of the *generic characteristics of complex adaptive systems* and will show how they relate to social systems and organisations. It will conclude by applying 'complexity thinking' to a method for the creation of *enabling infrastructures* [the combination of cultural, social and technical conditions that facilitate 'x'.] in two different contexts: (a) the conditions that facilitate co-evolution between the changing business process and information systems development; [(b) the creation of an inter-organisational trusting environment in IPTs (integrated project teams) in the Aerospace industry;]and (c) the creation of a new organisational form after restructuring, a merger or the spinning-off of a new business.

1. The Theories of Complexity

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 three decades by scientists associated with the Santa Fe Institute in New Mexico, USA, and particularly that of Stuart Kauffman [Kauffman 93, 95] John Holland [Holland 95, 98], Chris Langton and Murray Gell-Mann on complex adaptive systems (CAS), as well as the work of scientists based in Europe, such as Ilya Prigogine on dissipative structures [Prigogine & Stengers 1985, Nicolis & Prigogine 1989, Prigogine 1990], Isabelle Stengers [Prigogine & Stengers1985], Gregoire Nicolis [Nicolis & Prigogine 1989, Nicolis 1994], Peter Allen [1997], Brian Goodwin [Goodwin 1995, Webster & Goodwin 1996] and Humberto Maturana on autopoiesis.

By comparison there is 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 4-5 years. 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. Others have concentrated on non-human social systems, such that of bees, ants, wasps, etc.] Such a theory provides a different way of thinking about organisations, which changes strategic thinking and our approach to organisational form, that is the structure, culture and technology infrastructure of an organisation.

One way of looking at complex human systems is by examining the *generic characteristics or principles, common to all natural complex systems* and to consider whether they are *relevant or appropriate to social systems*. But there are two conditions to that approach. One 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 as complex social systems. The other condition is that it is beyond the scope of this chapter to examine all generic characteristics of complex systems and that only a selection can be included.

The former condition is emphasised because a number of authors consider the characteristics of complex systems 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 nature of system under study. The approach adopted here is to study the characteristics of human complex systems in their own right, without applying them exclusively as metaphors and without reducing them to those of biological, physical or chemical systems. Although reductionism, whereby all the phenomena at one level are explained entirely in terms of those of another [Hodgson, 2001? p89] may be untenable, it is necessary that explanations in one domain are consistent with explanations in another [ibid p90], that is, that they honour the *Principle of Consistency*.

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, however 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 reality.*

The approach taken by this chapter is to look at some characteristics or principles of complexity, both in their generic form and in their specific attribution to human systems.

There is however no ‘mapping’ between disciplines. Social systems are examined in their own right as complex systems with their appropriate complexity characteristics. The study of these principles or characteristics, will help us understand the nature of human systems and organisations (the deep ‘why’), and may help us to ‘manage’ them better. ‘Manage’ is in inverted comas, as complexity argues against the traditional approaches of management intervention and control. It argues for the provision of minimum conditions that will facilitate ‘x’, that will take advantage of the characteristics of emergence, self-organisation, exploration-of-the-space-of-possibilities and co-evolution to create coherence and new order. These conditions may be seen as the *‘enabling infrastructure’* that facilitates the running of organisations, enables their evolution and ensures their sustainability.

Fig 1

Fig. 1 shows some of the theories that have contributed to complexity thinking and a selection of generic characteristics: self-organisation, emergence, connectivity, interdependence, feedback, far-from-equilibrium, exploration-of-the-space-of-possibilities, co-evolution, hysteresis and increasing returns. The four principles grouped together 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.

Focussing on organisational complexity, the following working definition is proposed.

Organisational complexity *is associated with the intricate inter-relationships of individuals, of individuals with artefacts (such as IT) and with ideas, and with the effects of inter-actions within the organisation, as well as between institutions within a social ecosystem.*

Complexity is not a methodology or a set of tools. 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**.

2. Connectivity & Interdependence

Complexity arises from the inter-relationship, inter-action and inter-connectivity of elements within a system and between a system and its environment. Murray Gell-Mann [95/96] 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. Complexity is therefore associated with the *intricate inter-twining or inter-connectivity of elements within a system and between a system and its environment.*

In a human system, connectivity means that a decision or action by any individual (group, organisation, institution or human system) will affect all other 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 and 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, 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 rarely has 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' therefore may have associated 'costs' on other entities, either within the same system or on other related systems.

If a description of a complex system were to be attempted, it would run thus: a complex system is not merely a collection of many interacting parts or agents (entities capable of action). *Two entities interacting* together create complex inter-relationships, whose details *cannot be predicted*. They are capable of *adaptation* and *evolution* and can 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 – they create coherence. 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. Furthermore, the entities can *change their rules of interaction* and are able to *act on limited local knowledge*. They do not need to know what the system as a whole is doing. Finally, they are *self-repairing* and *self-maintaining*. Reference to entities as individuals or collections (systems) is deliberately ambiguous, to emphasise the point that all complex characteristics apply at all scales, both to the individual and to the whole, particularly when that 'whole' can be further analysed at different scales.

3. Co-evolution

Connectivity applies not only to elements within a system but also to related systems within an ecosystem. [An **ecosystem** in biology: "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 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* [8, 18, 19, 21, 27, 28, 36]; or *that one domain or entity changes in the context of the other(s).* This relationship means that co-evolution between entities can only take place within an ecosystem.

In human systems a social ecosystem includes the social, cultural, technical, geographic and economic milieu. The notion of co-evolution places the emphasis on the relationship between entities (the term *entity* is used as a generic term which can apply at different scales to individuals, teams, organisations, industries, economies, etc) and on the *evolution of those interactions* [9]. This emphasis is particularly important in social systems, as it is the interactions, and consequently behaviour, which co-evolve.

Complexity also emphasises *co-evolution <u>with</u>* rather than *adaptation <u>to</u>* a changing environment and thus changes the perspective and the assumptions, which underlie traditional management and systems theories [30, 31].

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. 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.

Figs 2 & 3 (side by side)

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 the economic, cultural and legal institutions. Strategies consequently, need not 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 one of empowerment, as it explains how all actions and decisions affect the social ecosystem. No individual or organisation is powerless – as each action permeates through the intricate web of inter-relationships and affects the social ecosystem. But co-evolution also argues for 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 also argues for a deeper understanding of reciprocal change and the way if affects the totality.

Strictly speaking, co-evolution takes place when 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 may be given. The first example was given by Maturana at an OU 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. Another example was given by a senior Marks & Spencer executive at an LSE Seminar [date?]. 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, and have produced something new, a new order or coherence.

Co-evolution also happens between entities *within* a system and the *rate of their co-evolution* [McKelvey date?] is a notion 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 break down. Some of the most successful organisations nurture their community milieu [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 (it is difficult to find the precise term, which differentiates the different entities without importing notions of hierarchy - all three terms will therefore be used interchangeably, without implying any hierarchical distinctions). Co-evolution is taking place at all 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' are not 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. It isn't a nested hierarchy of 'levels' but 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 connectedness.*

3.1 Degree of Connectivity

Propagation of influence through the ecosystem depends on the *degree* of connectivity and interdependence. “Real (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, p. 255] In human ecosystems the same is true. There are networks of relationships with different degrees of connectedness. *Degree of connectedness* means strength of coupling and the dependencies known as *epistatic interactions* - i.e. the fitness contribution made by one individual will depend upon related individuals. This is a contextual measure of dependency, of direct or indirect influence that each entity has on those it is related to or is coupled with. 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 with the individual in question.

