Seminar Notes On ‘Complexity Science and Order Creation’.

Abstract: ‘Human and social capital’ is the cornerstone of increasing corporate intelligence for generating ‘economic rents’. Complexity Science indicates that ‘adaptive tension’ dynamics (analogous to Bénard cell energy differentials) fosters an adaptively efficacious ‘distributive intelligence’. The optimal region for
improving adaptive fitness occurs between the 1st and 2nd critical values of adaptive tension. This region sometimes known as ‘the edge of chaos’ is where emergent self-organisation occurs. Below the 1st value the is little change due to bureaucratic structures, above the 2nd the system becomes chaotic and dysfunctional.The job of the CEO is to encourage staff to be autonomous agents, but at the same time to define the ‘context’ of the business and to set the
overall tension.

Director of Complexity Research : Eve Mitleton- Kelly
London School of Economics
Houghton Street
London WC2A 2A

Presenter : Bill McKelvey - The Anderson School, UCLA, California.

Compiled For The L.S.E.
by Geoffrey J.C. Higgs 8/6/01

Introduction

To mathematicians complexity theory was a great discovery, involving such things as ‘strange attractors’, ‘fractals’ and the ‘butterfly effects’. They could write simple equations and feed the data into a computer to get patterns which were not only visually amazing but enabled scientists to understand the apparently random behaviour of evolving dynamic systems. But to life scientists or social scientists or economists its use does not seem immediately obvious. In terms of our social or business lives we live in a fast changing world to which the laws of classical physics do not seem to apply. Can this new science of complex evolving systems help us to understand business and other social phenomena?

Conventional Science

In order to make sense of the world we make generalisations about it or try to identify the factors that make a situation what it is. This is also the way conventional science works. All lighted matches, for example, that come into contact with petrol at room temperature result in fires. The causal connection that we make depends on our ability to make a generalisation. Boltzmann had a problem when he developed the kinetic theory of gases. How was it possible to explain the pressure of a gas from the force of the molecules hitting the side of the container when there was a random distribution of kinetic energies? He solved the problem by statistical mechanics which uses averages.

Economists make generalisations and use averages when they study the macro-economics of countries and industries. When they consider companies and individuals in companies they make generalisations about them too. One of the most standard assumptions is that all individuals make rational decisions. But averages applied to people’s ability to come up with ideas is a very shaky concept indeed. Causality depends on generalising and generalising depends on the notion of homogeneity. The conclusion is that attributing causality implies homogeneity at some lower level and people for the most part are not homogenous.

The other assumption that conventional science has trained us to make is that systems, left alone, will attain some kind of equilibrium. To challenge this is not to challenge the Second Law of Thermodynamics but to say that providing a system has some form of energy being put into it there’s no reason to assume it will reach some steady state at all. Some systems do; they progress to stability and then stop. In mathematics terms we conceive this as a point attractor on a graph. Complexity theory deals with systems in which causal links cannot be identified and in which stable states are not end points but only phases in the process. The time scale over which change occurs has much to do with the kind of mathematical models that we construct. Newtonian mechanics for example successfully explains the planetary orbits because they change so little over say a billion years. The rate of change in biological evolution is somewhat greater and social evolution in the human population is extremly fast and probably getting faster.

Complexity Theory

Complexity theory deals with entities or components in a system which interact and themselves change, sometimes in unpredictable ways. This means there are two levels which we might analyse: the interaction or ‘connectivity’ of the entities or components and the variability of the entities themselves. Stuart Kauffman’s early models of a complex system actually used light bulbs that were all the same and either ‘on’ or ‘off’. The complexity that arose was due to the connectivity of the system.

Natural or biological evolution deals with eco-systems in which organisms change and subsequently adapt to the selective pressures of the environment which includes the competition of other species. Darwinism has three principles: one, that individual organisms are mutable, two, that change is passed on to descendants and three, that ‘natural selection’ selects organisms whose change bestows some advantage. Darwin himself, sometimes saw natural selection in terms of ‘survival of the fittest’ and sometimes as ‘adaptation’ to some environmental niche. Today these views are perhaps simplistic. Species do not always compete

and ‘niches’ are always changing. People, for example, like many other organisms ‘co-evolve’ and in doing so affect the whole system which in turn affects the individual. But the kind of analysis we carry out on a complex system depend largely on the epistemological method rather than the discovery of ‘natural kinds’ (species as real physical objects). We may distinguish certain self organising structures within the system and certain levels of connectivity in order to describe how complexity occurs but in the real world no lines can be drawn.

