5 Order, complexity and the industrial paradox

5.1 Introduction

5.1.1 In the previous chapter the conclusion was drawn that an industrial way of organising businesses will be meeting its limitations under conditions of increasing unpredictability and heterogeneity in the market. At the end of that chapter we concluded that the failure of communications to keep up with the requirements of the external environment lies at the base of the inadequacy of industrial structures. As communications[i] are governing the way different functions in the company relate to each other, in other words in which way order as a meaningful coherence of corporate functions is achieved, this issue is an issue of order.

5.1.2 In the coming section of this thesis (Chapters 5 to 8) we will start to explore the topic of order. The concept of order, and the way it is achieved, is the cornerstone of the thinking towards new ways to organise and manage businesses and business processes. We firstly explore different aspects of order and of the complexity science, which as a science is closely related to this topic. We will start to understand how order and complexity relate, and illustrate that order can be achieved through mechanisms completely different from our traditional way of organising companies and business processes.

5.1.3 In Chapter 5 we will start exploring the meaning of both order as well as complexity, predominantly looking at examples of both and with that build an understanding of the way such systems work and behave. We will then, in Chapter 6, apply this notion of order and to organisational issues. As a first step we will link Mintzberg's organisational concepts to the various type of order described in Chapter 6, and from that evolve into an exploration of interactive dynamic order as a basis for organising corporate functions and people. In doing so we will explore the various mechanisms, which underlie the emergence of this order, ranging from parallel experimentation through collective learning and proliferation of know-how.

5.1.4 Once we understand how interactive dynamic organisation can create orderly and meaningful structures, the question then arises how we can relate such structures to each other. This issue, addressed in Chapter 7, is of relevance within the company, whereas various parts of the company need to relate to each other while each possibly being an interactive dynamic (sub) system, but also, probably more important for this thesis, between the company as a complex dynamic system, and the market as a complex dynamic system. Or, more in line with the main thrust of this thesis, how the stakeholders' subsystems can interrelate to each other in such a way that they form an effective coalition of stakeholders.

5.1.5 Having understood the nature of complex dynamic order, the way it evolves and interacts with other systems, we will then look at issues of management and control with respect to the evolution of such interactive dynamic systems. It is the question of the meaning of management for such coalitions in the future, and the way management will and can contribute to the value generated by such coalitions.

5.1.6 And finally, in Chapter 8, we will relate the understanding which is developed to a number of real situations which have been documented in literature, or which we are capable of witnessing.

5.2 The exploration/exploitation dilemma

The industrial paradox can be expressed as the exploitation/exploration dilemma. Only if order between business entities can be achieved in an interactive dynamic way, based on a strong perception of the own identity, this dilemma can be resolved.

5.2.1 In Chapter 4 we discussed the emergence of complexity costs as an expression of the growing paradox of the industrial company in a highly heterogeneous market. There is yet another expression of the same paradox which we can observe in today's business: the exploitation/ exploration dilemma[ii]. Whereas complexity costs are the expression of 'friction' in the value creation mechanism, the exploitation/exploration dilemma is expressing the adaptivity of the value creating mechanism to external changes and opportunities.

5.2.2 In the long term survival of a company depends not only on its ability to exploit business processes in such a way that they lead to a sufficiently large economic result, but also on its ability to adapt to changing circumstances. Each company, operating in a dynamic environment, has to balance these abilities. Too heavy an accent on exploitation will finally, render the business processes inadequate when adaptation to changing circumstances is needed. An over-investment of time and energy in the exploration of new possibilities will mean that there is not enough left for reflective exploitation.

5.2.3 Today, companies are faced with the need to choose. Traditional industrial companies strongly focus on exploitation and derive their competitive advantage predominantly from this focus. Because of this competitive advantage, they can not work with inadequate (from the exploitation point of view) business processes without loosing their competitive edge. Exploration, consequently, takes place as a series of rather large quantum leaps in the structure of the business processes, which requires reprogramming of the various functions. After such reorganisation the company is ready for a new period in its life.

5.2.4 The alternative can be seen in companies in which the degree of industrial integration is considerably lower. They operate in a fast changing, heterogeneous market. Such companies resolve the exploration/exploitation dilemma by experimenting boldly and taking a great many initiatives. They hope that some of these will prosper, but they also know that a number will finally die because of lack of success. However, the mortality of this type of organisation is high. In general they are able to exploit the niches the larger players leave as a result of their need to achieve scale. As soon as such niches are passing a critical size (economies of scale!), the larger players start intruding, and in many cases take over the early innovators. With a shakeout as result.

5.2.5 A good example of this the publishing business. Whereas the large publishing companies have been reluctant to heavily invest in electronic publishing, many of them after failed experiments in the 1980's, such publishing has grown in numerous small companies. Many of them failed, but some were successful.

And these successful innovators are now increasingly taken over by the large publishers (e.g. Lexus Nexus, Reed-Elsevier).

5.2.6 On either side of the dilemma there is though a black hole. Success in exploitation, for instance, generally leads to company's optimising the basis of their success. Because of this optimisation pressure on exploitation increases and attention to exploration is reduced. This reduction in its turn leads to a reinforcement of the original success and so closes the circle. In other words, increasing emphasis on exploitation leads to a weakening of the company's exploratory ability. At a given moment these companies are caught by surprise by new competitors (such as the British economy as a whole experienced after the first Industrial Revolution)

5.2.7 At the other side of the dilemma, more emphasis on exploration increases the risk profile of the company, which in general leads to a higher cost-level. This makes a big success more necessary to compensate for the risk; and to increase the chance of a big hit, the number of projects is increased. However, more projects mean dilution of energy over more topics and therefore reduce the chances of success. Again, the circle is closed. The failure of the old conglomerates, where a multitude of companies was intended to spread the risk, often showed the consequences of over-exploration.

5.2.8 In order to avoid the pitfalls of these black holes, successful companies seek position somewhere between the two extremes. The real challenge though in highly heterogenised and unpredictable markets, is not exploitation versus exploration, it is the combination of the two. Additionally (which will become clear later (see Chapter 6.11), it is not the exploitation or the exploration processes which are central to the success of the company, but the ability to select successful innovations, to code knowledge and organise the diffusion process of know-how.

5.2.9 One of the best systems that we know, and one that combines all these aspects in an excellent way, is the human immune system. Unlike any other system, it is able to sustain the 'self' (exploitation), and yet it can adapt to a large variety of unpredictable threats coming at us from the outside world (adaptability and exploration). The effective combination of exploitation and exploration is due to the fact that there is a clear 'self' (which implicitly refers to goal and identity of the organisation), and the shaping of coherence from decentralised, interactive processes. Without goal orientation and a sense of identity, exploration and innovation processes have no direction and do not contribute to the 'self'; indeed, they could even lead to destruction.

5.2.10 Similarly, a company that has a strong identity but lacks interactive exploration and innovation, merely becomes static, and is unable to adjust to a changing world. Alternatively, lack of own identity will make the company as a ball, played by external circumstances. It is these aspects of identity, goal orientation and evolvability which deserve our attention if we want to create organisations from this perspective. Compared to the traditional industrial organisation the control emphasis shifts from the management of exploitation to the management of selection coding and diffusion processes.

5.2.11 Powell, Koput and Smith-Doerr (1996) come to similar conclusions in a study co-operative networks in biotechnology. In order to stay up to date, biotechnology firms have to do very well on exploitation and exploration simultaneously. In biotechnology networks, just purchasing the latest knowledge from others will not do:

"To stay current in a rapidly moving field requires that an organisation have a hand in the research process. Passive recipients of new knowledge are less likely to appreciate its value or to be able to respond rapidly. In industries in which know-how is critical, companies must be expert at both in-house research and co-operative research with external partners [...]"