In human systems connectedness between individuals or groups is not a uniform relationship but varies over time, with the diversity, density, intensity and quality of interactions between human agents. To assume that connectedness is uniform or homogeneous is to reduce the richness and reality of human interaction to that of a machine-like entity. Furthermore, it is the degree of connectedness, which determines the network of relationships and what determines the successful transfer of information and knowledge.

3.2 Fitness Landscapes

Co-evolution may also be considered within an ecosystem in terms of *related fitness landscapes*. Kauffman has developed the notion of *‘fitness landscapes*’, using the NK model, [Kauffman 1993, p. 29] where N stands for the number of entities or elements in a system and K stands for the degree of connectivity between the entities. Each entity N makes a fitness contribution, which depends upon that entity and upon K other entities among the N. That is, K reflects the rich cross coupling of the systems and measures the richness of epistatic interactions among the components of the system.

The notion of epistatic interactions is used by geneticists to describe the process of coupling in which a new gene links into the network of a species’ existing genes. In other words, the contribution, which a new gene can make to the species’ overall fitness, depends on the existing genes of that species.

In social systems this may be likened to the history of experiences and constitution of an institution - new ideas can only be ‘seen’ and developed if both the constitution and the history allow them to be ‘seen’ and be developed [Maturana 1997].

Another example of epistatic coupling in organisations is to consider the contribution, which a new recruit might make to the overall performance of the relevant unit (whether that is a team, department or the company as a whole). How much of a contribution is made will depend not only on the skills, talents and knowledge of the individual, but also on whether and to what degree, those skills are allowed to develop within the existing culture.

The NK model is abstract. Although we do not yet know what the real landscapes are like, Kauffman contends that we may be able to develop some intuition for their typical, or statistical structures by building simple models such as the NK model, which helps us understand their expected features. As the main parameters are altered, the model generates a *family* of increasingly rugged multi-peaked landscapes.

The problem with such models is that the ways in which different entities might be coupled to one another epistatically to produce an overall fitness for each system might be extraordinarily complex. In general, we truly have almost no idea what those mutual influences on overall fitness might be. If the fitness contribution of each entity is epistatically affected by a large number of other entities, the possible conflicting constraints among the complex web of epistatically interacting entities are both unknown and likely to be extremely complex. So complex that essentially arbitrary interactions are possible. The statistical features of their consequences, can therefore be modelled with a random fitness function. This leads to the NK model. The two main parameters are the number of entities N and the average number of other entities K, which epistatically influence the fitness contribution of each entity (the connectivity).

A *fitness landscape* is used in evolutionary biology to illustrate the competition for survival. Species attempt to alter their genetic make-up by taking ‘adaptive walks’ to move to higher ‘fitness points’, where their viability will be enhanced. Species who fail to move to higher points on their landscapes may be outpaced by competitors who are more successful in doing so, and risk becoming extinct through a process of natural selection. Kauffman models simplified versions of fitness landscapes, using the NK model, to represent a series of peaks and valleys of varying heights and depths.

A fitness landscape may also be used by companies to assess their ‘fitness’ within a competitive ecosystem [Kauffman 1993, Oliver & Roos 1997]. Such an exercise may be used to illustrate or clarify a number of issues: competitive fitness; conflicting constraints within a web of epistatically interacting entities; and participation within a co-evolving ecosystem. By changing different parameters, an organisation may take ‘adaptive walks’ within its industry ‘landscape’ – this would demonstrate the existing position as well as opening up other possibilities, which would improve its ‘fitness’ or competitive position. A fitness landscape would also demonstrate how each adaptive move affects the position of all other related businesses, how it ‘deforms’ the ‘landscapes’ of neighbours and would illustrate the concept of co-evolution.

Change therefore, may be seen in terms of adaptive evolution. But adapting entities confront *conflicting constraints* both in their internal organisation and in their interactions with their environments. These conflicting constraints typically imply that finding the ‘optimal solution’ is very difficult. But it also means that there may exist many alternative locally optimal solutions.

Furthermore, the consequence of attempting to optimise in systems with increasingly many conflicting constraints among the components brings about what Kauffman calls a *'complexity catastrophe'* [Kauffman 1993]. As complexity increases, the heights of accessible peaks recede towards the mean fitness. The onset of the catastrophe traps entities on a local optimum and thus limits selection. This is clearly important. If this applies to organisations, what are the implications and how can this limitation be avoided?

Having to cope with increasing conflicting constraints is one problem associated with information technology. **"**These conflicting constraints typically imply that finding the "optimal solution" is very difficult and that many alternative locally optimal compromise solutions exist in the space of possibilities.....Technological evolution, like biological evolution, can be considered a search across a space of possibilities on complex, multipeaked 'fitness', 'efficiency' or 'cost' landscapes." [Kauffman & Macready 1995]

Kauffman's work on fitness landscapes deforming as the environment changes, may lie at the heart of an extended understanding of adaptive organisations.

Another area, which is subject to the complexity catastrophe, is when growing a social network. The process shows the following characteristics. When two people are interacting the exchange is relatively limited, but better than one person working on his own. When a few more individuals join the group, the level and richness of interaction increases significantly, but there is a limit to the improvement. That limit is around 6 – 8 interacting individuals assuming that in a group of 8 each one needs to interact with 7 others.

As the number of individuals increases, if the direct connectivity increases at the same rate, it soon becomes extremely difficult to interact with all others in the group. Consider for example attempting to interact with 91 other individuals in a group of 92! Under those conditions, the complexity catastrophe will set in.

However, if the number of direct connections (or epistatic interactions) remains small, while the number of individuals increases, the fitness landscapes retain high accessible local optima. In other words, if *each individual interacts directly with rather few other individuals* within the network, then the network can grow without disintegrating. The same effect is created by *loosely coupled connections* in a network, which are only activated as and when necessary. While if the connections remain direct and permanently active, then the complexity catastrophe in the form of information overload will set in – e.g. the copying of all messages by email to everyone on a circulation list. Eventually, most people simply ignore such messages, when under constraints of time.

The complexity catastrophe due to conflicting constraints is a general property of complex systems. [Kauffman 1993] When a property applies to all complex systems, this means that it is part of their nature, and is not being applied as a metaphor or analogy from another discipline. [Kauffman 1993, Nicolis & Prigogine 1989]

Furthermore, for limited interaction, (small values of K) the local optima are not distributed randomly in space but are near one another thus ***there is global structure to the fitness landscape: the highest optima are nearest one another***.

This characteristic leads to the notion of the *'next adjacent'*. In the exploration for new ideas, the search needs to consider ideas, which are one step away.

At the opposite extreme, the parts are richly coupled. But in this case common experience suggests that conflicting design constraints make it difficult to achieve overall success. Such conflicting constraints lead to an adaptive landscape, which becomes more multi-peaked as the number of parts increases. Thus adaptations, which must search such rugged landscapes, tend to become trapped in very small regions of the space.

That is***, adaptive evolution is bounded*** by the character of fitness landscapes. But that character in turn depends upon the entities, which are evolving. Hence evolution can change the rugged structure of fitness landscapes and their impact on evolution by changing the adapting entities.

4. Far-from-equilibrium & Dissipative Structures

A profitable way of studying complexity is by looking at dissipative structures, which are open systems exchanging energy, matter or information with their environment and which when pushed far-from-equilibrium create new structures and order.

The Benard 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 value 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 value the liquid performs a bulk movement which is far from random: the fluid is structured in a series of small convection 'cells' known as Benard cells.

