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Complexity: The Co-evolution of Epistemology, Axiology and Ontology

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Abstract: *If epistemology is about what we know and how we know what we know (what is inside) and ontology is about what there is to know (what is outside) then the most fundamental challenge that complexity makes is that these can no longer be considered as separable. Traditional science was based on the idea that there was an objective reality outside, and that we could study it and do experiments on it that allowed us to build, cumulatively, an increasingly accurate picture of that reality. Whilst for simple physical problems, and for planetary motion, this was a reasonable working hypothesis, for biological and social systems this has always been a problem. Experiments are not repeatable or transferable, and situations are historically evolved involving local, co-evolving contexts, and therefore can potentially all be unique and lacking in any generic behaviours or laws. Complexity science brings us face to face with this elusive reality, and tells us that we must accept uncertainty, and admit that our cognition, our descriptions and our models are necessarily incomplete and temporary props to our current functioning. They help us make some sense of the past and the present, and are all we have to help us in taking steps into the future. Examples of these ideas will be given for ecological, social and economic systems, showing that models, despite their necessary incompleteness, can still be useful in clarifying and living with some of the real uncertainties we have, and in this way can help us explore possible futures. However, complexity also tells us that we need not limit our explorations to those suggested by our models, since they are necessarily incomplete, and that we should also indulge in "creative actions" in order to find out more about what might happen, and in this way both increase our possible choices of action, and also improve the scope of our models.*

Key Words: epistemology, axiology, ontology, complexity, economics, ecology, social systems, co-evolution, uncertainty, knowledge

INTRODUCTION

If epistemology is about what we know and how we know what we know – what is inside - and ontology is about what there is to know –

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what is outside – then the most fundamental challenge that complexity makes is that these can no longer be considered as separable. Axiology is the theory of values, and values are aspects of human behaviour that emerged during evolution and gave us aims, goals and opinions which through our knowledge direct our actions. But conversely, our values create our intentions and desires, and these in turn drive changes in our epistemologies, since they determine what it is that we wish to achieve, and therefore what seek to know in order to do this. Ontology - reality is therefore made up an underlying physical and ecological system, inhabited by individuals whose opinions are based on their values, which are affected by their experiences, and which also lead them to seek out knowledge in order to achieve their wishes. A fundamental circularity occurs because the actions that provide experience are guided by the epistemology, knowledge, of the individuals, and these are used to translate an individual's aims into action and activity, which produce the experiences that lead to values. Not only is there no longer an "inside" and "outside", since other individuals insides are outside any particular inside, but experiences are made up of the dynamic interactions of peoples' actions on each other, and these experiences are causing changes to values and epistemologies and therefore making it impossible to interpret our experiences in any definitive way. The underlying causes and meaning of experiences are changing.

Traditional science was based on the idea that there was an objective reality outside, and that we could study it and do experiments on it that allowed us to build, cumulatively, an increasingly accurate picture of that reality. Whilst for simple physical problems and for planetary motion this was a reasonable working hypothesis, for biological and social systems this has always been a problem. Experiments are not always repeatable or transferable, and situations are historically evolved involving local, co-evolving contexts, and therefore can potentially all be unique and lacking in any generic behaviours or laws. Complexity science brings us face to face with this elusive reality. It tells us that we must accept uncertainty and admit that our cognition, our descriptions and our models are necessarily incomplete and temporary props to our current functioning. They help us make some sense of the past and the present, and are all we have to help us in taking steps into the future.

In reality, complex systems thinking offers us a new, integrative paradigm, in which we retain the fact of multiple subjectivities, and of differing perceptions and views, and indeed see this as part of the complexity, and a source of creative interaction and of innovation and change. The underlying paradox is that knowledge of any particular discipline will necessarily imply "a lack of knowledge" of other aspects. But all the different disciplines and domains of "knowledge" will interact through reality – and so actions based on any particular domain of knowledge, although seemingly rational and consistent, will necessarily be inadequate.