5.3 Breaking the paradox

Breaking the industrial paradox is based on a different concept of order and the treatment of the market as a complex dynamic system. Whereas interactive dynamic order provides variety and responsiveness, while avoiding the cost of complexity, seeing the market as apparent (but not real) chaos will enable the reduction of phenomenological complexity. And with that reduce the apparent heterogeneity and unpredictability.

5.3.1 Looking at the two axes of the industrial paradox (see Figure 4-5) a different concept of order is required to improve responsiveness while avoiding the emergence of the complexity costs. Complexity costs, we argued to be the indicator for the discrepancy between the requirements of the external environment and the capabilities of the internal processes. We will do so by exploring the ability to achieve order by making use of interactive dynamic mechanisms. A different order, leading to meaningful coherence between corporate functions (meaningful with respect to its ambitions and goals). And in doing so increasing the variety of different solutions it can offer to the market place without incurring the penalty of complexity cost, provides a major contribution to the resolution of the paradox.

5.3.2 On the other hand, we will argue that there are situations in which we observe chaotic behaviour, while such behaviour proves to have a very orderly underlying structure. This is another face of order. In a situation in which the real complexity of a system is substantially less than the apparent complexity of the observed system behaviour, there is implicitly a form of order present in this system which does not show on the surface of the system behaviour. The complexity science addresses the behaviour of such systems, and the way in which they can be understood and used.

5.3.3 The question arises whether the apparent erratic and unpredictable behaviour of clients in the market place is representing a gradual evolution of the market place to total chaos, or, alternatively, a change of the market system from a linearly ordered structure into a structure which behaves to a much more complex form of order. We will illustrate in Chapter 8, and demonstrate in Chapter 9 that free markets, even while behaving apparently chaotic and unpredictable, indeed do possess an underlying structure of order, and hence could be considered as a complex dynamic system. And this provides the second aspect of our attack on the industrial paradox. As markets can indeed be treated as complex dynamic systems, the apparent heterogeneity in the market is much higher than the real heterogeneity once we start understanding the mechanisms of the underlying order, which helps us to reduce the problem on the horizontal axis of the paradox.

5.3.4 It is this combination (interactive dynamic order and complexity reduction) which provides a way out of the industrial paradox. On the one hand designing business processes and organisations which require substantially less management and control energy in creating a heterogeneous performance, on the other hand effectively reduce the real unpredictable heterogeneity by understanding the underlying mechanisms of the complex free market system.

5.3.5 The breaking of the paradox is illustrated in Figure 5-1. Rather than attempting to link the individual functional entities in the company to isolated phenomenological incidents in the market place, we endeavor to discover the underlying structure of order in market behaviour. We will as a result consider the market as a complex dynamic system, while on the other hand organise functional entities into networked systems which can interact with this hidden order. The interface aspects will be addressed in Chapter 7. This chapter will concentrate on defining both of the building blocks: the principles of emergent order on the one hand and the essence of complex dynamics on the other hand.

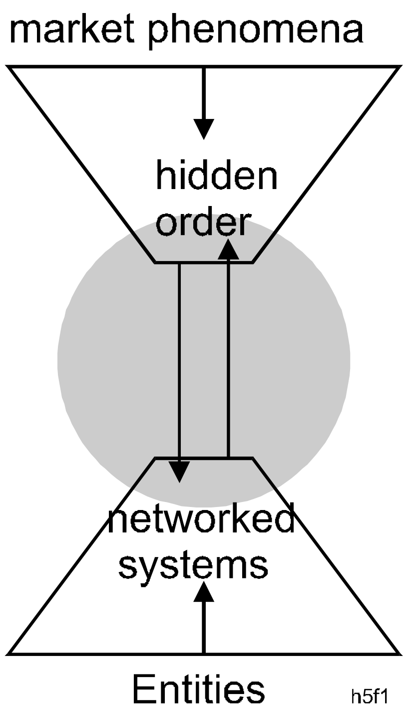

Figure 5-1: The double sided coin of complexity and emergent order

5.4 Definition of order

Order is a meaningful arrangement of relations between entities.

5.4.1 Order is a term that is ill defined in literature. Most authors assume some implicit concept of order without defining it. The Oxford dictionary defines order as: *“the way in which things are placed in relation to one another”*. The Dutch Van Dale dictionary describes it as: *“a regular position or arrangement of things as part of a whole”*

5.4.2 Order therefore implies an arrangement of interrelated elements. Ackoff defines such arrangement as a system when each of the elements is related directly or indirectly to every other element, and no subset of is unrelated to any other subset (Ackoff and Emery; 1972). The existence of a system implies order to be present (Boulding, 1956; In 't Veld, 1975). The concept of order, while implicitly taken into account by systems and network theorists, remains virtually undefined in systems and network literature. It seems, however, to be strongly related to the concepts of structure (the relations between the elements) and purpose (the capacity of selecting goals, the means to pursue these goals, and to continue to pursue the same goal, by changing the system's behaviour as external conditions change). Order, therefore, is a description of the interrelation of things (objects or otherwise; in general we will refer to these things as entities). It is not a property of the separate entities, but of the collection of entities.

5.4.3 The second element in both dictionary definitions is the presence of methods/rules that govern the arrangement/behaviour of entities. This does not necessarily mean that the arrangement can (immediately) be observed, although in many cases we refer to order if we can observe the arrangement/behaviour as methodical/regular.

5.4.4 There are, however, many examples which represent perfect order ('order' defined as above), without this order being immediately apparent. An example is the famous range of Fibonacci numbers [iii]:

1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233……..

This range was discovered about 1202 by Leonardo of Pisa (son of Bonaccio, ergo 'Filius Bonacci' or simply 'Fibonacci'). These numbers are best-defined recursively by the pair of formulas:

$$FIBO(n) = FIBO(n-1) + FIBO(n-2) \quad \text{for } n>2$$
$$FIBO(1) = FIBO(2) = 1$$

5.4.5 Non-apparent order will in many cases be the result of rules that are imposed on interacting entities (in this example the numbers), as is the case with the Fibonnacci range. Rules imposed on non-interacting entities will in many cases result in apparent order, though apparent order could also well be the result of interacting entities.

5.4.6 If order is absent, entities will behave in a non-coherent way. They are either driven by their own individual ambition (in the case of 'living entities', which we will refer to as agents [iv]) or by arbitrary external forces. In such cases the whole exists only as an collection of free-moving entities.

5.4.7 Combining the various elements, we will define order as the existence of a meaningful (in terms of being methodical and/or purposeful) relation between entities of any kind.

5.5 Types of order

There are three basic forms of order: chaos (absence of order), homogenous (microscopic) order and heterogeneous (macroscopic) order.

5.5.1 These three principal forms of order can be illustrated with an example from physics. Considering ice-crystals (the assembly of water molecules in a crystalline structure) as entities:

- Solid ice is a regular arrangement of such objects, which arrangement has a dimension that can only be observed at the molecular level. With the naked eye, we can see the ice, as a transparent block of material, but not the structure. The order is homogeneous and microscopic;
- Dry powder snow, in its ideal form, represents absence of order. The crystals do not have a regular arrangement to each other (they don't 'stick'), and their arrangement as a whole is completely governed by accident;
- Frost flowers that can be seen on a windowpane on a dry winter day, represent an order that is quite different from the previous two. It also represents a perfectly regular arrangement of objects, but the arrangement is macroscopic (can be observed with the naked eye) and is heterogeneous in the sense that there are many different ways in which the objects are positioned with respect to each other. This order is an emergent order, arising out of interactions between the molecules under particular external conditions as temperature and humidity, where as the 'solid ice' order is, as it were, 'forced' upon the crystals. This order we will refer to as emergent order.

