LSE Study Group

A Note On 'Dissipative structures and far from equilibrium systems'

Discussion led by Prof. Peter Allen, Cranfield, on 20 February 2002

<u>Abstract</u>: One way of studying complexity is by looking at dissipative structures which are open systems exchanging energy, matter or information with their environment and when pushed far-from-equilibrium create new structures and order.

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Morning Session

Paradigms are often difficult to shift. First there was the Newtonian paradigm, then came the shock of dissipative structures. There were a number of ways in which this came about, but in terms of fundamental principles it was the weakness of Reductionism as a sure-fire scientific method. Reflecting on natural systems, how they evolve and how we might model them, has enabled us to talk about a different paradigm. But models themselves can be of a number of different kinds. Newton's laws led to a mechanical model of the solar system in which the moon went round the earth and the earth went round the sun and the idea of equilibrium enabled prediction. Newton's laws provided an extreme economy of explanation. We have one equation and given his assumptions the movements of the planets could, in theory be calculated. The only problem with the assumption of equilibrium is that we don't have an explanation of how it might have begun or how it might end. But its predictivity is beguiling. It's predictive because the system doesn't change. The planets are frictionless, the system just runs and unless an 'invisible hand' (or a visible hand) comes in and starts poking around on human time scales it's completely predictable. So the idea that there was obtainable objective truth 'out there' in nature was reinforced. Get the components of a system right and the rules by which they interact and everything about the system follows. Newton's mental jump from an apple falling, to the interaction of the moon and the planets was a fantastic piece of intuition and impressed everyone so much that it's taken us more than three hundred years to get over it. But most systems on earth are dissipative; they involve friction and viscosity and run down. We used to do all those calculations in applied maths about projectiles and we'd discuss putting a factor for air resistance and so on but we'd still try to use Newton's law for prediction and when it didn't work for some particular system we'd simply say it wasn't predictable from a general law because we didn't have enough information. The tacit assumption was that science was all about linear systems that were predictable. And so we would change the question to 'can we draw graphs and describe a trajectory for this particular situation and perhaps say what will probably happen'. What we're talking about here is the socially constructed aspect of theory, one that attempts to throw nets over reality with a greater or lesser success.

And that is also true of models. Models are mathematical symbols expressed in certain logical relationships with each other. All of them are limited in some way as illustrations of reality in general. Newton's laws worked for the solar system accepting the assumptions he made and ignoring the history of the universe. Today there are linear and non-linear models, equilibrium assuming models, evolutionary models and co-evolutionary models, non-learning and learning models. And then there's the Second Law of thermodynamics, where for a closed system everything put together eventually falls apart.

Take a box that's divided by a partition into two volumes. In one we have red gas molecules and in the other we have blue. It has a certain order about it simply because of the separation. Take the partition out and diffusion causes the molecules to mix until the gas is to all intents and purposes homogeneous. It is 'symmetrical'. We can explain why it does that using Boltzmann's theory. The red gas and the blue gas molecules have a probability distribution of kinetic energies which is like a bell shaped curve on a graph. Some are moving slow, some are moving fast but the majority are around a great hump in the middle. Remove the partition and the molecules bump into each other until the same profile of distribution curve is obtained again. Now we can take an average momentum for the impact of molecules on the side of the container and work out the pressure. Of course if we sampled the system in different places we would find out that it wasn't homogeneous, but for most practical purposes we can assume that it is.

Scientists when faced with 'open' systems in which energy or matter was flowing in and out unevenly, tended to ignore them. Such systems had non-linear dynamics and the problem was that the maths was insufficient to describe them. Even a mathematical description of something like the turbulence in water running from a tap was problematic, yet the fact remained that there were many systems in nature that were just like that. However, there's more to open systems than the fact that energy or matter passes into them is transformed and passes out again. 'Feed' them with energy or matter to stop them attaining equilibrium and at a certain rate of flow they may change their properties in ordered ways. The Bénard process is like that. Discovered in the 19th century it consists of two glass plates between which is a thin layer of water. Apply heat to the bottom plate at an even rate and spread and it will initially simply conduct. Raise the temperature differential until convection starts and hexagonal patterns appear. But for a long time nobody recognised the importance of the phenomenon. It is an another example of what the Nobel Prize winner Prigogine called 'symmetry breaking'. What is interesting is that you have something that is potentially unstable going unexpectedly to something that is stable.