Wisdom requires an integrated view. These new ideas encompass evolutionary processes in general, and apply to the social, cultural, economic, technological, psychological and philosophical aspects of our realities. Often, we restrict our studies to only the "economic" aspects of a situation, with accompanying numbers, but we should not forget that we may be looking at very "lagged" indicators of other phenomena involving people, emotions, relationships, and intuitions – to mention but a few. We may need to be careful in thinking that our views will be useful if they are based on observations and theories that refer only to a small sub-space of reality – for example economics. The underlying causes and explanations will involve other factors entirely and their effects will drive reality in ways that people will judge according to the concepts and constructs with which they articulate their values. What matters over time is the expansion of any system into new dimensions and conceptual spaces, as a result of successive instabilities involving dimensions additional to those the current "system" appears to occupy.

This idea of evolution as a question of "invadability", with respect to what was not yet in the system, was the subject of a very early paper by the author (Allen, 1976). Essentially then, systems are seen as temporary, emergent structures that result from the self-reinforcing nonlinear interactions that result from successive "invasions". History is written not only by some process of "rational improvement" in its internal structure but more fundamentally by its dialogue with elements that are not yet in the system – successive experimental linkages that either are rejected by the system, or which "take off" and modify the system irreversibly.

Rational improvement of internal structure, the traditional domain of "systems' thinking", supposes that the system has a purpose, and known measures of "performance" which can indicate the direction of improvements. But this more fundamental structural evolution of complex systems that results from successive invasions of the system by new elements and entities, is characterized by emergent properties and effects, that lead to new attributes, purposes and performance measures. In the next sections therefore, we attempt to show that this structural evolution is not in fact "random" in its outcome, as successful invasions of a system are always characterized by the revelation of positive feedback and synergy, creating particular new, internally coherent, structures from a growing, explosively rich set of diverse possibilities.

Dissipative Structures - Models of Complexity

As is well known today, in systems with some degree of strong coupling between its elements, when a critical level of thermodynamic disequilibrium is reached then many amazing and surprising things can happen. One of the earliest and most studied cases was the "Brusselator', because of the intensive study it has received by the group at Brussels.

It consists of a simple, fixed, nonlinear reaction mechanism,

$$\begin{aligned} &A \longrightarrow X \\ &B + X \longrightarrow Y + D \\ &2X + Y \longrightarrow 3X \\ &X \longrightarrow E \end{aligned} \tag{1}$$

where A and B feed the reaction, D and E are produced by it, and X and Y are intermediates. Let us suppose further that X is red in colour, and Y is blue. The kinetic equations for this reaction scheme are very simple to write, and we assume that the products of reaction E and D are removed to avoid the occurrence of a back reaction:

$$\begin{aligned} &\frac{dx}{dt} = A - BX + X^2Y - X \\ &\frac{dy}{dt} = BX - X^2Y \end{aligned} \tag{2}$$

As is well documented, under conditions of chemical disequilibrium All sorts of moving or stationary patterns can emerge. For example, if we stir the reaction, then at a certain critical reaction rate, instead of the system being uniform (a homogeneous mixture of red and blue, of X and Y) it suddenly begins to oscillate steadily from all red to all blue and back, in a perfectly rhythmic manner. Even if perturbed momentarily, it will return to this particular, stable beat. The random, incoherent movements and reactions of the molecules is abruptly transformed into disciplined, coherent, coordinated behaviour worthy of a good choir! In a system that is not stirred all sorts of spatial and spatio-temporal structures can appear spontaneously: from simple left/right heterogeneities, to expanding spiral waves of various well defined dimensions, to moving or stationary bands of red and blue - a whole bundle of different possibilities.

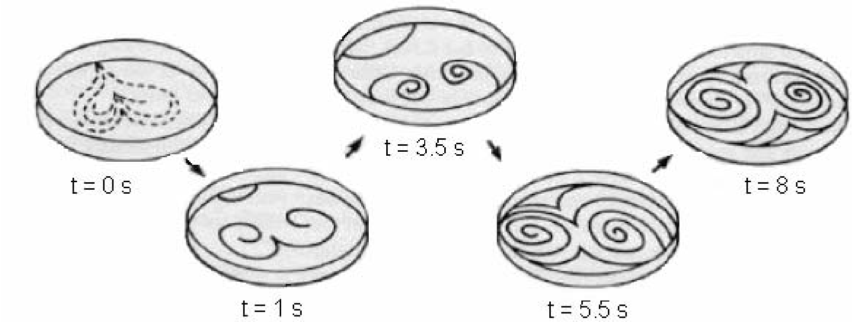


Fig. 1. Coloured patterns develop as the Belousov-Zhabotinski reaction is run in a Petri dish.