The ‘Engine’ of Complexity

The term ‘complexity science’ is somewhat misleading. It’s like calling the science of thermodynamics ‘hot science’. Complexity is a symptom of evolving systems as ‘hotness’ is a symptom of heat emanation but just as in thermodynamics we focus on where the heat comes from and where it goes, in complexity science we are more interested in how the complexity comes about.

In thermodynamics, heat flows from the ‘hot’ to the ‘cold’ usually in a random manner as in the convection currents in water which rise up until they reach some interface or constraint and then go down again. We can see this in the geology of the Earth and its atmosphere. If however a system is constrained in particular ways then order or pattern may emerge. This is the principle of the Bénard cell or process in which a thin layer of liquid is trapped between horizontal glass plates and a heat source is applied to the lower. A temperature differential develops between the plates but if the overall average is below a certain value (1st critical value) heat is merely conducted. When convection currents start they assume a hexagonal pattern. Above a higher value (2nd critical value) the order or pattern disappears. The pattern is a very simple example of what Prigogine called a ‘dissipative structure’; heat or energy flows into a system, is channeled in some way and then flows out again. Where the constraints or variables of a system are few the outcome may be fairly predictable. When however a number of variables are operating at the same time the system becomes complex and the outcome is not predictable.

If we ask what we mean by ‘order’ then Ron Ashby suggested a basic formal definition in 1962: ‘a link between A and B does not become order until it is in the context of some external constraint C’. Order or pattern requires constraints which come from the kind of environment in which it exists but it is the interactions between the components, entities or agents’ which create order as a response to conditions.

Stuart Kauffman says little about the ‘engine’. He speaks of the spontaneous appearance of order in the natural world and how molecules might get together to eventually produce life but not the ‘engine’ and this highlights the difference of approach between the Santa Fe scientists and the German school.

He does however talk about ‘complexity catastrophe’ (1993) as a problem of ‘too much complexity’; when interconnections in a system reach a level at which Darwinian selection shuts down; when ‘variance’ is minimised to the point at which there is nothing left to select. There is a biological principle that goes back to R.E. Fisher that says that the rate of biological evolution is proportional to genetic variance; that it is the rate of internal change that enables organisms to home in on new environmental niches and escape the law of competitive exclusion.

Use of Models

In order to understand how a particular complex system works we attempt to model it using a computer and then see if what we get bears some resemblance to the real situation. This approach is limited because of assumptions made in the initial conditions and in the generalisations and approximations. We have to allow for heterogeneous agents as well as the kind of connectivities there might be between them. We also have to be careful that we don’t take the model for the real world.

All ecosystems have components which co-evolve with each other and the environment. Where we draw the lines between components and between components and environment depends on the level of analysis. When we talk of co-evolution

we distinguish components within the system which are in some way self organising and autopoietic (self perpetuating). The co-evolving components influence the totality of the system and the totality influences the components but this thought model can be used at different levels from the micro to the macro. All of these extrapolations will suffer from some kind of artificial limitations and oversimplifications. We have to think hard about how important these assumptions and approximations are. Time scales are also important considerations in how our behaviour may influence a complex system and this determines the kind of models we make. Re-arranging your garden for thirty minutes each day is unlikely to affect the Amazonian rainforest in spite of the 'butterfly' effect but pumping carbon dioxide into the atmosphere over a long period probably will.

Industry as an Ecosystem

Complexity theory provides a useful metaphor for understanding the evolution of social systems. Economics is a branch of social science that deals with the production and distribution of wealth and companies consist of people who are engaged in this pursuit.