There were also chemical reactions in which regular patterns emerged. The Belousov-Zhabotinsky (BZ) was first noticed when experiments were being carried out with malonic acid, a bromate and a cerium salt solution. The actual recipe need not concern us here but what was observed were changing patterns of red and blue areas in a petri dish. When reacting chemicals are put together in a container they normally reach an equilibrium between products and reactants. Reactions with a high product yield have an equilibrium heavily biased to the product side. With the BZ reaction not only do beautiful spiral waves of colour emerge but the patterns can be changed by pumping more chemical into the system or extracting them. Importantly the patterns are never the same with the same starting conditions. It is predictable insofar as at certain concentrations of the constituents we know we will get patterns yet the size of the pattern isn't predictable. Of course in a flat petri dish we only see the patterns as two dimensional though they would in reality be in three dimensions.

The process is even more startling in that if we stir the constituents up we get what is called a 'chemical clock'. Normally we would expect stirring to maintain an homogeneous mix. As we change the rates at which chemicals are pumped in and stirred the 'residence' time changes. A very long residence time is the same as just having the chemicals in a dish. But as the residence time is reduced we see the solution going from red to blue and after a short while back to red and then blue and so on. This 'chemical clock' has a regular period and amplitude and what is also interesting is that if we perturb the system by injecting a few drops of chemical or tapping it with a finger there is a period of disturbance followed by a return to an oscillatory mode of the same amplitude and period as before. This is called 'asymptotic stability'.

Prigogine spent many years trying to find the laws which governed such a process without success but we now know that it not only involves auto-catalysis in which the rate of production of a constituent is increased by the presence of itself, but that there is a cycle of reaction which is analogous to the population cycles of predator and prey in the natural world. One reaction predominates then the other then the first again. The colour changes from red to blue and then back to red again because cerium ions are blue in their oxidised state and red in their reduced state. The chemical dynamics are like population dynamics; the rate of 'feed' is like the birth rate. Don't feed the system and it 'dies'. If we do feed the system and we maintain it in a 'far from equilibrium' state then because it has instability in it, it breaks symmetry in different ways. The interplay between the molecules is one that follows the laws of physics and chemistry but the emerging patterns indicate self organisation in that the boundaries of colour are not artificially induced. The emerging pattern requires a certain input to maintain it, and constrains the overall reaction rate because of the kind of pattern it is. A moving pattern is the result of diffusion and the production of ions the concentration of which is either increasing or decreasing. We can model this kind of process using a computer simulated tube which is divided into a number of zones. The ends are open to the environment enabling chemicals to flow in one end and out the other. Concentrations of chemicals are represented by numbers and each zone in which the reaction is occurring thus expresses rates of diffusion and ion production. By varying the input we induce oscillations the coherence of which is a function of the diffusion rates. Different diffusion rates produce many different patterns. Sometimes oscillations are in phase producing strong pattern and sometimes not. Diffusion rate equations can be written for each zone but what was extraordinary was that diffusion rates flipped from left to right or vice versa as the reaction rate was accelerated. Such symmetry breaking in a mixture that was initially homogeneous indicates the inapplicability of the Second Law of Thermodynamics.

Symmetry breaking is a fundamental characteristic of dissipative and evolving systems. Such systems in general require a new kind of description and demonstrate that nature can respond in ways which nobody has thought of. In the Bénard process it is not possible to predict in which direction the convection current will go in any particular zone and in the Belousov-Zhabotinsky reaction the pattern is also unpredictable. Chance seems to be 'built into' complex systems at some level for which we are unable to grasp the probability. In practical terms it is like the 'three body problem'. If we have three balls colliding the slightest difference in initial conditions means that we are unable to work out what will happen. Yet whatever the level at which we describe a complex system we are unable to overcome the chance element and at the bottom of any physical system lies quantum physics. In quantum physics theory it is impossible to specify both momentum and position simultaneously. And so for any particular system history matters. We can never repeat the experiment and scale is also important in assessing probability because quantum mechanics creates different kinds of 'noise' at different levels.