5.5.2 The roundabout example (see Chapter 4.5.8) also illustrates such difference in ordering principles. For our purpose (understanding order in the context of a business environment) this example is probably more illustrative than the frost flower. Order on cross roads with traffic lights is an expression of linear order. Order which is forced upon the system by external power. There is no meaningful interaction between the users of the crossroads; the traffic control system issues commands to the drivers (red = stop, green = drive). The drivers obey these instructions and collectively start displaying orderly behaviour. From a perspective of order a roundabout is completely different. It is not the central computer that governs user behaviour of, it is a set of interaction rules (left-hand traffic takes way) which does so.

5.5.3 So, some systems (dynamic, interactive systems) show surprisingly orderly behaviour at the systems (macroscopic) level, whereas no central power governing the behaviour of the individual entities is present. Also in economic behaviour emergent order can be observed. In e.g. double sided auctions[v] individual behaviour of both clients and suppliers can lead to a completely predictable transaction price level.

5.5.4 This phenomenon however is the exception, not the rule. There are many cases and circumstances where no apparent order in the relation between entities arises, whereas the entities are identical to the case in which emergent order arose. Frost flowers are a relative seldom occurrence, and when we used in continental Europe the right-priority rule for roundabouts, the only result was a traffic jam.

5.6 Passive emergent order

Passive emergent order can arise out of interaction between passive entities under conditions of simultaneous positive- and negative- feed back. No central control is required to achieve such order.

5.6.1 The characteristics of emergent order, arising from non-linear dynamic systems can be illustrated by some simple examples from the field of physics. The first example is that of the Bénard cells (see Figure 5-2). Imagine two flat plates. Between these plates is fluid. Under ambient temperature conditions this fluid there is no structural macroscopic movement between the plates. The plates are now being heated from underneath.

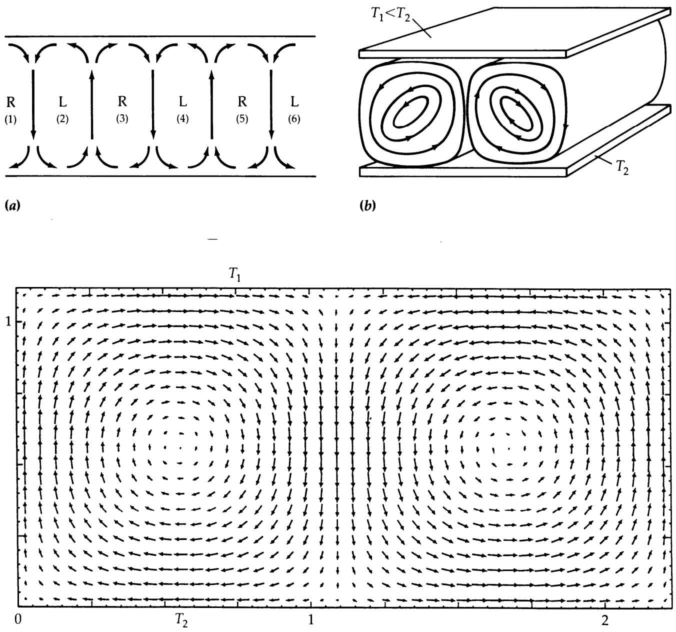

Figure 5-2: Bénard cells as emergent order (source: Nicolis and Prigogine, 1989)

5.6.2 For some time nothing happens. Then, at a given critical temperature the fluid starts moving. Hot fluid, due to change in specific weight, wants to move up and will eventually have to come down somewhere. Rotational cells start developing and take care of both the fluid that is going up as well as the fluid that is going down. It is impossible to predict where between the plates the fluid will go up or down, nor can the direction of rotation be predicted. Once the fluid has formed this structure, it will be stable and will remain so. Unless it is heated too much, where after vaporisation effects destroy the coherent dynamic structure.

5.6.3 At the macroscopic level, it would seem that the molecules interact in a very orderly fashion, as if pulled by strings. They all follow whatever the system dictates, on a scale that is substantially larger than the size of the individual molecules. This is an example of order without central control, order that emerges from the process as a result of interactive dynamics, under very peculiar external circumstances. Only if we look at the whole can we observe structure and order.

5.6.4 Another example, from the work of Nicolis and Prigogine (1989) is the so-called BZ-reaction. This reaction creates a chemical oscillator based on auto-catalysis (see Figure 5-3). Auto-catalysis is a process which generates a larger amount of reaction input-components of a particular reaction than the reaction started with. In the reaction equation we see that the reaction begins with 1 $HBrO_2$ etc. and that it yields $2HBrO_2$.

$$HBrO_2 + BrO_3^- + 3H^+ + 2Ce^{3+} \longrightarrow 2HBrO_2 + 2Ce^{4+} + H_2O$$

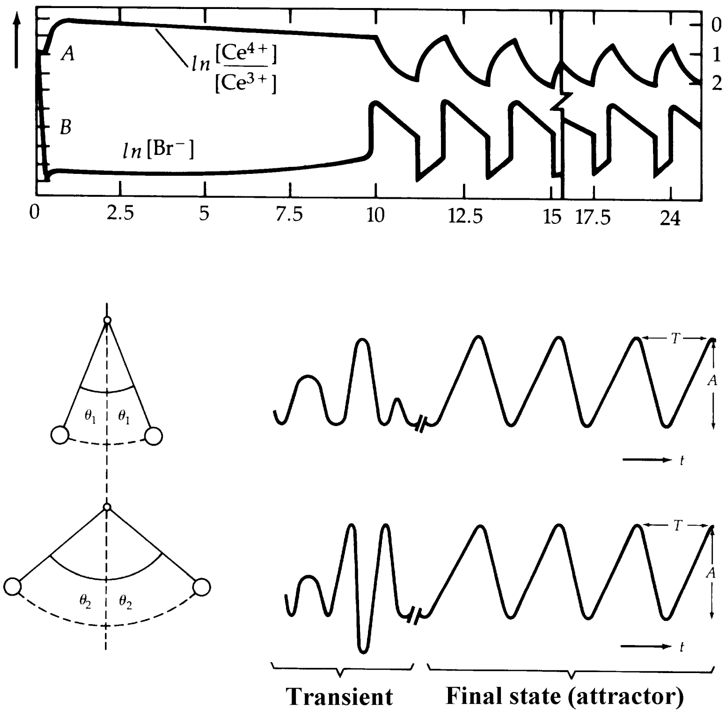

Figure 5-3: BZ- formula's (source: Nicolis and Prigogine, 1989)

5.6.5 This means that at the next stage of reaction there is more $HBrO_2$ than there was at the beginning. The reaction creates an avalanche of $HBrO_2$, it is driven by positive feedback [vi]. And positive feedback is synonymous with non-linearity. There is no longer a linear relation between cause and effect: small causes can have an enormous effect.

5.6.6 At a certain stage, counter-forces will develop in the reaction, as the quantity of other reagents diminishes. The avalanche will then come to a halt and will even reverse. The reaction behaves as an oscillator. As the chemical reaction continues, it changes colour. Going to the phases, it changes colour continuously; the result is a 'chemical clock'.

5.6.7 There is a fundamental difference between such a clock and a pendulum. Increasing the amplitude of the (frictionless) pendulum ($\theta_1 \rightarrow \theta_2$) will cause it to retain this amplitude. In the chemical clock this is different. If destabilised, it will come back to the same frequency because the frequency (the order) is embedded in the structure of the processes. If for any reason the rhythm is disturbed, the clock automatically returns to its natural rhythm. Whereas the pendulum 'remembers' the disturbance the chemical clock doesn't.

5.6.8 An 'attractor' governs this order in the BZ reaction. In an interactive dynamic system the attractor is the 'Equilibrium State' between the positive- and negative feed back-loops. If either is dominant, the system will go to a static state (negative feedback dominant) or decay to complete chaos (positive feedback dominant). Some attractors are very simple, others are multi-dimensional and very complex, like the famous Lorenz attractor. Simple or complex, the system will continuously move in the attraction loop giving the system dynamic stability. These systems never reach a static equilibrium. The system contains continuous imbalances, which drive the evolution. The attractor prevents these imbalances from becoming dramatic enough to make the system collapse. It 'attracts' the parameters that govern the system behaviour. As a magnet, it prevents the system to move too far from the equilibrium. If there were no attractor, the avalanche effect would cause the system to explode. It is the attractor that keeps the system in place and preserves its dynamic stability.