This process of self-organisation is a remarkable phenomenon that strikes at the heart of some of our deepest preconceptions concerning physical systems. For example, if we take a particular spatial structure, then at the interface of "red" and "blue" there will clearly be fluxes of X and Y caused by the concentration gradients. Our normal reaction would be to say that they are "explained" by the "forces" that must exist between the zones. But in fact these forces themselves are generated by the spatial structure of which the interface is a part, and which in turn reflects the fluxes that are occurring in the system. If, for example, the coefficient of diffusion were modified, or the temperature, then the spatial structure itself would change or perhaps even disappear. In this sense, the "cause" of this particular structure is the precise values of the fluxes, which in their turn, according to our simple preconceptions, result from this structure. Clearly, the circularity of the apparent "causation" is showing up some weakness in our way of thinking about things.

In reality, a "dissipative structure" is an entity that has as mutually dependent facets the flows and spatial structures that characterize it. Interference with one will modify both through a cascade of feedback processes. We see that we have a system that has created its own "boxes" and "arrows". Furthermore, we see that the "Modeller's Nightmare", i.e., the fact that complex systems evolve structurally (new boxes, new arrows) is quite clearly part of the behaviour of a dissipative structure. A particular type of behaviour, homogeneous temporal oscillation, moving parallel bands, etc. can spontaneously change to a qualitatively different one. If we had been rash enough to model the system on the basis of its particular macro-behaviour at the earlier time, then suddenly our model would fail to describe what was occurring.

Also, we come upon the dilemma that faces any ecologist trying to understand the system before him. We can "track" the energy flow in the Brusselator, or make balance equations (accountancy) for particular materials (carbon, nitrogen etc.); but these always only indicate or reflect the structure that had appeared in the system, and do not explain it, nor predict when some new structure may emerge. The "explanation" behind a particular “structure/flow" pattern lies in the history of instabilities it has traversed, and especially in the stability or instability of the structure at the moment we are observing it. What is new, and important, is that different solution branches can emerge which are qualitatively different from each other. We have, therefore, a non-conservation of symmetry, and hence of the number and nature of the "qualities" which characterize the system. In one stride we have moved from the relative banality of simple arithmetic to the quantitative modelling of morphogenetic processes whereby structure and function emerge, where the qualitative differences of the living world appear, and in which we find creation instead of conservation.

In this chemical example, molecules of a given type are identical (prototypical) and hence the organization within the system can be observed directly. This can change as the boundary conditions change, but the system does not evolve because the molecules themselves are not modified by their experiences.

Evolution represents a dialogue between the real, rich micro-detail of the system, and the simpler deterministic average behaviour that we have considered to be adequate to represent it. However, molecules do not really have aims and goals, and probably not interpretive frameworks and this is undoubtedly something that arises as a result of evolution.

OUR UNDERSTANDING OF ECOLOGY

We may like to think that it is essentially human to consider that values are of vital importance for understanding the behaviour of the organisms, but in fact this has been important even for the evolution of simple organisms. For example, if values are what makes an individual decide to do one thing rather than another then organisms do it too. Even ants decide to go for the more concentrated sugar source, and any species (if it is persistent) must actually like what it hunts and eats, and must also live in terrain where its prey occurs. Similarly, prey species must know that they should avoid things that resemble their predators, and so they must in fact have values, that drive their behaviour. Furthermore, this must be capable of changing if the critical features of their prey or predators changed, and each population will actually have variance around some average set of values, which will constantly test whether there is advantage to having slightly different version. So, a fox may have a “model” of rabbits, and will know places and times when they tend to be found, but most certainly can recognize them, even on a dark night, and with scent, sight and sound. However, this is not enough to make a fox a fox. What is required is that it also wants to chase a "probable" rabbit! So again, axiology, epistemology and ontology co-evolve. We can develop a mathematical model of the co-evolution of populations, and show how they must evolve over time, as internal diversities lead to mutually adaptive aims, goals and knowledge.