To what extent can we predict what will happen 'on average'? In the case of the gas molecules discussed earlier we used statistics of molecular behaviour to work out the pressure of a gas in a container. The assumption was that we could work out the behaviour of a mass of material from the behaviour of individual molecules. But with non-linear reactions going on we do not attain the kind of equilibrium we would expect for a linear reaction. We have uncertainty at the quantum level and we have uncertainty at the level at which pattern emerges. And more importantly we can never put all the molecules back to the initial starting conditions so we can never develop any average outcome for the system. Of course not anything can happen to a complex system. Pattern or structure is the result of a 'trade off' between different processes. It indicates some kind of stability; some balance between the processes of growth and decay, creation and destruction. When new structures or patterns emerge it means that the kind of equations we might have produced for what was going on before no longer apply. We might say that in general our determination of probability is a mark of our ignorance, but for some systems, at some level our ignorance will remain total.

We have however, made progress in our graphical representation of the change from linearity to non linearity. For a linear process we can plot a trajectory on a graph using the determining variables as dimensions. But at some point we may get a point of instability at which there is more than one solution for one, or maybe more variables. On a two dimensional graph we would then get what is called a 'bifurcation' where the system has more than one equally probable future. In such a case we cannot possibly know which path the trajectory will take though we may be able to state the alternatives. We can also test whether we have an asymptotic system by 'kicking' it a bit and seeing, depending on the degree of perturbation, whether it settles back again or 'blows' up. Averaging in order to obtain variable values assumes that the same description applies for all zones of a system. In a complex one we may have different fluctuations in different zones of the system. This is analogous to a natural ecosystem where for the same kind of equations we have different solutions for different parts of the world. Its a good question as to what happens at the interface where we may have one zone spreading whilst another declines.

The most important thing about an evolving process is that history matters. We can get some idea of this from origami or the art of paper folding. From a flat sheet of paper, depending on the folds that we make we might produce a bird, or a frog or a horse etc. The bird is interesting because when we get to fold eight or maybe nine we have to pull something out to get the wings and if we pull the tail a bit the wings actually flap. This is emergent functionality. Now traditional science can't describe the process so it studies the paper. What is its weight? What is its plasticity? etc. But all it would discover with our origami animals is that they're all the same. It's the folding process that gives rise to the emergent forms and functionality, and though we might see guide lines on a piece of paper which say 'fold here' and say 'Ah there's the DNA', we would still know nothing until we actually went through the process. And what is very important is that the folds are made in the right order. Now of course what offers even greater possibilities than a flat piece of paper is a knobbly chain like DNA itself. A piece of paper is dead and doesn't have metabolic processes doing the folding but it's quite a good example of the importance of sequence.

Ecosystems may have all of the characteristics we have been talking about. Peter, in the past, was trying to produce a model of Chesapeake Bay with all the different life forms that lived in it. Over a number of years animal and plant species were collected and counted and weighed to get some idea of the species biomass and work out a model of what eats what and so on. We can build a model on a computer and try to say something about pollution or the optimum limits of fishing. But even though the model had equations for changes based on the data to give a good idea of the population dynamics when the system was run it collapsed down to a few species to give a simple food chain that didn't really seem representative of reality. The problem occurred because average properties were attributed to each species. What happens in Chesapeake Bay is that some species come in and some go out but in reality it changes and adapts and stays very complex. So clearly the equations used in the model were inadequate. The equations expressed the change in a population as the number of births minus the number of deaths in a certain period of time, but that assumed that the particular species inhabited the whole of Chesapeake Bay. The model grossly over-simplified reality and led to implausible conclusions. The people who invented population dynamics may have had a grasp of all the factors for their particular area of study but later people imitated the method and assumed they could predict in other cases in the same way. The model also does not take account of the effect of individual variations. We are all individuals, even as far as our insides and though we may work in groups and talk to each other with a common language, it would be foolish to base an explanation of what we do on those things alone. We don't talk to people 'on average', we're not evenly spread across the world, and chance plays a big part in what happens in human society.