5.7 Active emergent order

Active entities (agents) applying co-operative interaction rules can create order without central control.

5.7.1 The previous examples are based on systems with passive entities, interacting under particular external circumstances. Another class of systems displaying emergent order are systems where the entities possess 'living characteristics' in the sense that they can communicate, act and have a self-interest (such entities we will refer to as agents).

5.7.2 Even structures of simple interactive agents, governed by simple, singular rules, can show a surprisingly orderly macroscopic behaviour and can create surprisingly complex structures.

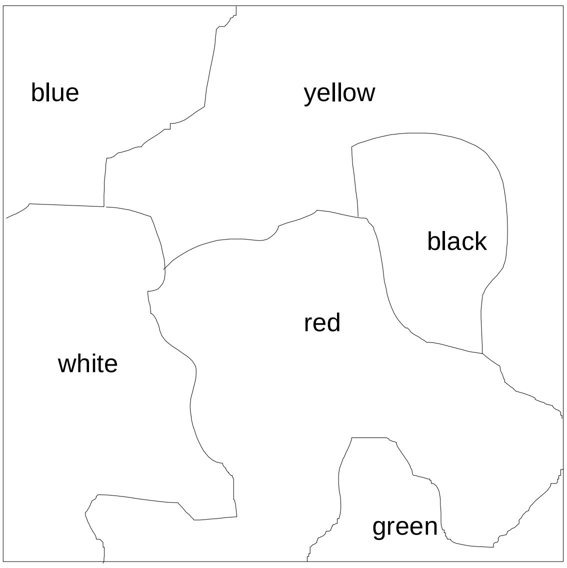

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Figure 5-4: Impression of intermediate results of the COLORS model

5.7.3 An illustration of a simple network of interactive agents is a computer model we created, called COLORS [vii] (see Figure 5-4). In this model number of agents use very simple rules to interact with each other, in order to pursue an individual goal. These rules are of the 'IF/THEN'-type and based on auto-catalysis; if the interaction is successful, it will create more of the ingredients required for success and thus auto-catalysis will create positive feedback. Quite comparable with the BZ-reaction mentioned before.

5.7.4 The agents in the models are coloured dots (pixels on the screen) There are 16 different colours, representing 16 different (groups of) agents. The actual model consists of a grid of 100 x 100 coloured dots on a computer screen, in which each dot represents an agent. The 10,000 differently coloured agents are randomly distributed over the square, thereby generating an randomly scattered pattern. As the programme runs, agents are selected randomly. If one agent finds an adjoining agent that has the same colour, they are allowed to produce a third agent of the same colour which extends their ‘territory’ in that direction. A very simple autocatalytic rule, driven by a random selection of agents.

5.7.5 This extremely uncomplicated system displays a remarkable richness of events. Macroscopically the very patchy, highly granular coloured picture immediately and rapidly begins to re-group in coloured areas. These areas seem to be fighting at their borders, like countries at war on a map. It very much resembles the ‘Risk’ game, in which players conquer each other’s countries by throwing dice. After some time, large coloured areas emerge and some colours disappear from the screen as they have been conquered by the others. When only two or three colours are left, a very long and stable period is established (which might be ten to fifty times as long as the original shake-out period). These two or three colours seem to co-exist more or less peacefully, until finally one of the remaining colours wipes out the other two.

5.7.6 Figure 5-4 shows a typical situation of the grid halfway through its evolution. The evolution of the process can be visualised by calculating the Organisational Entropy [viii], in Figure 5-5 a typical curve for the organisational entropy is plotted, which characterises the evolution of order in the system. It is remarkable that irrespective of the resolution, the entropy curves starting at the upper left-hand corner, declines rapidly, goes through a stable period and then drops off again. The curve slopes steeply, flattens out, and then forms a steep slope again. This evolution can be easily reproduced, not in the finite details but in the overall evolution of the process, which is very constant. The graphs always looks very similar, irrespective of the resolution and the number of times the program is run. Clearly some sort of intrinsic mechanism creates order in this very simple interactive structure.

5.7.7 The evolution in the COLORS model remarkably resembles the process of market evolution in a business environment. Let us assume that the 16 different colours represent 16 different suppliers in a market. In the first few pictures, after an initial random distribution of players over the total market, a rapid shakeout takes place. This shakeout is largely determined by the relative presence of a supplier in the starting position, which indicates the importance of market share. The stronger the starting position, the better the chance to survive. Furthermore, some players are positioned at a border of the graph, which enables them to guard their back, as they cannot be attacked from behind. The players that can achieve that position first, have a much better chance of surviving. Players who do not reach a border are attacked from all sides. This pattern is somewhat similar to that of a strong home market. In such a market we have a much better chance of success and survival. This is consistent with Michael Porter's observations that a buoyant, strong and demanding home market helps companies to develop their competitive position.

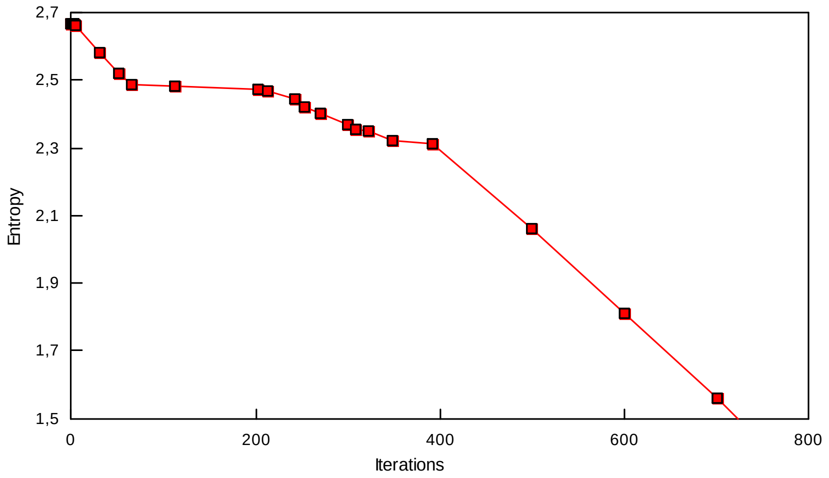

Figure 5-5: Typical entropy evolution in the COLORS model

5.7.8 The model then enters a relatively long, stable period in which two to four players are able to maintain a balance between each other. This seems comparable to an oligopoly, stable for prolonged periods of time. Players win and loose market-share, and there is no way to predict who will ultimately win. There seems to be a temporary ‘natural’ ceiling to market share, above which resistance in the market emerges [ix]. In the end, if nothing unusual happens, all players will gradually disappear but for one, who survives. The market has then turned effectively into a monopoly.

5.7.9 In real life, however, new players may be introduced towards the end of the oligopoly stage, applying new rules which are basically variations on the previous rules. Some of these new players will be wiped out in a very short time, but sometimes some of the new rules appear to be much more powerful than the existing ones and a new player comes to dominate quite fast. This process could reflect the way Microsoft, Intel or Compaq have taken up dominant positions in the IT-market in a very short period.

5.7.10 If figures 5.4 and 5.5 are to be related to the phases of a normal market evolution[x], then it might be not a sophisticated strategy or business school theory that drives market performance, but a simple mechanism of interactive order. It could well be that part of our marketing and economic processes are governed more by interaction processes and evolution of the system parameters than by strategic intelligence. At this time, however, this is purely speculation.