Can we extend the ideas and modelling methods from chemical kinetics – the population dynamics of reacting molecules – to ecologies? What differences would exist between chemical kinetics and population dynamics of real populations? If so, then can the lessons of self-organisation be transferred to ecologies, and from there to social systems. Let us consider this by taking the following example. Consider an ecosystem, and let us attempt to model it using population dynamics. We can establish the different species that exist there, and then find out how many of each population there are. We can also, by sampling, find out which population eats which other population and calibrate the multiple plant-herbivore and predator-prey interactions. Now, once this is established, we can put the whole system of equations on a computer, and run it forward. What happens is shown in Fig. 2.

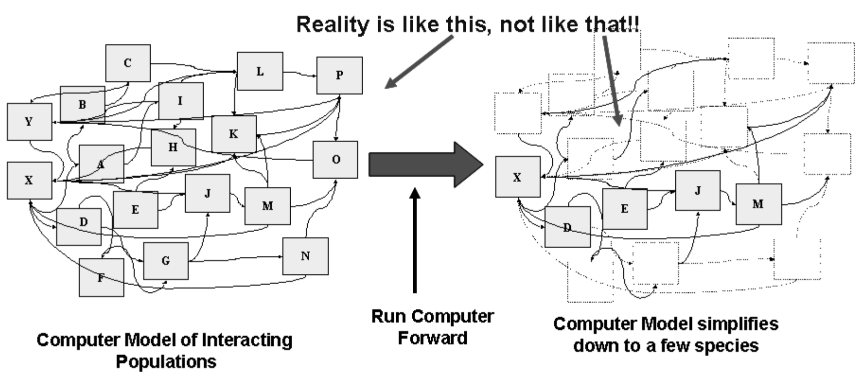


Fig. 2. A calibrated ecosystem represented by the population dynamics of its constituent species collapses when run forward in time.

This shows us that the "apparent" organization of the ecosystem is not even a coherent description of reality. The missing internal diversity provides the stability of the slowly evolving real system.

This is an astonishing result. It means that although the model was calibrated on what was happening at time t = 0 it diverged from reality as time moved forward. The real ecosystem stayed complex, and indeed continued to adapt and change with its real environment. But this shows us that the mechanical representation of reality differs critically from that reality. Our "mechanistic epistemology" fails to represent reality!

What is missing? This can be discovered if we examine carefully the assumptions that we made in formulating our population dynamics. What happened is that the loops interactions of a real ecosystem form parallel food chains, with cross connections and complications of course, but essentially with each level feeding on the lower one, some of these dying and others being eaten by the level above. The whole system of food chains loops back through death and micro-organisms that recycle all the carbon and minerals. When we run the population dynamics with the fixed, calibrated birth, death, capture and escape rates that we have found on average in the real system (in analogy with chemical reaction rates), the food chain with the highest performance simply eliminates all the others. In other words, in the model selection between metabolic chains operates and this selects for the highest performing chain. However, reality does not. Therefore we need to understand what is missing between the dynamic model and the original real system.

What is missing is the internal diversity of the populations. In chemistry, one molecule is very like another, and the only difference is their spatial location. Dissipative structures can create spatio-temporal patterns because of this. But populations of organisms differ in an infinite number of ways. Firstly in location, but also in age, size, strength, speed, colour etc. and so this means that whenever a population, X, is being decreased by the action of some particular predator or environmental change, then the individuals that are most vulnerable will be the ones that "go" first. Because of this the parameter representing the average death rate will actually change its value as the distribution within the population X increases the average "resistance". In other words, the whole system of populations has built in through the internal diversities of its populations, a multiple set of self-regulatory processes that will automatically strengthen the weak, and weaken the strong. In the same way that reaction diffusion systems in chemistry can create patterns in space and time, so in this more complex system, the dynamics will create patterns in the different dimensions of diversity that the populations inhabit. But neither we, nor the populations concerned, need to know what these dimensions are. It just happens as a result of evolutionary dynamics. In this way a model made in terms of the average population types interacting through average processes is not stable and will exhibit mutual adaptive adjustments all the time, rather then simply performing mechanistically.