The Chesapeake Bay model is an interesting example of what may happen if we strive for too much rationality. In science we have to prove our case and even in this study group we are relying on a rational process to convince ourselves that we're acquiring knowledge. Mechanical type models where the interactions of the components can be related in a simple way according to a general law are very appealing and there are a number of specific ways in which we might fail to represent reality in all its glory. The first is that in order to distinguish a system we delineate a boundary in much the same way as we conceptually distinguish the solar system from the rest of the universe. But what we have to be sure of is whether the distinguishing features are significant for the dynamics model which we're creating. In the case of the solar system they are, for most practical purposes. Having established a boundary we then try to describe what's in it, but that's a problem because if the things in it are evolving we don't know how fast they are changing. In an ecosystem there may be all kinds of selection pressures which evolve the species it contains including social and economic factors. But since we cannot grasp all the possibilities of what might happen we set up our equations only for the here and now. And then we make the third assumption and attribute smooth rate of change for the processes that are going on. We imagine that population growth is smooth or that making a product and selling it always follows the same sort of pattern etc. So our set of equations fail to take account of the noise that will kick the system from one attractor to another.

We can test whether a system has an attractor by perturbing it a bit and seeing what happens. If its trajectory after a while resumes its original path then it has an attractor. Perturb it a bit more and we may kick it from one attractor to another or it may become chaotic. It is noise that switches a system from one regime to another and we can build that into a model and say there's a number of things a system might do. But people tend to ask for definite answers, such as in the work on Chesapeake Bay. If we are honest there are many factors which could affect the system. The weather may affect the fish. So then people say, 'Well what is most likely to happen?' It sounds a reasonable request but actually it changes everything because then we look for the most probable distribution and average characteristics and smooth rates of change and take out chance and end up with a deterministic model in which the mathematics is that of the average. *I*n the end it's not at all the most probable anyway.

However we can build models of evolutionary processes which adapt. They can be used, not necessarily to explain only something that has happened, but also to explore the possible solution space. If we base agent rules and characteristics as closely as possible to those in the real world and run the system with many different conditions and parameters we explore the boundaries of reality for the particular system being considered. This has been done in a supermarket simulation where each customer was represented as walking into the store with a shopping list with a particular content, but adjustments were made to the model everytime it was run to get closer and closer to a real situation. A model can tell us things we don't know because it can reveal regimes or possibilities that have not yet been observed.

Discussion

The discussion largely concerned the relevance of complexity theory to business organisation and how a value of an investment in IT can be demonstrated. It was pointed out that, looking back on statistics of some 20 years ago, if we were still using the same information processing methods, the government would now have to employ some 90 million clerical workers.

The role of business consultants was discussed as to the kind of service they can offer. It was suggested that the main role was to review the way decision makers in both the public and private sector see their organisation's identity and what opportunities for change there might be in the future. Such considerations are not just financial, complexity theory leads us to seeks a biodynamic theory that looks at the development of human culture and how it affects what is happening in the world today.

Complexity theory to business executives often seems too abstract or its assertions intuitively obvious but that is because they fail to realise that its application is more a way of finding possibilities or opportunities than it is of finding solutions. Company managers tend to say, 'well it's obvious that nothing in business is predictable and diversity is good but so what?' It is essential that we adopt an approach that makes sense for the day-to-day running of an organisation as well as those major occasions for change that result from take-over and mergers. Application of complexity theory to an organisational process involves a 'paradigm shift'. A new way of thinking is the precursor to a new way of acting and a new way of working can give rise to accelerated change.

In general, this new way of thinking involves treating organisations as living systems and just as these evolve so should business organisations. The ICoSS project uses an 'active system' approach and currently works collaboratively in its research with several multinational companies. It's general strategy is to apply complexity thinking to some part of an organisation to find conditions that facilitate the emergence of beneficial organisational forms following merger, restructuring or new business venture. It is not a retrospective study but a focus on the way people can look to the future.