5.7.11 The roundabout example, mentioned before, also is an illustration of systems with active agents, which display emergent order out of rule based interaction. Many other examples could be found, but one which is particularly interesting, because it shows the application of a multiplicity of rules, and also demonstrates the co-operative nature of rules which are underlying emergent order, is the example of ants. (British Telecom, 1996) [xi]. An ant colony is a miracle of organisation, in which each ant knows its job, and keeps doing it independently of all the other ants. It appears to be possible to reproduce the macroscopic structure and order of the ants' food-gathering process by using three simple rules. It is not said that ants actually know these rules, or even that their behaviour is rule-based, but computer simulations using these rules quite neatly reproduce the real situation. In fact, British telecom uses comparable rule sets to model its communications networks. Four rules have been detected:

- If you find food, take it home, marking a trail to show your route between food and home;
- If you cross a trail and have no food, follow the food trail;
- If you return home with food, put it down and go back along the same trail;
- If the first three rules do not apply, wander around at random looking for food [xii].

5.7.12 This example demonstrates that order is not only an emergent property of the system as a whole, but it also explains why very simple creatures with very small brains can together perform very complex tasks like building and maintaining a nest. It also shows that the rules governing their (interaction) behaviour can be expressed in IF/THEN terms, and displays the co-operative nature of such rules, as all three rules imply co-operation rather than antagonism (see also Chapter 6.5 and 6.8.9).

5.7.13 Another example which brings us closer to everyday life. We experience the dynamics, the unstable equilibrium between positive and negative feedback and the non-linearity of interaction with other agents, for instance, when we are driving a car on a busy motor-way.

5.7.14 Let's imagine first that we are driving on an empty road and we know where to go. Our guidance consists of fixed things like road markers, signposts, etc. There is no interaction with other drivers, we just follow the central rules. Someone has laid down these rules, someone has laid out the best route to the place where we are going, a speed limit of 100 km p/h has been fixed; there is a continuous interface between our acts and the central rules. While we are driving we check our position and our speed, which we want to be maximal. Are we still on the right road and is our speed still right? If we are driving too fast, we reduce our speed; if we are driving too slowly, we go faster. If we take a wrong road, we return to the correct one. Everything is based on a procedural order.

5.7.15 Let us now imagine that the road gets more crowded. At a certain moment there are so many vehicles that we can no longer freely follow the procedural order. We want to drive 100 km per hour but we can't, because everyone else is driving much slower. We want to take an exit, but it is crowded and we can't use it. Suddenly interaction with other users starts building up. Probably all of us have experienced drivers who rely on the taillights of the car in front. The simplest form of interactive driving. It is very erratic and very dangerous, because the variety and unpredictability in the behaviour of the driver in front The required speed to response to that behaviour causes overreacting, creating even more problems for the driver behind. A minor incident, for instance a car standing still on the emergency lane, can create a traffic jam. So a very small cause creates a huge effect, since the disturbance is transmitted backwards in the queue in a non-linear way.

5.7.16 In such a situation it is advantageous to look at a total picture. By anticipating the implicit pattern of relations that is developing in the process, rather than the isolated events, a safer way of driving is practised. If it does work well, as it sometimes does, we feel part of a system, in a way that we can manage. In general, we can manage ourselves quite well in this type of situations in everyday life.

5.8 Entropy as a measure of order

The level of order in an organisational system can be expressed in a measure of entropy.

5.8.1 In their book ‘Exploring Complexity’ Nicolis and Prigogine (1989) deal with dissipative systems. These are systems that give rise to irreversible processes, as opposed to conservative (in the sense of ‘conservation’) systems that have processes that are time-reversible, i.e. they obey Newtonian laws. The irreversible approach of these dissipative systems, then, leads towards a final state. Nicolis and Prigogine state:

> *“For isolated systems, in which no exchanges with the environment are allowed, this irreversible trend is expressed by the second law of thermodynamics.”*

This means that the entropy will grow over time, and the system tends towards increased disorder, until entropy becomes infinite (total chaos).

5.8.2 Entropy is associated with the number of states that can be realised. As Nicolis and Prigogine state:

> *“Indeed, we may argue that the more restricted the number of these states, the more ordered the system will be.”*

The formula used to calculate the entropy of a system is:

$$E = - \sum P_i * \log P_I \qquad (i = 1 \rightarrow m)$$

Where:
m = number of states; i = state, and

P_i is the probability of entities to be in state i

5.8.3 This measure of entropy can, using this formula, also be used to characterise the level of order in an organisational system[xiii]. For instance in the COLORS model:

- m = the number of colours
- P_i the probability of entities having colour i.

5.8.4 In the same way not only the state of the agents, but for example the existence of connections in a networked structure can be defined as states, or indeed any other variable characterising the system-order.

5.8.5 Entropy has in this way been used to characterise the order in economic systems and organisations. The state of a system is the whole of the elements (content), the attributes of these elements, and the relations between these elements (structure). A system’s state can be more or less orderly. A closed system will, according to the second law of thermodynamics, tend to a state of maximum disorder (or chaos). In this case, there will be no more differences with its surroundings (and strictly it couldn’t be considered a system any more). This state of order and disorder can be measured through entropy measure (In ‘t Veld, 1975)[xiv]. A system can only sustain itself by importing energy (or orderliness) from its environment. Thorelli (1986) confirms that a network tends to disintegrate under the impact of entropy in absence of conscious coordination efforts, or as he calls it 'network management'.

5.8.6 The nature of order is of central importance to the ability to create value, and complex dynamic order is a grey area between structural order and total chaos. Therefore it is useful to define a way of measuring order in organisational systems. The application of organisational entropy to characterise the level of order in an organisation will be discussed in Chapter 6.2.

5.9 Complex systems: apparent chaos versus real chaos

Not all seemingly chaotic behaviour arises from absence of order. Non-linear dynamic systems (even very simple ones), can show very complex behaviour. At the phenomenological level these systems cannot easily be distinguished from random chaos, although they are completely predictable and can be reproduced

5.9.1 The concept of order and the concept of complexity are very closely related. They are largely based on similar principles, use similar terminology, and are both (at least with respect to emergent order) closely related with the dynamic behaviour of interactive entities. In practice though we are confronted with two faces of this underlying theory. The one, which has been addressed before, is the notion that some systems of interacting entities will display macroscopic order without an apparent central force governing the behaviour of the entities.

5.9.2 Not all seemingly chaotic behaviour though arises from absence of order. One particular class of systems, non-linear dynamic systems (even very simple ones) can show very complex behaviour. At the phenomenological level these systems cannot be easily distinguished from random chaos, although they are completely predictable and can be reproduced. In his book: 'Micromotives and macro-behavior', Thomas Schelling (1978) treat similar phenomena in social contexts.

5.9.3 In our everyday world, non-linear phenomena have always been around. For many of the macro-events we observe, the linear description is though a sufficient explanation, but this does not mean that our world is a linear system. This notion is not new. In the early 18th century scientists such as Leibniz and Newton started thinking of non-linear physics and mathematics. There were phenomena, either in astrophysics or in molecular physics, that could no longer be explained by Newton's description of the mechanic world, especially its linear part; they did not seem to fit Newton's rules. This culminated in Heisenberg's and Einstein's theories on quantum mechanics and relativity; these scientists examined mechanics and movement beyond Newton' linear world. The next step in non-linear order was taken by Ilya Prigogine, whose work on thermodynamics earned him the Nobel Prize for physics. Prigogine started examining the non-linear behaviour of chemical systems [xv]. In the 1960's and 1970's Prigogine's work was gradually applied in many areas of the physical sciences, and later on in biology and neurology.

5.9.4 Complexity addresses the apparent chaotic behaviour of systems (hence the absence of microscopic order) whereas under this apparent chaos there are identifiable rules and mechanisms which could be considered, in the definition of this thesis, as perfectly ordered. Either because the interaction rules can be detected, or because simple recursive mathematical equations create a wealth of phenomena from which the underlying logic cannot, at least not easily, be detected by looking at the phenomena. In fact order and complexity are two sides of the same coin. They share a lot of principles and concepts, but we are interested in different exponents of these fundamentals and principles. Complexity, one could say, addresses the question of order the other way around.