People in business aim to produce profits which are above the particular industry's norm. This means you beat your 'run of the mill' competitors and flourish while they whither away. Stock market prices are much dependent on these so-called 'economic rents'. 'Strategy', in the past often meant just taking a 'low cost' position and a 'high quality' one and consultants who advised on 'best practice' would recommend that that you took the manufacturing part of the operation to the 'Far East' so that you could buy cheap labour. That and improved quality got the business on the 'efficiency curve' in which you hoped to beat your competitor. But the truth was that you could only buy a little time before your competitors did the same. Old strategy focused on capital and labour, new strategy focuses on 'human and social capital' which provides the ability to stay at the forefront of the industries evolution, to find new niches in the business environment and exploit or develop them faster than anybody else. Old strategy focuses on industry-level competition dynamics, new strategy focuses on inter-firm dynamics. The way to achieve a sustainable competitive advantage is to evolve just that bit ahead of other people and to do that it may be necessary to speed up the firms internal rate of change.

Speed up the rate of internal change and you won't get stuck where your competitors will oust you. On the other hand too much internal divergence and the firm will lose its integrity and coherence. You need to somehow measure the rate of change in the industry and have sufficient rate of change in your own firm to give a sustainable competitive advantage. As firms get more mature they tend to slow down but the answer is not to buy up a lot of small 'dot coms' in the hope that it will speed up your internal metabolism. Such small 'high tech' companies have a very fast metabolism to cope with a fast changing environment. Seventy to ninety percent of the attempts to graft small high tech. companies onto large established organisations fail either because the small company gets killed off or because it simply turns into another division of the parent or worse still causes the downfall of the parent. It's like grafting chicken legs on to a dinosaur.

But it's not just the grafting of chicken legs that's a problem. Because General Motors in the States had a reputation as a high cost producer of low quality cars the Saturn Corporation was created with a $ 6 billion investment to be the opposite. Saturn was created separate, marketed separate and had a wholly different corporate culture. Then General Motors wanted Saturn to come out with a mid range car with the body parts from Europe which meant importing the G.M. platform and logistics. This effectively destroyed the processes of Saturn in terms of its 'human and social capital' including the marketing edifice. G.M had a hard time getting new ideas and re-organisation so they created Saturn but they then contaminated it by importing the old G.M. culture. It's a 'legacy problem'.

Human and Social Capital

If companies consist of people then the ‘human capital’ is the individual genius of each person. But a company full of isolated geniuses doesn’t give you much, just as if you have a network of idiots you don’t get much either. So the ‘social interaction’ is important and the two are normally taken together as ‘human and social capital’.

We need to build up the general capability of a firm by increasing its human and social capital. We can employ people that we judge to be bright and creative but how can we estimate the level of the social capital? Social capital springs from the interactions of individual employees. So it’s an emergent property. People meet at the coffee machine or the lunch table or the bar and (hopefully) discuss their ideas or their problems with colleagues who they think can help them. The measure of whether this interaction is useful is evidence that such contact results in groups or committees or teams that get together formally and seek funds and management to develop new products or services. Frank Douglas of Shell has the funnel metaphor. You might give a prize for ideas and your employees will come up with 1000 ideas, but you need an innovation funnel full of human and social capital to sift and develop the one or two that will end up as new products on the market. You need to know how many good ideas, sloshing about in the social capital are making it to production.

People as Autonomous Agents

Creativity is usually defined as people coming together and associating new ideas. Systems that evolve in a Darwinian manner have mutation as an important factor in the complexity. But companies may have people whose behaviour is always the same either because they do not see beyond their immediate responsibilities or because they are constrained by a ‘command and control’ structure and do not have a base for generating new ideas and skills. Agent diversity is essential to a systems ability to adapt. Peter Allen’s studies of fisheries in Africa and Nova Scotia show that when you take away agent diversity in an ecosystem the adaptive capability of a system dies. Experiments at the Los Alamos Laboratory in the US show that in models where agents are given the task of getting through a maze, that diminishing the diversity of the agents reduces their ability to get through it. In more sophisticated models neural networks are trained to invest in financial markets according to certain patterns on the indexes. But agent autonomy is also important. In models of systems in which agents invest money in the stock market the agents learn at different rates. Developing memory shows that the ‘rules’ by which agents invest in the stock market change over time and there is a ‘genetic’ algorithm which enables the agents to change the kind of responses they have when they come into contact with other agents. Agents can become more diverse or less diverse. What happens is that agents begin to find the ‘rules’ that work in the particular market circumstance and their actions become more and more similar. In the end everyone ends up buying and the share price goes up and up because more investors find the ‘winning’ formula until there a sudden change in the economic environment and the market crashes because the rules no longer work. There’s nobody to sell to because everybody is trying to sell. The agents are then forced to diversify and the cycle starts again. The 1987 Asian meltdown was because people on Wall Street had found a formula. On the other hand too much agent diversity leads to anarchy. We need novelty but how do we keep order?