What we have to do is to find a way in which we can explain to business people how to let go of those controls which are hindering development and success. But it would perhaps be naive to say to an organisation, 'let go all controls and let's see what emerges'. We mustn't equate self organisation and emergence with chaos. There is a middle ground between not having any leadership and totalitarian control. We can say to a manager that you may as well regard your organisation as a complex developing system because you have nothing to lose and once you start doing so there are different courses of action. Part of the emergence process is feedback and leadership can ask, 'this structure seems to have emerged do we find it's helpful to what we are and what we want to be?' And if it isn't you feed it back onto the system. You don't say, 'it's not working so I'm going to do so and so.' You intervene in different ways in different places but not in order to control or force change.

There are really no outside observers in the process and as a consultant you do not act as one. Everyone engaged in the process is an agent who is making some contribution though some people are more autonomous than others. As agents people are not necessarily constrained by their job description they can potentially be just as much a part of others teams as other people can be of theirs.

Whole systems or organisations have emergent properties (patterns) which individual entities do not possess and which particular properties or patterns emerge cannot be predicted. What properties or patterns we actually observe are dependant on our perceptual abilities. But there's an important difference between a system which is merely complicated and one that is complex in the way that biological systems are complex. A motor car is complicated and more than the sum of its parts but it is a machine which by itself does not evolve. Yet it is the product of a human design process which is a complex one and it only has evolutionary potential as such.

There is also an important distinction to be made between something that evolves and something that adapts. Adaptability is the potential to respond to a change in the environment which will enable an organism to survive and flourish. Evolutionary potential is the added ability to be pro-active even if it is unconscious. And in a species that requires diversity. Diversity can solve the problems we didn't know we had. Its always difficult to completely say in biology what things are for because organisms are evolving their usefulness as they go and that goes for a person's role in an organisation.

'Adaption' implies there is some sort of feedback and a pro-active conscious organism might say, 'How should I be different from what I am now or should I be what I am now and go somewhere else?' There is a problem in using the term 'feedback' in relation to biological organisms since it implies a closed loop. 'Co-evolve' is better because it takes the changing environment into account. Diversity drives evolution and some of Peter's models demonstrate that individuals need to be diverse for the good of the species otherwise it simply gets extinguished.

'Evolution' connotes that there is a certain amount of randomness in the system since Darwinism involves chance mutation on which natural selection acts. But in a human organisation things get selected because people think they know something. People are part of nature just as everything else is and we often presume more about our possible effects than we should. The underlying randomness of events in the world is more 'creative' than our efforts because it gives rise to things that we truly haven't thought of yet. Anything that can be computed from what we perceive to be our current situation is already reasonable from the paradigm in which we are at present working. We are already 'channelling' by the time we say something might or might not work. In a general sense we don't prescribe the kind of diversity we want yet we intuitively believe it has value. Apart from aesthetics we are hard put to prove the value of diversity yet we happily pass laws for the conservation of wildlife. Common sense often plays a large part in our decisions. It seems sensible to assume that in general people will want to do a good job rather than a bad one. When we start to use complexity theory in organisations we take out some of the control mechanisms and see what happens. The 'proof of the pudding is in the eating'. People evolve themselves during the process. As consultants all we can do is really to help people to see things differently. It is a big mistake for a consultant to come in from the outside and say things like:

'you should be like Jack Welch of GEC'. It doesn't work, because it's a process that starts with what the organisation is and involves a new learning curve. There's no particular golden egg out there.

Peter's career has led him from physics to a study in the 70's of ecology and urban modelling. Developing the models of the co-evolution of transport systems and cities involved profiling of resources, environment, job description and decision making all within a holistic framework. In the 80's there was little government funding because of a belief that the 'invisible hand' of the free market was all that was necessary but work for the Canadian Fishing Industry led to some interesting models which demonstrated the need not only for efficient fishermen who exploit the current 'maps' of fishing expertise but for those who discover in an apparently random way. The moral is that if you want to exploit your current business situation you get an MBA, but if you want to exploit the future you have to have some 'blue sky' research which is currently not justifiable on a 'returns' basis.