Several things have happened: (a) the water molecules have spontaneously organised themselves into right-handed and left-handed cells. This spontaneous movement is called *self-organisation* and is one of the key characteristics of complex systems; (b) from molecular chaos the system has *created order* and a *structure;* (c) although we can predict that the cells will appear, the handedness or direction of rotation *can neither be predicted nor controlled*; (d) the system was pushed far-from-equilibrium by an *external* *constraint or perturbation*; (e) the homogeneity of the molecules at equilibrium was disturbed and their *symmetry was broken.* Symmetry breaking is another feature of complexity; (f) 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 classical thermodynamics heat transfer or dissipation was considered as waste, but in the Benard cell it has ***created new order***. It is this ability of complex systems to create new order and coherence, which is their distinctive feature. The Benard cell process or thermal convection is the basis of several important phenomena, such as the circulation of the atmosphere and oceans, which determines weather changes. Another example is continental drift. Convection is also the basis of the transfer of heat and matter in the sun, which in turn affects solar activity. [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 a necessary 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, p. xxi]

Dissipative structures like the Benard cell, demonstrate many of the features of complexity, which apply to chemico-physical systems from a laboratory experiment to the weather and solar activity. By studying the common or generic characteristics of complex behaviour across different domains, we begin to understand complexity. For example it is clear that self-organisation is a spontaneous coming together of elements to create coherence from previously random activity. There is also apparent paradoxical behaviour resulting from both determinism and chance. We know that the cells will appear and this phenomenon is a result of determinism, yet the direction of rotation cannot be predicted or controlled and is the result of chance in the form of the particular perturbation at the time of the experiment. This cooperation between chance and determinism in physico-chemical systems also appears in biology in the "duality of mutation (chance) and natural selection (determinism)." [Nicolis & Prigogine1989, p 14]

What Prigogine and Nicolis show [1989] is that when a constraint is sufficiently strong, the system moves far from equilibrium, and re-adjusts to its environment in several different ways. That is "*several solutions* are possible for the *same parameter values*. Chance alone will decide which of these solutions will be realized. 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." [ibid p14]

In dissipative structures the split into alternative solutions is called ***bifurcation*** – the term is misleading in that it means separation into two, when in fact there may be several possible solutions. However, as it is easier to explain the splitting of possibilities into two alternative paths, this method will be used, with the proviso that multiple solutions are also possible. In the Benard cell, a unique solution is present until the heat differential reaches a critical value. At that point the cells self-organise themselves and have to decide whether to become right or left-handed. The two possibilities are present simultaneously. Fig 4 which is borrowed from Nicolis and Prigogine [1989 p72] illustrates bifurcation.

Fig. 4

An observer could not predict which state will be chosen; "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." [ibid p72] At a totally different scale, the notions of chance and history are used by Kauffman to describe a view of evolutionary biology, "… 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 systems context, it is the series of critical decisions each individual takes from several possible alternatives that determine a particular life path for an individual, an organisation or a nation. Once the decision is made, the entity may become a historical object, but *before* the decision is finalised, the alternatives are sources of *innovation* and *diversification*, since the opening up of possibilities endows 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.

In the methodology described at the end of this chapter, three types of 'inhibitors' are identified. They are those one can do nothing about, those one can do something about and those constraints, which create new order. From this perspective inhibitors become enablers, as the system explores and finds new ways of working, as shown by the discussion on dissipative structures. Being aware of these characteristics of complex systems, we can shift our perspective. If we see 'inhibitors' as potential 'enablers' we open up and facilitate innovation and diversification. This may appear trivially obvious, yet few organisations deliberately encourage the exploration of alternative solutions as a matter of course. A suggestion box is not what this is all about. It is rather a matter of providing the conditions whereby it is safe to explore, where self-organisation is encouraged and the necessary support is provided to try out different ideas. The Humberside TEC in the UK and Sencorp in the USA, both provided such conditions. [Mitleton-Kelly & Subhan 2001; Sencorp Report date?] As a result the culture, the way of working and relating and consequently the organisational form changed. It was rather instructive when Ken Slocum and Scott Frondorf [ ] answered questions at the seminar they led at the London School of Economics. Many of the questions, based on traditional management did not make sense to them. Their way of thinking had changed so much it was difficult for them to re-adjust to conventional management thinking.

Symmetry breaking means that homogeneity is broken and new patterns emerge. It is interesting to consider that symmetry breaking is a prerequisite to information, in the sense that when the pattern of homogeneous data is broken by differentiated patterns, then this 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 are sought from the expected norms. When a dissipative structure leaps into a new order, then it requires more energy or information to sustain it than the simpler structure it replaced. In terms of the flow of information, a stable system can be sustained with a sluggish flow, but a much more vigorous and richer flow is necessary for a system operating far-from-equilibrium

Nonequilibrium has enabled the system to avoid thermal disorder and to transform part of the energy communicated from the environment into an ordered behaviour of a new type, the *dissipative structure*, which is characterised by symmetry breaking and multiple choices. In chemistry ***autocatalysis*** (the presence of a product may enhance the rate of its own production) shows similar behaviours and the Belousov-Zhabotinski (BZ) reaction, under certain nonequilibrium conditions shows symmetry breaking, self-organisation, multiple possible solutions and hysteresis (the specific path of states followed depends on the system's past *history*). [Nicolis & Prigogine 1989, Kauffman 1993, 1995] Furthermore, *self-reproduction*, a fundamental property of 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 and these systems whether biological, physical or chemical, display similar characteristics.

Similarly in social systems, when an organisation moves away from equilibrium or 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 and consciously push a human institution far-from-equilibrium. On the other hand understanding the behaviour of complex systems, humans can also provide help and support for the 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 thus become dependent on the designers to provide a new framework to facilitate and support the 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 design and control the outcome. However, if re-design were to concentrate on the provision of *enabling infrastructures* while allowing the new patterns of relationships and ways of working to emerge, new forms of organisation will arise which would be more attuned with the culture of the organisation. The new emergent organisation will thus be unique and not susceptible to copying. It will furthermore be more robust and sustainable.

5. Feedback, Increasing Returns and Unpredictability

5.1 Feedback

Feedback is traditionally seen either as negative or positive. A familiar example of negative feedback is a central heating system. A thermostat monitors the temperature in the room, and when the temperature drops below that specified, an adjusting mechanism is set in motion, which turns the heating on until the required temperature is attained. Similarly, when the temperature rises above the set norm, the heating is switched off until the desired temperature is reached. The gap between the required 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.

Positive and negative feedback mechanisms are also described as: "reinforcing (i.e. amplifying) and balancing. While the former is seen as a driver for change the latter operates whenever there is goal-seeking behaviour." [Kahen & Lehman, http://www-dse.doc.ic.ac.uk/~mml/]. Putting it another way, positive (reinforcing) feedback creates change and negative (balancing, moderating or dampening) feedback creates stability. Two points need to be made regarding the Kahen and Lehman quotation. First, feedback *'mechanisms'* are related to engineering and other machine-type systems, as indicated by the language used (i.e. 'mechanism'). Since this chapter is dealing primarily with 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. Second, the term 'goal seeking' is taken to mean that the *actual* system behaviour is seeking to attain the condition of a *desired* system. It is however worth making the point that biological evolutionary processes are not 'goal seeking' in the sense that they are *directed*. Organisational evolution, on the other hand, is not a direct analogue of biological evolution, as cognition and learning do provide a strong element of direction. However, both biological and social evolution depend on emergence, self-organisation, exploration of the space of possibilities, and other processes whose outcome is not goal seeking or directed, in the sense that there is a *specific desired outcome*, which can be planned and whose behaviour can be *precisely* predicted. [Mitleton & Papaefthimiou, 2000, 2001]

In **far-from-equilibrium conditions**, non-linear relationships prevail, and the system becomes "inordinately sensitive to external influences. Small inputs yield huge, startling effects" [Prigogine & Stengers 1985, p. xvi] and the whole system may reorganise itself.