Old Management New Management

Old style management was largely hierarchical with the CEO directing from the top. But the ‘command and control’ structure tends to shut down agent heterogeneity and therefore shuts off the source of possible creativity. In a changing business environment you need diversity to ensure the survival of the company. But there’s an optimum state between too much order which gets rid of diversity and too little which gives a chaotic situation where agents are more likely to be working for themselves rather than the company.

Theories of leadership have changed from the factory owners who simply wanted people to work harder to produce more widgets to the the heroic leader of the 1980’s who was to have charisma and a vision which was supposed to cascade

down through the organisation. True, it was ‘situational’ and was supposed to be geared to the kind of organisation it was; more autocratic for a military one, less autocratic and much more participatory for say a design group or advertising agency. But as the rate of change of the business environment increased so did the turnover rate of CEOs. It was often found that the vision didn’t sustain for long enough. Moreover the more the employees functions were prescribed the more bureaucracy was engendered and this increased the risk of being locked into a culture that was out of step with the prevailing business environment.

Adaptive Tension

The Bénard cell is a useful metaphor for understanding the processes that go on in a firm that is operating in some particular field or industry for two reasons. The first is that it requires a constant energy input. All firm require an energy input whether in terms of resources or the activities of its staff. The second is that there are lower and upper critical temperature values (1st and 2nd values) between which pattern or order emerges. The external business environment in which a firm finds itself not only imposes the constraints of the particular industry but also a selective pressure to adapt to its change. We can see this pressure to keep up or adapt as a tension, analogous to the temperature differential in the Bénard cell.

Under Pressure

Jack Welch joined General Electric as CEO in 1961 and since then the company has produced $270 billion worth of shareholder value. That’s more than any other firm at any other time. What Jack is particularly good at is managing the adaptive tension. The essence of the message is simple: be number one or two in the industry or you go down. General Electric has reduced its management levels from nine to five and reduced its corporate staff from 1700 to 700. Some firms in the US have reduced their corporate staff by 90%. The policy has been to delegate responsibility to lower level management and to make that management more eclectic in its ability by moving it around. Toyota has adopted a more softly softly tension building approach by posting information about what workers in similar positions but at other locations within the company are doing along with what the competition is doing. Incentives at General Electric may seem draconian but new ideas and practices are put on their internal information network as quickly and as efficiently as possible so the access to social capital is also high.

Adaptive tension starts with an analysis of the firm’s position in the industry. Our technology is here when our competitors are up there. Our costs are up there when our competitors are down here. A paucity of new ideas is symptomatic of too little adaptive tension. The company is below the first critical value with too much order and too much bureaucracy. There’s not much adaptive tension in the company if staff meet at the coffee machine complain about things and then simply go back to their desks. Even if there are some new ideas nothing comes of them We don’t see emergent networks of people that stay together, that ask for funds, that build prototypes? We don’t see conversations on the e-mail and there is software that will analyse the e-mail traffic in different ways to find out this information. Progression of ideas produces memo’s and minutes of meetings.

Leadership

The CEO’s job is to focus the firm towards the industry in which it is engaged. No commercial company arises from the social system as frogs were once supposed to rise spontaneously from wet mud. It needs planning and conscious effort. And if a company is failing because it is out of sync with what it needs to survive and thrive in the industry it is the responsibility of the CEO to define the context in which people work and set the tension. This is not to say CEOs tell people what needs to be done. ‘Be number 1 or 2 in the industry is a ‘tension statement’ not a ‘content statement’. Bill Mckelvey has a simple tension setter with his doctoral students. Each week they have to say what they

plan to do. This is subtle tension setting because they have to say something new each time. But the tension level has to be set just right otherwise they suffer dysfunctional stress.