What assumptions do we make in order to create a mechanical model of a complex system? This is shown in Fig. 3.

Here internal diversity plays the role of non-prototypic elements in the system. In reality the system is created by the interaction of the populations of non-prototypic individuals.....

The "system" is created by evolutionary processes that are driven by the micro-diversity of the individual elements - the non-prototypical.

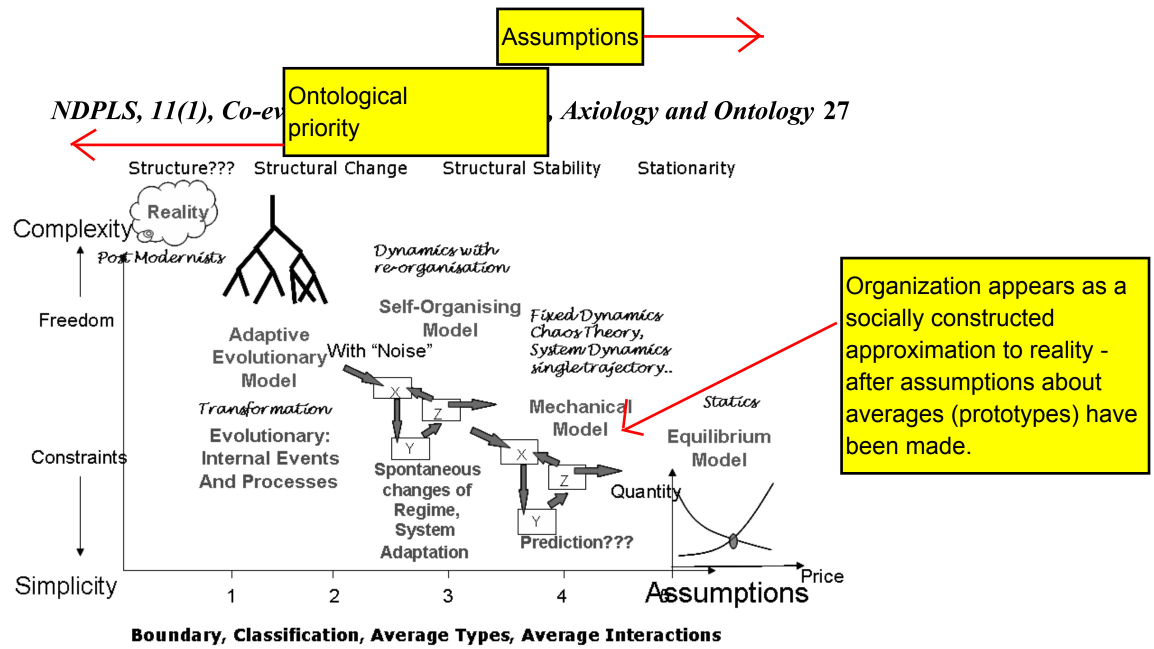


Fig. 3. This shows the results of successive simplifying assumptions that take us from a complex evolving system to its mechanical representation.

This succession of models arises from making successive, simplifying assumptions, and therefore models on the right are increasingly easy to understand and picture, but increasingly far from reality. Once assumption 3 is made, that of average types, then the model loses all capacity to evolve, since these types are fixed and can only change in relative numbers. No new types can appear. The operation of a mechanical system may be easy to understand but that simplicity has assumed away the more complex sources of its ability to adapt and change. They become more like "descriptions" of the system at a particular moment, but do not contain the magic ingredient of micro-diversity that will really allow the system to undergo structural change and create a new, qualitatively different system, with some new variables and some emergent performance. The ability to adapt and change is still present in the "evolutionary" model that only makes assumptions 1 and 2, but not those of average type and average behaviours. This therefore tells us that the evolutionary capacity is generated by the behaviours that are averaged by assumptions 3 and 4 – average types and average events – and therefore that organisations or individuals that can adapt and transform themselves, do so as a result of the generation of micro-diversity and the interactions with micro-contextualities. This tells us the difference between a reality that is "becoming" and our simplified understanding of this that is merely "being" (Prigogine, 1981).