Part of that process is the outcome 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." [ibid, p. xvii]

In human systems, far-from-equilibrium conditions operate when a system is perturbed away from its established norms, or away from its usual ways of working and relating. When it 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 a new order and organisation - i.e. find new ways of working and relating – and thus create a new *coherence*. (It may also find several other possible solutions.) Positive or reinforcing feedback processes underlie such transformation. But there are other processes also at work, such as self-organisation, co-evolution and exploration-of-the-space-of-possibilities**. The two types of feedback mechanism are therefore not sufficient to describe all the feedback processes in complex systems**, but they do provide a starting point and they do capture the constant movement between change and stability.

One reason for interventions, which create far-from-equilibrium conditions, is that the current feedback processes are no longer working. These are usually negative or balancing feedback processes, which in the past were able to adjust or influence the behaviour of the organisation, and to produce the desired outcome. When efforts to improve or optimise behaviour, in order to improve performance and market position, continually fail and when small incremental changes are no longer effective, then organisations resort to major interventions in an effort to produce radical change. These however may also fail and the organisation seems to become locked in a constant cycle of restructuring. One reason for failure is over-reliance on 'adjustment mechanisms', which operate on negative feedback, and which have worked in the past. But in a turbulent environment, the fitness landscape of the entire ecosystem is changing and we cannot always extrapolate from past experience, as new patterns of behaviour and new structures do emerge, which may be the outcome of positive feedback processes.

In human systems, degree of connectedness, dependency or epistatic interaction may determine the strength of feedback. It may therefore be useful to rethink the notion of feedback when applied to human interaction. *Feedback in this context is taken to mean influence, which changes potential action and behaviour*. Furthermore, in human interactions feedback cannot be a straightforward input - process - output procedure with predictable and determined outputs. Actions and behaviours vary according to the degree of connectedness between different individuals, as well as with time and context.

Co-evolution may also be dependent on reciprocal influence between entities. An interesting and important question is therefore *how does degree of connectedness influence co-evolution?* This becomes particularly relevant when considering enabling conditions for co-evolution. Another related question is *how does the structure of the ecosystem affect co-evolution?* Kauffman makes the bold statement that "We have found evidence ... that the structure of an ecosystem governs co-evolution." [18, p. 279] But this confident statement is based on simulations of the abstract NK model. It is however intuitively convincing and there is work examining the evidence that the same is true of social ecosystems [LSE Complexity Programme]. The relevance of these questions is that *feedback processes have a bearing on both degree of connectedness (at all scales) and ecosystem structure, and hence on co-evolution.*

Furthermore, the two familiar ‘mechanisms’ of positive and negative feedback are not sufficient to describe the multiple feedback processes in complex systems, and we need to rethink feedback in this context as multi-level and multi-process non-linear influence.

5.2 Increasing Returns & Unpredictability

Brian Arthur argues that conventional economic theory is also based on the assumption of negative feedback or diminishing returns, which leads to a predictable equilibrium point. 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 drop in prices by the early 1980s. But, Arthur argues, such stabilising forces do not always operate. "Instead positive feedback *magnifies* the effects of small economic shifts", and increasing returns or *positive feedback makes for many possible equilibrium points.* Consequently, a particular economic outcome **cannot be predicted.**

This feature of more than one possible equilibrium points, has also been described by Nicolis and Prigogine [1989] for physico-chemical systems. What they noticed was that “two (or sometimes several) simultaneously stable states could coexist under the same boundary conditions.” They call that 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 the system follows depend on its past history. This phenomenon is called ‘**hysteresis’** and is closely associated with bistability. The point here is that past history affects future development, but not in a predictable way, as there are several possible paths or patterns, which the system may follow. These characteristics explain why the *precise* behaviour of a complex system cannot be predicted, while keeping it within certain bounds.

The classic example associated with Arthur’s argument of increasing returns [Brian Arthur, 1990 + book?], showing a virtuous circle and self-reinforcing growth, is that of 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." [Brian Arthur, 1990]

Positive feedback is not the only element affecting unpredictability. Chaos theory shows that the smallest change or variance in the initial conditions, could lead to major *qualitative* changes in the behaviour of the system. This *sensitive dependence* to initial conditions means that very small variations in parameter values could lead to great variation in system behaviour. Furthermore, "errors are not distributed in the way statistical theory assumes; instead, variances are infinite so that standard estimation techniques break down." [Parker & Stacey 1994, p13]

Consequently, if the *quantitative* effect of positive feedback is associated with the *qualitative* effect of sensitive dependence, it becomes impossible to guarantee or accurately predict a specific outcome.

5.3 Bounded Instability and Markets

However, although the specific behaviour of a dynamic system may be unpredictable, the range of possible behaviour does have limits. That is, there are limits to the instability. Complexity theory calls this limited range of behaviour: ***bounded instability***. For example we know that the temperature in London will not reach 90°F in January and that it will not be below zero in July. We cannot predict what it will be precisely for the 21st of January and July next year, but we know that it will be between certain limits. Those limits are set around *attractors*. Unstable, complex behaviour does not have infinite range, it is limited or bounded by *attractors*. ***An attractor binds a system to a pattern of behaviour***. This may be attraction to a stable point, to a regular cycle such as a pendulum or to more complex forms of behaviour. If an attractor has multiple points of attraction within a finite space it is called a *strange* attractor and it limits a system's unstable behaviour within those limits.

That state of *bounded instability* is qualitatively different from either a state of stability or one of instability. A complex, dynamic system can exist in three different states. Two of those states are contradictory: one is a state of stability and the other is a state of instability. But in the *transition phase* between the two extremes, there is a third state of *bounded instability.* That third state, *the edge of chaos*, can accommodate stability and instability, certainty and uncertainty, order and disorder *at the same time.* This is the state where the components of a system are not stable yet they do not "dissolve into turbulence", either. [33]

But what is the significance or relevance of the three states and their behaviour, to social systems?

The three states of stability, bounded instability and instability are analogous to a stable market environment, a market with a high degree of uncertainty which does not deteriorate into disorder, and a totally unstable market. The discussion which follows, will concentrate on the first two states, those of stability and bounded instability and will show that although different strategy and planning approaches are appropriate in each state, there is no strict dichotomy.

If an organisation exists in a state of *stability*, then conventional planning approaches may be used with a high degree of success. When Ackoff wrote in 1970 that "planning is the design of a desired future and of effective ways of bringing it about," [Ackoff 1970, p1] he was reflecting a stable American corporate environment. He was also expressing an implicit belief in the Newtonian machine metaphor. In a stable environment, patterns of behaviour are recognisable, can be predicted with a relatively high degree of accuracy, and conventional planning approaches may be applicable. But when uncertainty increases, the patterns of behaviour begin to change. They are new, no longer recognisable, and they cannot be extrapolated from past experience.

In the state of *bounded instability*, strategy and planning acquires a new meaning and the emphasis changes from established methodologies to new ways of thinking. Some planning tools, such as scenario planning, may still be used, but they will need to be applied in a different way and seen from a fresh perspective. If uncertainty increases to the point of *instability*, with the associated high turbulence, then all conventional planning approaches become totally ineffective. The difference between the states of bounded instability and instability, is that in the transition phase, analogous to the edge of chaos, the behaviour may be new but it does have pattern and structure. It will be the ability to recognise new patterns as they emerge, which will provide organisations with a real competitive advantage in future. Thinking in complexity terms helps in 'seeing' the new patterns.