5.9.5 Complex systems are based on three principles: dynamics, non-linearity, simultaneous occurence of positive and negative feedback. Without the dynamics, the state of the system would be constant. Non-linearity indicates interactivity of some kind within the system, and the simultaneous positive and negative feedback are necessary keep the dynamic behaviour of the system within the ‘reach of the attractor’. Without this complex systems would be one of two things. If the system would only have negative feedback, the system would be completely predictable and would always returns to its equilibrium. It would not develop or evolve. If it had only positive feedback, it would be like an avalanche and the process would destroy itself in chaos. It is on the boundary between the two systems that a balance is struck between negative and positive feedback resulting in complexity.

5.9.6 Especially in, and around, the Santa Fe Institute, founded to study the theory and application of ‘complexity theory’ in a wide range of areas as economics, biology, information systems and organisation, much work has been done to further our understanding of complex systems. How close complexity and order are related can be detected form the title of Mitchell Waldrop’s (1992) book on the history of the Santa Fe Institute: ‘Complexity: The Emerging Science at the Edge of Order and Chaos’. The work in Santa Fe has been extensively used in building the concepts and theories of this theses. Especially the work on ‘increasing returns’- economics by Brain Arthur, the work of Stuart Kauffman on solution topologies of networked systems and John Holland’s work on agent bases interactive order.

5.9.7 As stated, there are systems that appear to be fully orderly underneath apparent chaotic behaviour. Apparently a deeper, hidden, order exists. Or, formulated in a different way, systems in which the behaviour can be described in a shorter way than the actual behaviour can be described. Referring to the Fibonacci numbers: there is a (much) shorter description of the range than the numbers themselves. This is equivalent to Murray Gell-Mann’s definition of complexity: the complexity of a system can be measured by the shortest code that will reproduce the behaviour. The shorter the code, the less complex the system is.

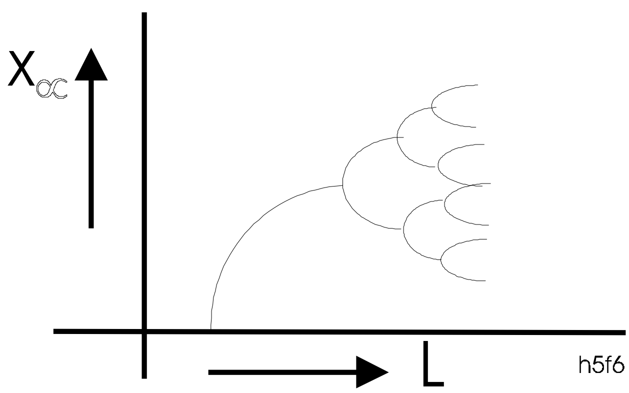

Figure 5-6 May’s rabbit population

5.9.8 As with order, complexity can best be demonstrated by using examples. A very famous, one which is widely quoted, is Robert May's, illustration of the evolution of an imaginary rabbit population (see Figure 5-6). May tried to predict the final size of this population, without limitations for size of population or time.

5.9.9 Let us assume that next year's population (x_{n+1}) equals the population of this year (x_n) times a reproduction factor L, which indicates the number of new-born rabbits. Let us further assume that some unspecified mechanism (remember the attractor requiring both positive and negative feedback) will create a counter-force in order to prevent the population from exploding. For that we introduce a factor in the equation which becomes smaller with growing population: ($1 - x_n$). (Mathematically this is valid only if x is between 0 and 1.)

The resulting equation is very simple:

$$x_{n+1} = x_n * L * (1 - x_n)$$

This equation is non-linear and it is interactive, because cause and effect influence each other. Furthermore it is dynamic and it contains both positive- as well as negative feedback.

5.9.10 If we plot the reproduction factor L on the horizontal axis (see Figure 5-6) against the final size of the population, L will at first be too small to sustain the population: too few new rabbits are born. If L is less than 1, next year's population will be smaller than this year's. If we start with any amount of rabbits, we will end up without a population.

5.9.11 At a certain moment, however, the population will begin to grow. If we look at the curve in the figure we would expect it to flatten out at some point, but it doesn't. At a certain value of L a bifurcation occurs. This means that the population in the year x_{n+1} is different from the population in year n, but in year n+2 it equals the population from year n, whereas in year n+3 the population is again equal to the population in year n+2. So the population oscillates from year to year. Increasing L will create further bifurcation and result in four, eight, 16 etc. alternating states. The number of these bifurcations explodes until suddenly there are three different populations alternating. At this point the process starts all over again (Figure 5-7 shows the emergence of a fine bifurcation structure when L grows). No matter how closely we zoom in on this structure, we will find repetitive, fractal structures.

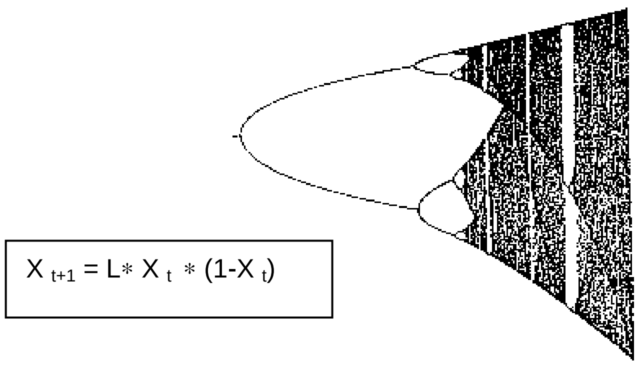

Figure 5-7: Deterministic chaos

5.9.12 Let us assume that in this imaginary population L has a specific value. Over the years we would observe a change in population size that would be seemingly random. If we would judge the phenomena, we could not make any sense out of it. Yet, there is a very simple underlying structure. It is non-linear because of its interaction and it has no equilibrium; it never stabilises once we pass a certain level of L[xvi]. Apparent chaotic at the phenomenological level, completely ordered underneath.

5.10 Complexity in economics

The existence of increasing returns economy is an expression of market economies as a complex dynamic system

5.10.1 For some reason it wasn't until the mid-1980's (when Brian Arthur started applying these mechanisms in economics) that a relationship was discovered between business issues and the non-linear, dynamic systems behaviour. Arthur (1996) brought out the contrast between the 'material resources based' economy, bound to decreasing returns, and the knowledge-based economy, bound to increasing returns. In the materials economy production tends to be repetitive. It favours planning and control and hierarchical relationships between the bosses (the planners and controllers) and the workers. This simultaneous repetitiveness, planning and control allow for constant improvement and optimisation of cost and quality. In the knowledge-based economy, competition shifts to a 'quest for the next technological winner' (who can become 'locked in', drive all others out of the market and reap huge profits). Therefore, management becomes mission-oriented instead of production-oriented, which causes hierarchies to flatten. The deliverers of the 'next technological winner' for the company must be organised in small teams, like commando units, that report directly to the CEO or the board.

5.10.2 The school of 'increasing returns economics' in fact dates back to Adam Smith, who gave the famous example of the pin factory. Whereas one skilled craftsman can manufacture only a few pins a day, ten specialised craftsman working together are able to make thousands of pins in the same time. The output grows disproportional to the inputs, which means increasing returns to scale. In his book 'Principles of Economics' (1890) [xvii]. Alfred Marshall, exploring partial equilibria, noticed the existence of increasing returns, next to decreasing and constant returns. However, he realised that acknowledging increasing returns, whether in supply or demand, would upset his elegant theory. As a consequence increasing returns were 'excommunicated' from economics. However, the subject kept coming up. In 1928 Allyn Young wrote a classic article on increasing returns and Edward Chamberlin and Joan Robinson worked on it in the 1930's. During the same period John Hicks stumbled upon it. He recognised the implications for the general equilibrium economics and wrote*: "The wreckage would be that of the greater part of economics"*. Not surprisingly, the largely mathematical schools that dominated the economics of the 1960's and 1970's ignored this problem almost completely and the subject was only kept alive by Kaldor. It was not until the interest in chaos economics heightened that economists began to think in non-linear relationships and dynamics.