The design process is a complex system of decision making. In science Newton and Descartes proposed a world view in which it was believed possible for people to discuss and decide within a space that was objectively true. This assumed that communication was about an objective reality and that decisions were made using the same kind of metric. Whilst it is obviously silly to say that our individual perspectives of reality are all entirely subjective it is nevertheless true that what we perceive is to a large extent socially constructed. We are all the slaves of our physiology but as we discuss and change our ideas our perceptual landscape evolves and co-evolves. Ideas lead to selections which operate on us as we operate on them. We are in the middle of the diagram that Peter showed us earlier and the benefit of models using computers is that we can use them not to convince ourselves that something is true about the world but to help us imagine. Exploring a system with a model of what we think might be the case can show us where we are definitely wrong. When a model doesn't do what we thought it would we have to rethink. We engage in a dialogue with it. In a more general sense all our mathematical pictures are artefacts in our striving to understand reality. And as we simplify we restrict both our knowledge of the present and of the future. It's important to see that our models, like, for example, the equation for the 'ideal' pendulum are emergent forms of our perception and only temporary descriptions of a complex reality. But it also may change our understanding itself. Making sense and modelling are part and parcel of the same sort of thing.

But the dynamics of the real system may force the pace of model change. If we're modelling in 1990 and we get a certain trajectory with our x, y and z co-ordinates and we get a different one in 1995 and in year 2000 then the system may be changing in a significant way that our model isn't telling us. The quantitative is only an indication of the qualitative. Such changes may cause the system to move from its determining variables x, y, and z to entirely new ones. New dimensions may be turned on, others may be turned off. We try to understand complex systems quantitatively but our exploration should also be about the symmetry breaking that takes place.

The determining characteristic of a system in thermodynamic equilibrium with its environment is that if we kick it , it may be momentarily perturbed but it will then return to a stable state. If however we hold it in a far from equilibrium state by, for example, feeding energy or matter into the system then it undergoes qualitative and quantitative change. If there are fluctuations shown by the dimensions we are modelling than there may be cycles that are moving from one 'attractor' to another. An 'attractor' is a stable state towards which a system moves, but it may be a point or a cycle or in the case of a 'strange attractor' the trajectory may wander. The equations are usually mechanical but for certain parameters there is an extreme sensitivity to starting conditions which makes the trajectory configure a surface rather than a ring.

Such non linear system dynamics was hailed as a breakthrough in understanding so called 'chaotic' systems and were thought to be the answer in understanding complex systems. But like the ideal model of the pendulum they take out the 'noise' and only provide a very limited description of reality. Nevertheless as a modeller setting up equations and playing with them is a good way of asking what regimes may exist. In artificially starting from different places (starting conditions) and seeing where the model ends up we may discover regimes that are real but not yet observed. That intelligence is in the modeller rather than the model.

Because there is 'noise' in a system it can jump from one attractor basin to another and adopt a regime that may be chaotic or cyclic or stationary. Noise gives a kind of vitality and a system such as an urban model may hover but then suddenly surprise us. There are usually so many possible structures that the only way is to 'shake' the variables in an urban system and see what kind of 'clumping' occurs and there may be several different kinds of qualitative structure.

However understanding qualitative structures from quantitative analysis is also fraught with possible error because of 'averaging' in which the values used in the analysis again represent a gross simplification of reality. What is required is an evolutionary model which allows for diversity. in such a model the participants (individual elements) are changing resulting in changing interactions leading to new structures and attractors. A full model links the changing environment to the system and the changing interactions of elements at different levels. It becomes a learning, self organising system and one whose past history is important. Building such self organising dynamics into the urban models enabled them to explore possible structures in which industry might aggregate in central or peripheral areas. But it was the addition of 'noise' that enabled exploration of possible regimes of operation. Building in general 'noise', however does not get to grips with the kind of change that the individuals or elements are likely to undergo themselves. Such individuals are 'agents' and we have to talk about how such agents form and change their rules.