6. Chaos and Complexity

Chaos Theory sees complexity in terms of emergent order co-existing with disorder at the *edge of chaos*. When a system moves from a state of order towards increasing disorder, it goes through a transition phase called the 'edge of chaos'. In that transition phase new patterns of order emerge among the disorder and this gives rise to the paradox of order co-existing with disorder. Complexity is seen in terms of *the order, which emerges from disorder.* The term 'edge of chaos' was coined by Chris Langton [Waldrop 1994 p 230] when he was studying second order phase transitions.

But Chaos Theory is not identical with complexity and they need to be distinguished as their application to social systems may differ. Chaos theory or non-linear dynamics is based on the *iteration* either of a mathematical algorithm or a set of simple rules of interaction, which can give rise to extraordinarily intricate behaviour, such the detailed beauty of fractals or the turbulence of a river, described by Brian Goodwin [1997] 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." Chaos provides some powerful analogies associated with the edge of chaos, the emergence of order, and the co-existence of stability with instability. But, in chaos theory the iterated formula remains constant, while *complex systems are capable of adapting and evolving* and 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 1994 p 12]

When applying chaos theory to human systems, the analogy becomes inappropriate and misleading. Humans are not mathematical algorithms; they have cognitive faculties, which enable them to change their rules of interaction. Furthermore, complex social systems, do not necessarily function through iteration, as understood in mathematics, unless iteration is defined so broadly to accommodate cycles of learning and adaptation, that it becomes practically meaningless. Principles or properties, which are based on chaos theory and apply to chaotic systems, need to be applied with great circumspection to social systems, and only as metaphors or analogies.

6.1 Self-similarity

The terms used above have varied from 'element', to 'system' and to 'entity'. The use of language reflects one of the characteristics of complex systems, which is that similar characteristics apply at different scales. In an organisational context the generic characteristics of complex systems will apply *within* a firm at different levels (individual, team, corporate), as well as *between* related businesses and institutions, which will include direct and indirect competitors, suppliers and customers, as well as the legal and economic systems. The term often used to describe the repetition of *self-similar* patterns across scale is *'fractal'* and is associated with chaos theory.

The concept however also has certain similarities with the notion of *'hierarchy'* in systems theory. Hierarchy in this context does not refer to the vertical relationships of organisational structure or power, but to the notion of *nested subsystem.* But the interpretation of 'subsystem' 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 scales. 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." [24, p317]. The emphasis in systems theory is on the *wholeness* of the part rather than on the constitution or representative characteristics shown by that part. Checkland [24] makes that clear in his definition of hierarchy: "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." [24, p314]

7. Emergence

Emergent properties, qualities, patterns or structures, arise from the interaction of individual elements; they are greater than the sum of the parts and cannot be predicted by studying the individual elements. Emergence is the process, which creates those properties or qualities or new structures.

In systems theory it is linked with the concept of the 'whole' – i.e. that a system needs 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.

Another view of emergence is offered by Gregoire Nicolis [1994][8] studying physical complex systems, who describes emergence in terms of self-organising phenomena. While Francisco Varela [Varela & Maturana 1992, Varela 1995] 26, 27], 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.

The above are different points of view of essentially the same concept. What they do not do is *explain* the *process of emergence,* which is associated with the issue of scale. Nicolis has attempted such an explanation in terms of "mechanisms". He identifies "non-linear dynamics and the presence of constraints maintaining the system far from equilibrium" as "the basic mechanisms involved in the emergence of ... (self-organising) phenomena" [Nicolis 1994][8]. The concepts of ‘far-from-equilibrium’ and ‘self-organisation’ are essential to an understanding of complexity, but they do not fully explain the process of emergence.

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] [26] But adds that to understand emergence fully, we also need to understand the *process, which enables that transition.*

Emergence is also associated with feedback and the reciprocal influence between microscopic events and macroscopic structures: “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]

The interplay between micro-interactions and macro-structures or properties is the closest we have come to understanding emergence.

Complexity researchers are attempting to understand the relationship between micro and macro behaviour and the properties within and between systems, and to explain the process of emergence [e.g. 4 plus others to be published].

8. Exploration-of-the-space-of- possibilities

The sciences of complexity have shown that for an entity to survive and thrive it needs to explore its space of possibilities and to encourage variety. Complexity also indicates that the search for a single 'optimum' strategy is neither possible nor desirable. Any strategy can only be optimum under certain conditions, when those conditions change the strategy or solution are no longer optimal. Consider this notion in terms of fitness landscapes. If an organisation considers itself at the peak of its industry's fitness landscape and its success entices it to relax, it may suddenly find that the ecosystem has changed and the fitness landscape is completely different. It may find itself in a valley instead of on top of a peak. To survive it needs to be constantly scanning the landscape and trying different strategies. One view is that an organisation needs to have in place several micro-strategies, which are allowed to evolve before major resources are confined to a single strategy. This reduces the risk of backing a strategy too early, which may turn out not be the best one. It also ensures sensitive co-evolution with its changing ecosystem.

When markets were stable and growth was a constant, single optimum strategies based on extrapolation from historical data, were thought to be feasible. But unstable environments and rapidly changing markets require flexible approaches based on requisite variety. [Ashby 1969] [28]

But variety alone is not enough. New connections or contributions also need to be 'seen'. Very often it is not expensive research and development which produces major innovations, but 'seeing' a novel function for a part of an existing entity, in a new light. That is called, ***'exaptation'*** and emergence. "Exaptation is the emergence of a novel function of a part in a new context. … Major innovations in evolution are all exaptations. Exaptations are not predictable" [Kauffman 1997] [30]

A trivial 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 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, 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, however, whether for a new product or a different way of doing things, it is not possible to explore all possibilities - but it is possible to consider change one step away from what already exists. This is called the ***'adjacent possible'***.

9. What is A CES Organisation?

If organisations were seen as complex evolving systems, co-evolving within a social ecosystem, then emergence would be facilitated and not actively inhibited; self-organisation would be encouraged and so would exploration-of-the-space of possibilities. Managers would understand about degrees of connectivity and how they affect learning and the exchange of knowledge. Finally such an organisation would be seen as an entity capable of creating new order, capable of re-creating itself.

This however would require quite a fundamental change of approach to management. It would mean that the emphasis changed from top-down control and intervention to the creation of conditions, which facilitated constant co-evolution with its changing environment. That kind of approach would reduce regular restructuring, and facilitate change as an organic process. The emphasis would also be on the *co-creation* of the organisational form with those directly affected, instead of externally imposed design.

The above description may appear to be an ideal dream, far from reality. But some organisations have tried these ideas, with varying degrees of success [Lewin & Regine, Sencorp, Zimmerman, Susanne Kelly …] A new project, funded by the Engineering & Physical Science Research Council in the UK, will test these ideas. The 3-year collaborative project, which started on 1 July 2001, has four industrial partners (Shell Internet Works, Rolls Royce Marine and BT's Brightstar (British Telecommunications's incubator of new businesses) and a fourth partner to be appointed), a 12-person research team and several academic and business experts, making up an International team of Advisors.

The project aims to identify the socio-cultural and technical conditions that will facilitate the co-creation of new organisational forms after a merger or acquisition, organisational restructuring and the spinning-off of a new business.

Two earlier projects have prepared the ground. One project looked at the co-evolution between changing business processes and information systems development. The notion of a 'natural experiment' and of enabling conditions, which facilitate the creation of new order, was developed during that project and will be described below. A second project with the Aerospace industry looked at inter-organisational relationships and focussed on trust, creativity and risk. It helped to develop the notion of the socio-cultural and technical infrastructure and helped develop the methodology. Finally, a short pilot study in Shell tested the first part of the methodology.

What the project is trying to test is whether, knowingly using the principles of complexity the industrial partners can create organisations, which can co-evolve with their changing environment and recreate themselves as they grow, thus reducing the need for constant imposed restructuring.