5.10.3 Brian Arthur was the first to study interactive dynamic order in economics in an integrated way. In the late 1970's his ideas were coolly received, but the breakthrough came in the 1980's (amongst others through the Santa Fe

Institute), which led to wide interest and research in the subject of increasing returns and non-linear dynamics in economics[xviii].

5.11 Measuring complexity

The complexity of an interactive, dynamic system of agents can be expressed by the connectivity of such networked system.

5.11.1 Measuring complexity is in principle finding the shortest description capable of regenerating the observed phenomena. Gell-Mann's measure of complexity however is difficult to apply (how would we know whether we indeed do have the shortest description). One of the ways to apply this measure is to 'measure' the dimensional space required to match the phenomena observed. This is the measure we will use in our description of the market as a complex dynamic system (see Chapter 9). In principle we could also apply the Entropy measure to characterise the level of order underlying a complex dynamic system.

5.11.2 A more interesting[xix] approach though, offered by Stuart Kauffman (1993) form his work on order and complexity in biological systems, is the N/K characterisation (see par. 5.8).

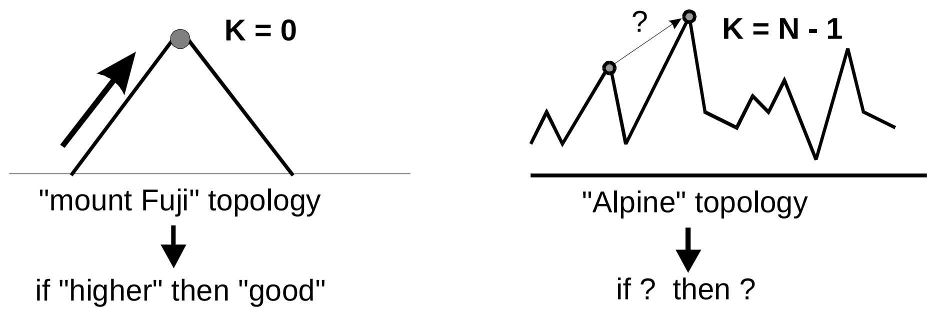

Figure 5-8: Kauffman's N/K topologies

5.11.3 As the number of nodes increases, the maximum number of connections increases parabolically and rapidly grows to very substantial numbers. The complexity of the network increases dramatically with the number of connections, much stronger than with the number of nodes.

5.11.4 Kauffman's N/K topology (1993) is a simple formal model of a so-called 'rugged fitness landscape' (cf. the distribution of fitness values over genotypes; depending on this distribution, the landscape can be more or less mountainous). In this model, N refers to the parts of the system (cf. genes in a genotype). Each part makes a contribution to fitness, which depends on that part and on K other parts among the N. This means that K reflects the interactions, or cross coupling, of the system, the maximum of K being of course N-1. It turns out that in a system in which each site (or entity) can display two values (0 and 1), to a very large extent only N and K matter when it comes to determining the complexity of the system; the distribution of K among N is far less important [xx].

5.11.5 Each site makes a fitness contribution that depends in a random way upon its own value and upon the value of the K other sites with which it interacts. The fitness of each site is the normalised sum of the randomly assigned fitness contributions of the N sites. This distribution shapes the fitness landscape along the following properties:

- The number of fitness peaks in the genotype space;
- The lengths of the walks via fitter neighbours to fitness optima;
- The total number of mutants tried before an optimum is reached;
- The ratio of accepted and tried mutations on a walk;
- The number of alternative optima to which one genotype can climb;
- The number of genotypes which can climb to the same optimum;
- The rate at which the fraction of fitter neighbours dwindles to zero along walks to fitness peaks;
- The similarity of local optima.

5.11.6 These properties are kinds of rank-order statistics that change as N and K are changed. These features are, however, largely insensitive to the underlying distribution of K among N.

5.11.7 Having established this, Kauffman examines a few cases. The first one is K=0, i.e. there are no interactions. In this case, the structure of the fitness landscape has one single optimal genotype; all other genotypes are sub-optimal and can climb to the global optimum via fitter neighbours within only one mutation (i.e. 0 or 1, optimal or sub-optimal). It follows trivially that there are no optima other than the single global optimum. The solution landscape is smooth in that the neighbouring points have (nearly) the same fitness value. Kauffman uses the image of mount Fuji: a smooth surface, one global optimum, which can be reached by sequential upward steps.

5.11.8 The second case is when K=N-1. In this limit, each gene is affected by all remaining genes. The resulting fitness landscape is extremely rugged, i.e. entirely uncorrelated.

5.11.9 Another case is when K=2. Kauffman found that for small values of K, local optima are not distributed randomly in the space, but are near one another instead. More precisely, he states, the highest optima are nearest to one another. Thus the landscape has a global structure: it possesses a kind of 'Massif Central'.

5.11.10 Kauffman argues that as K increases, the scene changes from smooth landscapes, through a group of increasingly rugged landscapes to fully uncorrelated landscapes (assuming N to be constant). Thus, the richer the interactions, the more rugged the fitness landscape. Furthermore, as K increases, the number of conflicting constraints increases. When K increases to N-1, conflicts between the constraints reach an optimum, which leads to poorer local optima than for smaller values of K.

5.11.11 From the mathematical work of Kauffman on N/K models, the N and K value of a network appear to have important implications for the solution topology within the network. The solution topology indicates the relative quality of solutions, which can be achieved through the network. We saw that in simple networks, as in Figure 5-8 the solution topology is like a mountain with smooth slopes and a clear top (Mount Fuji topology). To reach the top the network can use a relatively simple rule, even when the top is invisible. As long as every step forward by the network is an improvement on the former, it will know for sure that it will finally arrive at the top. It is simply the optimum proposition which presents a clear maximum by moving in the right direction, step by step.

5.11.12 This is not true for the right-hand network in Figure 5-8. As a consequence of the increase of the number of connections the solution topology becomes rough, and more peaks and valleys emerge. The topology looks more like an alpine range than a 'Mount Fuji-landscape'. If a local peak has been reached, it is not immediately clear how to reach the next one, because each alternative means a worse position. Learning to move in such topologies is, therefore, substantially more complex in terms of solution rules than in the simple network. This has a consequence for organisation networks: as the network becomes more complicated in terms of the number of players and connections, within the existing knowledge the solution space becomes too complicated to move to higher ambitions. Such self-organising groups run the risk of being stranded on a local optimum. Knowing that they can improve, they fail to find out how that should be done. Another important phenomenon is the 'adaptive walk': a genotype adapts (for instance, it flips its value from 0 to 1) as long as it has neighbours whose fitness is higher. This walk continues until the expected number of fitter neighbours drops below 1. In very rugged landscapes this can cause genotypes to be trapped or frozen into small regions - locally optimal, but certainly not globally. The evolution of solutions might come to a standstill when the network ends at a local optimum of the solutions landscape.

5.11.13 Large, densely connected networks run a larger risk to arrive at such local optima than small or sparsely connected networks. When two complex systems, each with their specific solutions topology interact, this observation will have important impact (see Chapter 7.6-7.7), interfacing networked systems). Whereas more densely connected systems provide a richer potential of solutions, this will also increase the chances of 'getting lost' in the solutions space. There is likely an optimum where a balance is struck between the requirements of the environment (e.g. the market, expressed in a needs-topology) and the system (e.g. the companies supply system in a solutions topology). To rich a solutions topology will increase the energy required to avoid being stuck on local maximum, to narrow a topology will under-exploit the market potential.