The problem is how do you set processes in motion that guarantee the heterogeneity and autonomy of the agents in a system thereby retaining creativity whilst a the same time efficiently producing a product or a service? You need order and you need the Shell funnel by which ideas lead to products that make money. People in established companies tend to be trained into bureaucratic behaviour and tensions need to be created to get them behaving like autonomous agents. It is human and social capital that gives a firm the edge. Economists tend to say that the way a company generates economic rents is by being in the right industry. Given that money making is the object and some particular industry is the most profitable then all firms ought to be in it. But if that was the case then nobody would be making economic rents and profits would be marginalised.

Defining Context

The CEO defines the boundaries of the organisation. Jack Welch did a lot of buying and selling of divisions in deciding that for General Electric. Established companies may suffer from both too much bureaucracy (below 1st critical value) and too much chaos (above 2nd critical value). The aim is to prevent chaos by defining ‘context’ and using ‘adaptive tension’ to create new order. Definition of context is the ‘raison d’etre’ of the organisation and where its strengths and weaknesses in dealing with the business environment. In the Western world most organisations are economically driven in some sense but the ‘mission’ is not always obvious. The context of Academia is different from public service and public service is different from the Militia.

Adaptive tension is the motivation to be a good agent for the company and it may be created by the CEO but it could come from within. For a commercial company the bottom line for the employees is that if we don’t work we’ll starve but above that there may be many driving forces. For a small company it may be the sheer entrepreneurial excitement but for a larger public company it is satisfying the shareholders. Context should spring from the CEO but the adaptive tension statements can be made at all managerial levels. The adaptive tension in the accounts department for example should be less than that in the research and development and, as it ever was, R and D will view accountants as boring bureaucrats and Accounts will view R and D as profligate and undisciplined.

Over time context and motivation may change as dependencies grow and in general successful companies get bigger and dependencies and responsibilities increase. But defining ‘context ‘ can be a problem. There’s a case example of the company BTR which had a clear policy of acquisition of small companies in one or two forms of engineering. They were very successful in these assimilations until they picked on Hawker Siddely who claimed to be experts in 28 forms of engineering and had a presence in 70-80 countries many in partnership with local governments. This was a case of too much context for BTR to grasp. The Hawker Siddely group came in with so many existing ties and path dependencies that agents couldn’t re-organise and BTR probably hasn’t recovered.

Sometimes there are conflicting contexts for public service organisations such as the National Health Service in the U.K. In this case the politicians create the context for the N.H.S., the N.H.S. creates the context for the treatment of the public and the public elect the politicians. But the interests of each of these bodies are different. Until somebody defines an overarching context the system will be at odds with itself.

Weakening Ties and Setting the Tension

CEOs and managers generally have a duty not just to define context but to undo ‘strong ties’ or ‘path dependencies’. In the biological world it is the ‘epistatic’ links between genes that make some mutations more possible than others. Epistatic links preserve an organism's integrity but in a company it may also result in a stifling bureaucracy. Bill McKelvey’s secretary used to have a sign up over her desk saying: ‘There’s no reason, it’s just policy’- an apt

aphorism on bureaucracy. It's what often results in the 'no's to any new initiative. In biological models it is epistatic links that flatten the fitness landscape so that there is little difference between the peaks and troughs. Without peaks and troughs you don't get novelty. But organisations are a lot more flexible than organisms. You can't loosen an elephants legs from its body and expect them to function independently with only the nerves connecting but you can divide an organisation so that only the people who have to connect do connect. Sony effectively did this with the 'Walkman' personal recorder. The equipment was specified to consist of twelve different modules; the battery, the receiver, the speaker etc., etc. 120 variants of modules were produced for different markets with each independent division of the company coming up with its own variations on its module. If Sony had tried to optimise the design for a particular outlet it would not have been cost effective but by keeping enough 'slack' between the modules they were able to accommodate a wide range of client requirements.

Nevertheless inducing the agents to become more autonomous means you have to generate the adaptive tension and contextual drivers to influence the kind of self organised order that might come out of it. Agents left to their own autonomy may develop all kinds of order some of which are important to the context and some which aren't. There may be kinds of order in a company that nobody sees and some that people try not to see and in Shell's funnel there may be a lot of order that is not described and should be. Yet the more the funnel is successful the more attention will be paid to it and the more people will want to change their incentives and useful networks will emerge.