In order to understand the difference between a system in which the individual elements change their rules of interaction and one that doesn't we should perhaps consider the Brusselator. If we had data on all the change in concentrations of the chemicals involved in the process we still wouldn't know it was producing spiral waves of colour. But that particular pattern that emerges is an indication of how the entire system is changing. The chemistry resulting from little molecules bumping into each other is giving rise to the emergent property of spiral waves. The spiral waves have their own dimensions but they're different to the ones we would use for the concentrations of the constituents. The way in which we see the Brusselator as a chemical clock is something else. If the process hadn't involved red and blue molecules we would have perceived the emergent property visually. So again what we perceive is determined by our physiology. It something we perceive as a subsystem of the environment and is only part of the environment. Suppose there were no coloured ions involved and people were measuring concentrations. What they might see would be little wobbles in their overall output and they perhaps wouldn't know whether it was the system or something to do with their instruments. Theories are based on what we observe but there are various levels of abstraction. The physics of the very large and the very small is virtually unimaginable to most people. Mathematics, symmetry breaking and topology are all ways in which we abstract data to make sense of it.

Peter's simple definition of a complex system is one that can of itself have more than one future. If there is enough non linearity, 'degrees of freedom' and internal diversity so that we may perhaps be able to influence but not predict the outcome then it is a complex system. The only systems that are not like this are machines which have to be carefully built and are only perfect for a very short time because as soon as wear starts they do strange things. 'Degrees of freedom' are the number of ways a system can be and sometimes there can be more than one state for the same entropy. If there is more than one solution for a particular parameter value then there is an equal choice of different futures. A two dimensional graph would show what is called a bifurcation. Organisations which contain human agents capable of making independent decisions have in theory almost unlimited degrees of freedom and the system is capable of self transformation. Such systems are all around us. This study group is certainly one.

So we can make a distinction between a biological dissipative structure and the Brusselator in that the latter is not co-evolving because it doesn't have individuals or agents who change their rules of interaction. A molecule of bromine or malonic acid doesn't go around changing its rule of interaction. The molecules are not registering their experiences and being changed by them. The Brusselator only has two levels which are necessary to understand: the chemical interactions and the environment.

What about the weather system? It is only predictable over the short term. It has 'feedback' in that, for example, clouds are formed by water vapour, which affects the way in which heat is reflected, which affects the clouds and so on. The complexity depends on which level the system is described. Globally the system is affected by the oceans and the biosystem. It can do things which are surprising and change its regime. We wouldn't necessarily call it adaptive unless the biosystem became the determining factor and we could perhaps say there was memory and learning. But we can see that it's very different from the Brussellator which is a laboratory experiment. We put in particular molecules and only certain things can happen to them because they don't learn and they don't learn because they don't have the individual diversity that enables it.

What about a termite nest? The termite nest is the emergent property of an adaptive community. It arises because pheromones are the means by which the termites communicate. So it has memory. Termites live in a tricky context (environment), and evolution has developed for them a set of mechanisms that are inheritable yet are relatively simple and robust. But perhaps only robust within a fairly limited context. The nest functions because pheromones diffuse in certain ways. Change the gas in the atmosphere and the nests might disintegrate because the pheromones would diffuse differently. It's robust within its context and the system can adapt because the termites genetics allow it to do so. Yet adaptive is not a good word to apply to the termite nest. It has co-evolved with the environment and with other species.

We can look at business organisations in much the same way. Yes they're adaptive in that if you have a certain task to perform and you have a certain tool for doing it you can ask how you can refine the tool. But the design process has an evolutionary aspect. You either already know how to make something better or you explore in a random way and progress through a selection process. Retention depends on the kind of evaluation process you set up.

So to conclude. Systems may be complex in that the elements of the system interact according to a number of fixed rules and this can lead to 'self organisation' and different regimes and so on. But this is different to a system in which the elements learn and themselves change. When the third level is reached in which the internal nature of the element changes following its experiences then you have evolution proper. We as modellers evolve our models and really play the game at a meta-level. We don't expect our models to provide all the answers though they are an indication of how fast we're learning.