5.11.14 This phenomenon is elegantly observable in modern PC operating software as Windows 95. In an attempt to create a solution for every conceivable situation the number of possibilities for connection and parameter-setting between the large number of building blocks in the program is now so large that many users fail to find their way through the solution space.

5.12 Conclusions

5.12.1 In this chapter we have explored the curious world of order and complexity. It has become clear that order represents a much wider range of phenomena than the order that is created by central command and control or the observable relations between the entities of a system. Order can, under certain conditions, arise out of the system itself, provided this system is capable of open interaction with the environment. Both passive as well as active entities can display emergent order.

5.12.2 On the other hand not all systems are what they seem to be, especially when it comes to order. There is a class of systems, complex dynamic systems, which is completely orderly in its behaviour, while the phenomenological representation of the system can only with great difficulty be distinguished from chaotic behaviour. Complexity and order are in this respect for dynamic systems two sides of the same coin. Dependent on whether we are interested in creating order, or alternatively understand underlying order in apparently chaotic systems, we will look at different sides of the same coin.

5.12.3 The importance of these observations relates back to the industrial paradox which was described in Chapter 4.4. If we were to create order from interaction between the functional elements of our business processes, interactive order promises a much richer solution space (depending on the connectivity of the networked systems) than ever could be achieved in an hierarchical system, while avoiding the communications break down as was described at the end of Chapter 4.

5.12.4 On the other hand, if markets could be considered as complex dynamic systems, there might be a deeper, hidden, structure of order which will helps us in reducing the phenomenological level of unpredictability and heterogeneity to a usable structure to interact with the internal networked processes. Both expectations though will have to be developed further in order to understand their viability. With respect to emergent order in organisational processes from the interactions between subsystems, this will be addressed in the Chapters 6 and 7, while the theory developed in these chapters will be applied to supply chain-, information- and organisational processes in the Chapters 10 through 12. Addressing the complexity of advanced markets is the main topic of Chapter 9.

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[i] The distribution of instructions is seen as -one way- communications as well.

[ii] In a classic article, March (1991) clarifies the distinction between exploration and exploitation. Exploration is characterised by search, variation, risk taking, experimentation, play, flexibility, discovery, innovation. Exploitation is characterised by refinement, choice, production, efficiency, selection, implementation, execution. Firms that exclusively focus on exploration will bear the costs of experimentation without gaining its benefits, because they have too many undeveloped new ideas and too little distinctive competence. Firms focusing exclusively on exploitation, however, become easily trapped in suboptimal stability. As a result, March states, maintaining an appropriate balance between exploration and exploitation is a primary factor in system survival and prosperity.
In evolutionary models of organisational forms, the same discussion is framed in terms of balancing the processes of variation (i.e. exploration) and selection (i.e. exploitation) of organisational forms. Effective selection among forms, routines, or practices is essential to survival, but the same is true for generating new alternative forms, routines or practices. Particularly in a turbulent environment, the rate of exploratory variation determines evolutionary dominance of an organisation.

[iii] Quoted in Hofstadter, 1979.

[iv] ‘Living’ as used here is not necessarily identical to the biological meaning of the word. It is used to, quoting Francesco Varela, indicate that the entities do have own ambitions enabling them to move against the gradient of ambient forces. They are in this sense different from ‘dead’ entities, which are behaving only driven by external forces. It is this definition of ‘living’ which also underlies de title of Arie de Geus’ book ‘The Living Company’ (1997).

[v] The double auction is an example of what is called ‘robust design’. Robust design means that the behaviour of the individual interacting with the design is largely insensitive to the general intelligence of the individual or the individual’s knowledge of the particular artefact that has been designed (Levinthal and Warglien, forthcoming). In terms of the fitness landscapes (Chapter 5.11) it represents a landscape with a single peak. The double auction can be deemed a robust design because regardless of the differences between the economic agents involved, it will always result in an optimum equilibrium outcome (orderly behaviour). Or, as Wilson (1985) states: “If there are sufficiently many buyers and sellers, then there is no other trading mechanism that would increase some traders’ expected gains from trade without lowering other traders’ expected gains from trade” (quoted in McAfee and McMillan, 1987). Further economic analyses of the double auction principle has been performed by Fudenberg and Tirole (1991) and by Gibbons (1992).

[vi] In many systems feedback loops occur. Dependent on the nature they are referred to as negative or positive feedback loops. Negative feedback systems are like a heater at home. We put the central heater on 20°, whereupon it keeps heating the house until the temperature reaches 20°, after which it stops. The heater works towards a steady state, it looks for an equilibrium. Once the equilibrium is reached and nothing changes (and the house does not lose any heat), the heater becomes inactive.
Positive feedback systems work exactly the other way around. Suppose our central heater at home would have a positive feedback system. In that case as soon as the 20° would be reached, the heater would start burning faster and the higher the temperature would become, the faster it would burn. It would work like an avalanche mechanism, within which small deviations are transmitted to create very large deviations. Positive feedback amplifies the deviations instead of damping them.

[vii] A floppy disk is supplied with this thesis, containing the COLORS programme. Starting the programme (Colors.exe) under Windows 95 will demonstrate the emergence of order on the computer-screen.

[viii] In physics entropy is used as a measure of dis-order. In analogy with physics we define in Chapter 5.8 a measure for organisational disorder, which we will refer to as organisational entropy. Although in the strict physics definition the entropy concept cannot immediately be applied to organisations, a ‘loose’ application of the entropy formula to organisations gives a neat measure to characterise the (dis-)order in organisational systems

[ix] In our consultancy practice we have noticed similar effects for market leaders who control a substantial share of the market. Possibly the (natural) barriers we see emerging in the COLORS programme, also exist in the real market situation

[x] This is an interesting topic for further research, as will be addressed in Chapter 13.

[xi] For extensive research on ant’s behaviour, see Hölldobler and Wilson (1994).
[xii] For a very simple computer model example of ant’s behaviour, see http://www.cerfnet.com/~shaper/java/langston/.
[xiii] This is a gross simplification of the physical (Bolzmann) definition of entropy in thermodynamics. In physics the entropy-measure is a reflection of the probability of states, calculated over all possible states of the system. The state of such particle is expressed by its position and momentum, both in 3 dimensions. In our definition of organisational entropy, we will characterise the state using one simple parameter. In the COLORS model this parameter is the color of the particle, in other examples it is the existence of utility/communication-links between two entities.

[xiv] An interesting quote by professor In ‘t Veld (1975) regarding the entropy measure:
“It is interesting to ponder on negative entropy and organisations, but honesty induces me to say that in the practical the solving of business problems, it has been of no use to me whatsoever.”

[xv] See amongst others Prigogine (1961; 1980).

[xvi] From a mathematical point of view the principle is very simple to explain. The mathematical equation which governs it is a parabola. If $y = x_{n+1}$ and y becomes the next x, it mirrors x and y all the time. That gives a y, which y becomes a new x and mirrors the x-axis. As long as the parabola that is governed by L is underneath that line, then no matter where we start we end up at zero. If the parabola crosses the ‘mirror line’, then oscillations occur with increasing complexity, dependant on L. The essence is that it is a very simple mathematical structure and all points that are visible in this chaotic bifurcation plot, are points on that curve. Point by point we can reproduce this very complex and chaotic picture by re-running the algorithms. Using similar mathematical principles, we can make pictures that look like leaves of trees. Mandelbrot equations generate beautiful fractal structures, almost as objects of art. Beautifully coloured paintings based on fractals are made by for example Pincer.

[xvii] We refer to the eighth edition of Marshall's book (1938).

[xviii] See amongst others Smith (1776), Marshall (1938), people like Young (1928), Chamberlin (1962) and Robinson (1933), Hicks (1936), Kaldor (1985) and Arthur 1988; 1994).

[xix] Interesting, because it enables us to look at the problem of interaction between two complex dynamic (sub) systems in their exchange of value.

[xx] The number of values each site can display is also a very important complexity factor.