Table 1. The successive assumptions needed to produce a mechanistic description of a natural system.

Number	Assumption Made	Resulting Model
1	Boundary Assumed	Some local sense-making possible – no structure supposed
2	Classification Assumed	Strategic, Open-Ended, Evolutionary – structural, qualitative change occurs, successive systems, successive structural attractors
3	Average Types	Operational, Probabilistic, Nonlinear Equations – assumed structurally stable, allows calculation of resilience and robustness
4	Average Events	Operational Mechanical Equations, deterministic, – assumed structurally stable

All of this is fairly irrelevant for the chemistry of simple molecules, because a population does not have internal diversity, and so there is nothing for evolution to work on. However, as soon as we reach organic molecules, with complex polymers, and different ways of folding, then we see that these same ideas apply and an evolutionary process becomes possible that makes the real system more than its mechanical representation.

Clearly, at a more strategic level, we may expect structural changes and new variables to occur. The key assumption that we made that reduced the strategic view including structural change to the operation view where structural change is excluded (Allen, 1993, 1994a, 1994b, 2000; 2001a, 2001b) was an assumption that we could ignore the internal diversity of the populations. In chemistry, one molecule is very like another, and the only difference is their spatial location. Dissipative structures in chemistry (Nicolis & Prigogine, 1977) can create spatio-temporal patterns because of this. *But populations of organisms differ in an infinite number of ways.* Firstly in location, but also in age, size, strength, speed, colour etc. and so this means that whenever a population, X, is being decreased by the action of some particular predator or environmental change, then the individuals that are most vulnerable will be the ones that "go" first. Because of this the parameter representing the average death rate will actually change its value as the distribution within the population X increases the average "resistance". In other words, the whole system of populations has built in through the internal diversities of its populations, a multiple set of self-regulatory processes that will automatically strengthen the weak, and weaken the strong. In the same way that reaction diffusion systems in chemistry can create patterns in space and time, so in this more complex system, the dynamics will create patterns in the different dimensions of diversity that the populations inhabit. But neither we, nor the populations concerned, need to know what these dimensions are. It just happens as a result of evolutionary dynamics.

We see a key framework that exists at the heart of complex systems thinking. The framework sorts or groups the factors into three categories, which are based on and build on the three sets of system factors identified by Allen. In specifying a more general model, three "fundamentally different factors lead to the values of parameters in the working of the system" are identified (Allen, 1997). These are set out as the following:

1. *The values of external factors*, which are not modelled as variables in the system. These reflect the environment of the system, and of course may be dependent on spatial conditions. Temperature, climate, soils, world prices, interest rates are possible examples of such factors. In the outside world, it could be that this system is seen as playing a "role" in the outer world, and therefore fitting in to some outer purpose and axiology.

2. *The effects of spatial arrangement*, of juxtaposition and configuration, of the entities underlying the system, affecting self-organizing and autocatalytic effects. In ecology clearly the connections reflect predator, prey, parasitic and cooperative roles, and there fore the structure of the system partly results from the aims and goals of the individuals. This must be true also in human systems. This is the ontology of the interacting agents.

3. *The values corresponding to the 'performance' of the [underlying] entities*, due to their internal characteristics like technology, level of knowledge or strategies, but also to degree of motivation and to individual epistemology. This contains the evolving axiology and epistemology of the agents.