10. Enabling Infrastructures

10.1 The Bank Case Study

[The Bank and the Building Society case studies were written by E. Mitleton-Kelly and MC Papaefthimiou for the FEAST workshop in London, 2000 and will be published in 2001.]

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 exogenous pressure of legal and regulatory requirements, which needed to be implemented before the bank was ready to handle the common European currency. However, although the exogenous pressure was a necessary condition, it was not sufficient for success. Many other conditions needed to be created internally and this section describes some of them, which contributed to a local *socio-technical enabling infrastructure.*

The project introduced new technologies, and because of its high profile was also able to import an international team of technical experts. But what facilitated the technical success were certain social conditions initiated by the Project Manager in charge of the project. One of the most important aspects was the facilitation of a closer working relationship between the business and information systems professionals, which was not the norm in that particular organisation. The system developers, business managers and operations personnel, simply did not like talking to each other, unless absolutely necessary.

One of the project managers initiated a series of monthly meetings when 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 environments of technology, business and operations to talk together regularly and in a way that was going against established ways of working. Initially the meetings were not welcomed, but in time, the various stakeholders involved in the projects began to identify cross-dependencies in terms of the business project relationships, which led to new insights, and new ways of working. Once the conditions were provided the individuals involved were able to self-organise, to make the necessary decisions and take the appropriate actions. This illustrates micro-agent interaction, which is neither managed nor controlled from the top. Once the inhibitors were removed and the enablers put in place, new behaviours and ways of working emerged. The monthly sessions improved communication between the different domains by improving understanding, but they also allowed for the emergence of new ways of working, and in the process helped the business become fitter or more competitive.

The research identified some of the conditions, which enabled that new way of working and relating and some of the conditions, which could potentially have restrained it. The operation was small and local to London. It was called a ‘natural experiment’ because those directly involved were trying out new ways of working, which were different from the established culture.

Some of the enabling conditions were:

a) New procedures introducing regular monthly meetings, which enabled *good networking* and *trust*, as well as a *common language* leading to mutual *understanding*.

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

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

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

e) An *interpreter* mediated the dialogue between the domains. This ensured understanding on both sides but also protected the technologists from constant minor changes in requirements.

The potential inhibitors were:

a) Charging for system changes

b) Management discontinuity and projects not completed

c) Differing perceptions – e.g. improving legacy infrastructure seen as a cost by business managers

d) Loss of system expertise, through restructuring, downsizing, outsourcing, etc

e) No documentation with high interconnectivity and incremental growth

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

g) Contradiction of how legacy is perceived and what is being done about it

Legacy systems are information systems, which no longer support the business process. They are often very old systems, which suffer from innumerable modifications that have not been documented. As these systems are often essential to the running of an organisation they are closely integrated with newer systems and with many of the essential applications. Their inter-connectivity and inter-dependence is massive, but unknown. It is when a new modification creates effects in unexpected parts of the system that these dependencies are discovered.

Legacy systems are such a problem that the UK Government, through one of its Research Councils, funded 28 projects in different Universities, working with industrial partners, to examine the problem and offer some solutions. One important finding from the entire research programme was that legacy is not simply a technical problem, but a socio-technical one. The project under discussion, focussed from the outset on the socio-technical nature of legacy and the conditions described emphasise the social aspect.

Another important element in the Bank natural experiment was the articulation of business requirements as an iterative process with regular face-to-face meetings. To put this into context, the elicitation of business requirements is rarely the outcome of a dialogue. They are usually written down by those least qualified to undertake the exercise. The outcome is often new systems, which are already ‘legacy’ in the sense that they do not fully support the business process for which they were designed.

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 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 level of trust, which were essential enablers of co-evolution. These social processes can also be seen as *feedback enabling or facilitating processes*. For example, trust facilitates better communication, which in turn enables the building of IT systems that facilitate the evolution of the business.

What was achieved in the London operation of the bank, took a particular individual, supported by his senior manager, to create the conditions that enabled dialogue, understanding and a good articulation of requirements. He created the initial conditions, to improve the relationship between the domains, but he could not foresee how the process would work or 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 conditions were right and they were prepared to *self organise* and work in a different way. The new relationships were not designed or even intended. They happened spontaneously in the sense that they were enabled but not stipulated.

The achievement however, could be a one-off. Unless the new procedures and ways of working become embedded in the culture of the organisation, they are likely to dissipate over time. Once the initiator is no longer in place, the danger of dissipation or reversion to the dominant mode of working will assert itself. In this case there has been some embedding and some continuity, but the process is fragile. A new set of organisational changes could destroy it. Part 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 and the Bank’s culture is one of constant change in management positions. *“Every two years someone else is in the post so that there is that lack of continuity.”* If the rate and degree of change is too great then the network will become invalid.

10.2 The Building Society Case Study

The emphasis in the bank study was on the natural experiment to illustrate how some enabling conditions helped create a new way of working and relating. The emphasis in the building society case study will be on some complexity principles, which created an enabling infrastructure.

a)*"Gurus" as emergent phenomena; operating far-from-equilibrium and exploration of the space of possibilities.*

The part functionality and shortcomings of the legacy systems, the continuous changes and enhancements, and the difficulty involved in the process due to lack of proper documentation gave rise to the so-called "system experts" or "gurus". These people have invaluable system knowledge and expertise and have either a business or a technology background. The "experts" from the business side, act as interpreters between the business users and the IT developers by helping in the translation of business requirements into technical language. This helps to overcome the communication problem between the business users and the IS developers. While the technical gurus have a deep knowledge of the undocumented legacy system and are able to help the new developers navigate its intricacies.

The "gurus" *emerged* out of necessity. Lack of skills, lack of system knowledge, and lack of documentation, exacerbated when IT professionals moved, retired or left the company, acted as a constraint to business evolution. Constraints are not always a bad thing, as they can force both the individual and the organisation to find a different way of working to overcome the constraint. A trivial but illustrative analogy is a boulder in the middle of a stream of water. It cannot be moved, but the water can flow around it, perhaps cutting new channels in the process. The organisation therefore had to find a different way of operating. One way of looking at the process is that constraints may push the organisation *far-from-equilibrium*, in the sense that they push it away from the standard way of working, from the norm. The gurus are not the norm, there is no career path or job description for them and no one could have predicted their emergence. When pushed far-from-the-norm individuals and organisations are forced to explore alternatives. This exploration may be deliberate or it could be implicit and emergent.

However, exploration needs to be enabled and emergent properties need to be recognised and not inhibited. In this case the gurus enable a different way of working, and help to overcome certain constraints, which could have a deleterious effect on the development of the business.

b) *Self-organised informal networks, epistatic interactions and connectedness.*

A particular multi-disciplinary project on legacy systems, brought together various experts. They found that they worked well together and could help each other. This was a new departure in established ways of working. Once that project was completed the team was disbanded, but the *informal network* it created, has since been often resurrected, on a self-organised basis. Whenever there is a project related to IT legacy systems, people in the network call each other and try to work on the project together, on an informal basis. Because of their previous experience of working together, they know each other's expertise and can call on those with the necessary knowledge. No manager external to the group dictates or directs these interactions. The individuals within the self-organised group initiate them. This is self-organisation in a micro-scale where individuals take the initiative to talk to others. With improved communication, results were always good. The enablers here were knowledge of available skills and expertise gained through the initial project. But subsequently, flexibility in allowing self-organised groups to work together helped. However, to create a robust enabling infrastructure, it would be necessary to acknowledge the value of such interactions and actively encourage them. Both the self-organised groups and the gurus are also illustrations of *epistatic* interaction. The contribution of each individual depended on those other individuals he/she worked with, and was enhanced in particular contexts.