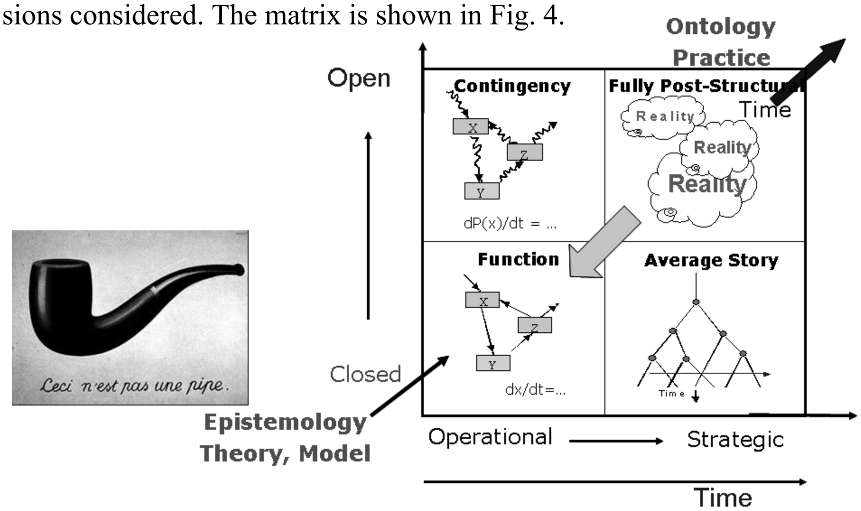
These three levels are all coupled by interaction, and so changes that occur in any one will affect the other two. This in turn will affect the environment of the environment, the underlying entities of the underlying entities, and so on in an irreversible cascade outwards and inwards that makes everything essentially irreversible.

THE COMPLEXITY MATRIX

These ideas can now be taken beyond ecology and transferred to the human domain. What are the implications of this new understanding of complexity for management? Indeed, is there any role for management in a complex world? After all, if the world is truly “post-modern,” and each of us is in a unique, novel and incomparable situation, then maybe there is no advice or method that can be laid down?

Our position however, is not so extreme. We believe that are lessons to be learned and a method that can be followed, questions that can be helpfully asked, which increase the chance of an adaptive, evolutionary management process. All systems that emerge, persist and wish to grow must deal with the fact that by their present actions they must attract resources, and they must also change their actions to fit into the future.

In this connection we can re-write our deconstruction of complexity on shown in Fig. 3 as a two by two matrix that looks at the short and the long term, and at the closed and open nature of the dimensions considered. The matrix is shown in Fig. 4.



Top Right is for the strategic destiny of open systems - reality! Lower left is the "model", the seeming organization that is "not" reality - but may be useful. Business ideas are conceived as simple models but then launched in the real, evolving, open world.

Fig. 4. The Complexity Matrix expresses our different understandings of the system in each quadrant.

Lower Left Quadrant: Production

This quadrant contains a mechanical model of the system, either a simple ecosystem of interacting pure “populations” or a simple business model describing a process designed to turn input materials and labour into output products and services. This is a structurally fixed system that functions on basis of certain fixed assumptions about the environment. So, it assumes, for example, that the input resources are available as required at a given cost, and that customers will buy the production at a given price. It assumes that employees will have the appropriate skills and will work at the wage levels provided, and it assumes that the machines, the power supply, the waste disposal, water supply etc. all function without problems. If all these elements could be guaranteed constant and uninterrupted, then the process could be "tuned" to peak efficiency, and minimum cost. But, *"ceci n'est pas une pipe"* and the "map is not the territory"! So we should never believe that our simple model of reality at a given time is that reality.

Upper Left Quadrant: Contingency

In reality, in the short term, there are still a series of factors that come from outside the closed set of routines and processes defining the business and that can affect the smooth running of the business process. So, the upper left quadrant shows us that the prudent manager needs to allow for "contingency" and for dealing with breakages, wear and tear, accidents and possible problems with resources, or with the customers for the activities of the system. Clearly, fires arise because of such things as careless disposal of smoking materials, or some electrical fault. Both of these events are not part of the business processes, but come into the system from dimensions that are "outside" the processes. Some of them are therefore foreseeable, on the basis of past experience, while others will not be. The development of a fire alarm system, of a machine monitoring service, the use of security companies and of insurance policies would cover quite a lot of the calculable risks that would be foreseeable in the running of a typical business. Providing the business was typical, these would be relatively easy to establish and plan on the basis of the statistical experience of other companies. Obviously, however, if there were some special circumstances like a terrorist threat associated with the particular characteristics of the owner, or the location of the business, then contingency plans and insurance could only be worked out in a specific project designed to "model" and simulate possible events, and to estimate their probabilities. However, there will always be events or circumstances that cannot be foreseen, and which do not have a probabilistic representation.

> This quadrant allows risk to be estimated for the existing organizational structure. It can be helpful in dealing with contingencies, but will not avoid the eventual transformation or death of the system.