The quality of contribution or epistatic interaction also depended on degree of coupling and connectedness. Networks or webs are not constantly connected (Kauffman 1993, 1995). Their robustness lies on their ability to re-establish dormant connections, when necessary.

c. Legacy as positive feedback and pattern repetition.

The way management views the legacy systems, and continuation of the same processes reinforces the legacy systems. The business, organisation and technology processes interact with each other on established and repeated patterns to produce more legacy.

Even when the organisation has explored its space of possibilities and introduced new technology, established thinking, ways of working and relating can counteract and reduce the expected advantages. The building society implemented a component approach to systems development to enable new insurance products to be designed and marketed within a short period of time. It was expected that the new approach would solve many problems and enable new products to be marketed within a couple of weeks instead of the usual 8 weeks, by allowing those responsible for product marketing to bypass the problems associated with legacy. The marketing people could use components to develop a new application to support new insurance products that could be designed and marketed quickly. This would enable the organisation to co-evolve quickly with its marketplace. However, despite all the expectations, the mindsets, technology procedures and ways of working which originally helped create the old legacy systems, are being repeated. The repetitions of patterns of behaviour, as reinforcing feedback processes, recreate the legacy problem space.

11. The ICoSS Methodology

The complexity analysis in the bank 'natural experiment' and the building society case study, were done in retrospect. Neither organisation had used complexity thinking deliberately to change their way of working, while they had both used elements of it intuitively. This is of course the case with most successful organisations. Good CEOs and managers understand intuitively the nature of the organisation as a complex social system, when they are not aware of the vocabulary. By contrast, the MD and senior managers in the Humberside TEC (Training and Enterprise Council) were very much aware of the principles of complexity and used the vocabulary in day-to-day operations. [Mitleton-Kelly & Subhan, 2001]

The TECs were a civil-service type body, operating throughout the UK and responsible for training in firms in their geographic region. The Humberside TEC was the only one using complexity. They used it to guide and explore different ways of working, but they also used it to justify and legitimise their activities. They did not use the theory blindly, they used it because it resonated and supported what they wanted to achieve. It complemented and supported the style of the MD and of his senior executives. There were no linear causal mechanisms. It was not because they used complexity that they were one of the most successful TECs in the UK. The causalities were multiple and non-linear.

Another project with the Aerospace industry helped to define the methodology, while a pilot study in Shell, tested the first part of it. The whole methodology will be tested and refined in a new 3-year project called ICoSS, in collaboration with Shell Internet Works, Rolls-Royce Marine and BT's Brightstar (incubator of new businesses). The methodology is based on complexity thinking and shifts the emphasis from control and intervention to the provision of enabling conditions, to facilitate emergence, self-organisation and co-evolution with a changing ecosystem. In the Shell and BT cases, the ecosystem itself is being significantly recreated. All three companies are actively exploring their space of possibilities to find new businesses and new niches in the market. They are deliberately using their history (the brand name or technical discoveries or core skills) and they are pushing their operations far-from-equilibrium (away from established norms) to create new order.

The methodology has three phases in time, but many activities are carried on in parallel. The effects should however be non-linear. There are two parts in Phase 1. One part is introduction to complexity thinking and application of the principles and language to live problems. Applying the theory to practice from the very beginning is essential in fostering understanding. The other part in Phase 1 is a set of semi-structured interviews. These are recorded, transcribed and analysed to extract the underlying assumptions of that part of the organisation, the dilemmas they face (equally desirable, but apparently contradictory objectives) and the common themes (areas of interest or concern) which many of the interviewees raise unprompted. Assumptions are those principles, which influence decisions and determine actions; identifying them is important, as they may be potential inhibitors or enablers. They may be difficult to identify and we use 2-3 researchers to read through the interviews to validate each other's interpretation. Apart from the interviewers and researchers working on the material and the transcriber no one else has access to the research protocols. The ethical standards are very high; all interviewees are asked at the beginning of the interview if they object to being recorded; also all researchers and the transcriber have to sign non-disclosure agreements. All findings are non-attributable and no individual is ever identified to their colleagues.

The assumptions, dilemmas and common themes are then presented to all the interviewees and to the core team. The core team is a team of 2-3 individuals who will work closely with the researchers during the project. Presenting the findings may be a difficult and sensitive process, as the organisation may be shown what it may not wish to hear. Once the initial shock has worn off, the findings are used to build ***a framework of***

enabling conditions, using the principles of complexity. This is a co-creation process between the organisation and the researchers. Once the framework has been identified and is being implemented the project has moved into Phase 2. This is the longest phase and requires a lot of support, not only from the research team but also from the other industrial partners. They are all trying out similar ideas but in different contexts. They are able to help each other when things don't go according to plan. There is however one other source of support. They are the team of Advisors. They are both business people, experienced in setting up new businesses and in running large organisations, and academics working in complexity but in different fields. The Advisors will spend time with the industrial partners to explore new ideas, but to also support them in the implementation phase.

Phase 3 will run partly in parallel with phase 2 and will start recording the findings, and developing training material so that other organisations may be able to use the results. Research Councils fund such projects for the benefit of the whole of industry, dissemination and exploitation of the findings is therefore an essential element of the project. Part of the dissemination activities will be to communicate the findings to the rest of the organisation. Learning from the 'natural experiment' will be a major benefit for each industrial partner.

Summary and conclusions

This chapter introduced some of the principles of complexity based on the generic characteristics of all complex systems and used the logic of complexity to argue for a different way of 'managing' organisations. Not through control and intervention and constant restructuring but by the identification, development and implementation of an *enabling infrastructure*, which includes the cultural, social and technical conditions that facilitate 'x' whether that is the day-to-day running of an organisation or the creation of a new organisational form.

The enabling conditions are developed using the principles of complexity. We know that most reorganisations fail to meet their objectives. One of the contributing factors is that complex systems cannot be 'designed' in great detail. They are made up of interacting agents, whose interactions create emergent properties, qualities and patterns of behaviour. Humans in particular do not work to strict rules and their behaviour does not have machine-type predictability. Small variations or fluctuations in behaviour can be amplified through feedback processes and create significant qualitative changes at a macro level. It is the actions of micro-agents and the immense variety of those actions that are constantly influencing and creating emergent macro patterns or structures. In turn the macro structure of the ecosystem influences the individual entities and the whole process moves constantly between micro and macro behaviours and emergent structures, influencing and recreating each other.

The complexity perspective argues for an organic approach to change. Humans are remarkably resourceful. If they are allowed to self-organise they will create the structures and relationships necessary to overcome the constraints constantly presented by the environment. Complexity however does not argue for a total hands-off approach. That would be going too far for the psychological health of most executives! That is precisely what the Humberside TEC tried to achieve and it succeeded to a large extent, but that took a great deal of commitment to an idea, which most executives would find too risky.

The approach is rather one of gentle fostering, of creating the enabling conditions but then constantly re-adjusting the parameters in a subtle way, of accepting that control and intervention are counterproductive. It is not an easy approach and a CEO will need to be fully convinced of the rightness of the approach and convince others. When an organisation is open to exploration it means that it will take risks and try new ideas. Again, risk taking is not meant to damage the organisation in any way, it is meant to help it find new solutions, alternative ways to do business or offer a service, to keep evolving without major imposed restructuring which destroys the established connectivities and does not facilitate the re-establishment of the new ways of connecting [Mitleton-Kelly on BPR date?].

But this approach does not only suggest a different way to manage it also implies that all those involved take responsibility for the decisions and actions they carry out on behalf of the organisation. They neither take unnecessary risks, nor are they blamed if the exploration of possible solutions does not work. That is the nature of exploration. Some solutions will work and most will not. But there are two additional elements to responsibility, one is that the agents are autonomous, that is that individuals have the power to make decisions at their own level and do not need to refer up the hierarchy; the other important element is that they are given the skills, the information and all the support necessary to carry out informed decisions. Sencorp, a manufacturer of industrial fasteners in Cincinnati, works on precisely those principles and has done so for over 15 years. They call their employees ‘autonomous, responsible agents’ and they provide them with all the support necessary. Part of that support infrastructure is time to think. Thinking time is a legitimate activity. So is ‘playing’ with ideas. Sencorp provides meeting rooms with removable whiteboards. Any team can use the rooms and then unhook the whiteboards, so that they can continue the discussion another time.

Part 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 for that learning to take place. Learning is a prerequisite for adaptation and the conditions for learning and for the sharing of knowledge need to provided.

Complexity is a very young discipline. Its great strength is that it crosses the boundaries of disciplines in both the natural and social sciences. It may one day provide us with unified approach linking all those disciplines, as it is only by understanding the behaviour of complex systems in other subjects that one gains deeper insights in one’s own field. In terms of social systems, much work is being done in a variety of areas from anthropology and psychology to economics and organisational science. In the latter context, it will in due course change the way organisations see themselves and will help us understand their nature as complex systems and this will change the way that we 'manage'.

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Both projects explore the findings from the sciences of complexity and examine the implications of generic characteristics of complex systems for organisations. The focus of the second phase will be to develop tools, models and approaches which will aid the co-evolution of the business process with IS development.

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REFERENCES – to be relisted using the Harvard method

1. KAUFFMAN, S.: 'The Origins of Order: Self-Organisation and Selection in Evolution' (Oxford University Press, 1993)

2. KAUFFMAN, S.:'At Home in the Universe' (Viking, 1995)

3. HOLLAND, J.: 'Hidden Order: How Adaptation Builds Complexity' (Addision Wesley, 1995)

4. HOLLAND, J.: 'Emergence: From Chaos to Order' (Addison Wesley, 1998)

5. PRIGOGINE, I. & **STENGERS,** I.: 'Order Out of Chaos' (Flamingo, 1985)

6. PRIGOGINE, I.: 'Time and the Problem of the two Cultures', First International Dialogue on the transition to Global society, Landegg Academy, September 3-9 1990

7. NICOLIS, G. and **PRIGOGINE** I.: 'Exploring Complexity' (WH Freeman, 1989)

8. NICOLIS, G.: 'Physics of far-from-equilibrium systems and self-organisation' Chapter 11 in 'The New Physics' ed. by **DAVIES**, P. (Cambridge University Press, 1989) (reprinted 1994)

9. ALLEN, P.M.: 'Cities & Regions As Self-Organizing Systems : Model of Complexity' Environmental Problems & Social Dynamics Series, Vol 1, (Gordon & Breach Science Pub; 1997)

10. GOODWIN, B.: 'How the Leopard Changed Its Spots' (Phoenix, 1995)

11. WEBSTER, G. & **GOODWIN**, B.: 'Form and Transformation: Generative and Relational Principles in Biology' (Cambridge University Press, 1996)

12. ARTHUR, B.W.: 'Positive Feedbacks in the Economy' Scientific American, February 1990

13. ARTHUR, B.W.: 'Increasing Returns and Path Dependence in the Economy' (Michigan, 1995)

14. HODGSON, G.M.: 'Economics and Evolution: Bringing Life Back Into Economics' (Polity Press1993)

15. PARKER, D. & **STACEY**, R.D.: ‘Chaos, Management and Economics: the Implications of Non-Linear Thinking’ Hobart Paper 125, 1994, Institute of Economic Affairs,

16. STACEY, R.D.: ‘The Science of Complexity: An Alternative Perspective for Strategic Change Processes’ in Strategic Management Journal, Sept 1995, Vol 16, No 6, pp. 477-495

17. STACEY, R.D.: ‘Complexity and Creativity in Organizations’ (Berrett-Koehler, 1996)

18. PARKER, D.: ‘Nonlinear Dynamics and Organisational Adaptability’ Research Paper, April 1995

19. LANE, D.A. & **MAXFIELD, R.: ‘**Foresight, Complexity and Strategy’, in ‘The Economy As an Evolving Complex System II : Proceedings’ 1997, (Santa Fe Institute Studies in the Sciences of Complexity, Vol 27) by ARTHUR B.W. (Editor), DURLAUF, S. (Editor), LANE, D.A. (Editor)

20. MCMASTER, M.: ‘The Intelligence Advantage : Organizing for Complexity’ (Butterworth-Heinemann, 1996)

21. GELL-MANN, M.: ‘The Quark and the Jaguar: Adventures in the Simple and the Complex’ (WH Freeman, 1994)

22. GELL-MANN, M. *Complexity J.* Vol. 1, No.5, 1995/96

23. GOODWIN, B.: LSE Strategy & Complexity Seminar, on 23/4/97, report on http://www.lse.ac.uk/lse/complex

24. **CHECKLAND,** P.: ‘Systems Thinking, Systems Practice’ (John Wiley, 1981)

25. CHECKLAND, P. & **SCHOLES,** J. ‘Soft Systems Methodology in Action’ (John Wiley, 1990)

26. **VARELA,** F.: paper given at the ‘Complexity & Strategy Conference’ London May 1995

27. VARELA, F. & **MATURANA,** H. ‘The Tree of Knowledge’ (Shambhala, 1992)

28. **ASHBY,** W.R.: ‘Self-regulation and Requisite Variety’ in Systems Thinking, 1956, Ed by F E Emery, (Penguin 1969)

29. KAUFFMAN, S. & **MACREADY**, W.: ‘Technological Evolution and Adaptive Organizations’, *Complexity J.* 1995, Vol 1 No 2 pp.26-43

30. KAUFFMAN, S.: Complexity and Technology Conference, London, 11 March 1997

31. MATURANA, H.: Workshop at the Open University, March 1997

32. OLIVER, D. & **ROOS**, J.: 'The Poised Organisation: Navigating Effectively on Knowledge Landscapes' a Paper presented at the Strategy & Complexity Seminar, London School of Economics, 13th February 1997 and on http://www.imd.ch/fac/roos/paper_po.html

33. WALDROP, M.M.: 'Complexity: The Emerging Science at the Edge of Order and Chaos' (Penguin, 1992)

34. ACKOFF, R. L.: 'A Concept of Corporate Planning' New York (Wiley, 1970)

35. Report of SENCORP seminar at the LSE on the 3rd December 1997, http://www.lse.ac.uk/lse/complex

ALSO:

36. AXELROD, R.: 'The Evolution of Cooperation' (Penguin, 1990)

37. BOVAIRD, T. & **SHARIFI,** S.: 'Partnerships and Networks as Self-Organising Systems: A Case Study of Rural Acion for the Environment' Research Paper, Sept 1995

38. ESPEJO, R. & **HARNDEN** R.: 'The Viable Systems Model: Interpretations and Applications of Stafford Beer's VSM' (Wiley, 1992)

39. GLEICK, J.: 'Chaos'" (Heinemann Ltd, 1987) reprinted 1990

40. LEWIN, R.: 'Complexity: Life at the Edge of Chaos' (Macmillan, 1993)

41. LUHMAN, N.: 'Essays on Self Reference' (Columbia, 1990)

42. PEAK, D. & **FRAME,** M.: 'Chaos Under Control: The Art and Science of Complexity' (WH Freeman, 1994)

43. SEGEL, L.: 'Grappling with Complexity' *Complexity J.* , 1995, Vol 1, No2