An important point however, is that, whatever the routines that constitute the normal business processes, they will actually follow a trajectory in time that will take the business to its functional dynamic attractor. With the additional presence of the fluctuations and noise associated with this contingency quadrant, the system may well re-configure itself and flip between different regimes of operation, representing other possible attractors.

Lower Right Quadrant: Strategic Analysis

In the lower right quadrant, we have a strategic "sense-making" of what has happened. It is about the evolution of the business, and of the sector in which it has evolved. A picture of the past can be drawn, in which key innovations can perhaps be identified and the "future direction" of the products and of the business organisation can also be reflected upon. The R&D department will be attempting to improve the products and services delivered by the company, both by designing better products, and by designing better business processes and organisational structures. The development process undertaken in the R&D departmer will both be subject to agreement from the management concerning th "fit" of a new product or process with the aims and goals of the organisa tion, and also will be subject to the experiences encountered when th new products, business processes or organisational forms are tried out i reality in the left hand quadrants.

This is how we make sense of history. We make a story of how things became what they are. But this was not inevitable and the future is not given.

This lower right quadrant is really the place where an initiall open set of possibilities is turned into concrete innovations and developments, and these passed on to become a short-term reality. Clearly, one could also reflect on new designs and processes that decreased the "contingency" requirements by being inherently less vulnerable to particular dangers. In fact the system shown in the lower left quadrant corresponds to the end of the evolutionary tree shown here. This quadrant is therefore about the past, the present and the next step.

Upper Right Quadrant: Exploration

This is the quadrant in which Management must encounter new aspects of reality. It may be new opportunities posed by new technologies, or new competition from different directions, changing patterns and costs of necessary resources, or of customers. There may be emerging environmental issues like pollution of the atmosphere or of the local river, or the long-term risk of climate change. There may be changing trends occurring in the economic sector, and in customer needs and competitors' capabilities. These will all need to be noticed by an attentive management process, made sense of in terms of type of threat or opportunity and degree of urgency, and turned into strategy concerning the "positioning" of the business, its internal resources and its emergent capabilities. This can only occur if there is a sense-making process that looks out at the opportunities or threats and tries out possible responses, and a set of diverse options in the minds of the management as to where and how they wish to modify the current functional processes of the business.

In the short term, a set of efficient processes must operate to achieve the multiple dimensions of performance that are required for the business to pull in resources to live and grow. It must also formulate the necessary contingency plans and actions to survive foreseeable events that may disrupt it. Such questions as designing resilient supply chains, and rapid customer care would be part of such a system. However, with part of this “surplus” it must also pay for the right hand quadrants in which the future business processes, and their contingency plans are also cooked up, hopefully providing a smooth transition from one structure to the next.

EMERGENT MARKET STRUCTURE

The ideas developed in the sections above can also show us how important dynamic capabilities are for firms in the market place. Here we see how these dynamic capabilities are what is responsible for structuring of economic markets, as competition creates ecologies of firms, creating and filling interacting market niches. The fundamental process can be explored initially using a simple model in which we consider the possible growth/decline of several firms that are attempting to produce and sell goods on the same market. The potential customers of course will see the different products according to their particular desires and needs, and in the simple case examined here, we shall simply consider that customers are differentiated by their revenue, and therefore have different sensitivities to price.

The structure of each firm that is modelled is as shown in Fig. 10. Inputs and labour are necessary for production, and the cost of these, added to the fixed and start-up costs, produce goods that are sold by sales staff who must "interact" with potential customers in order to turn them into actual customers. The potential market for a product is related to its qualities and price, and although in this simple case we have assumed that customers all like the same qualities, they have a different response to the price charged. The price charged is made up of the cost of production (variable cost) to which is added a mark-up. The mark-up needs to be such that it will turn out to cover the fixed and start-up costs as well as the sales staff wages. Depending on the quality and price, therefore, there are different sized potential markets coming from the different customer segments.

When customers buy a product, they cease to be potential customers for a time that is related to the lifetime of the product. For high quality goods this may be longer than for low quality, but of course, many goods are bought in order to follow fashion and style rather than through absolute necessity. Indeed, different strategies would be required depending on whether or not this is the case, and so this is one of the many explorations that can be made with the model.

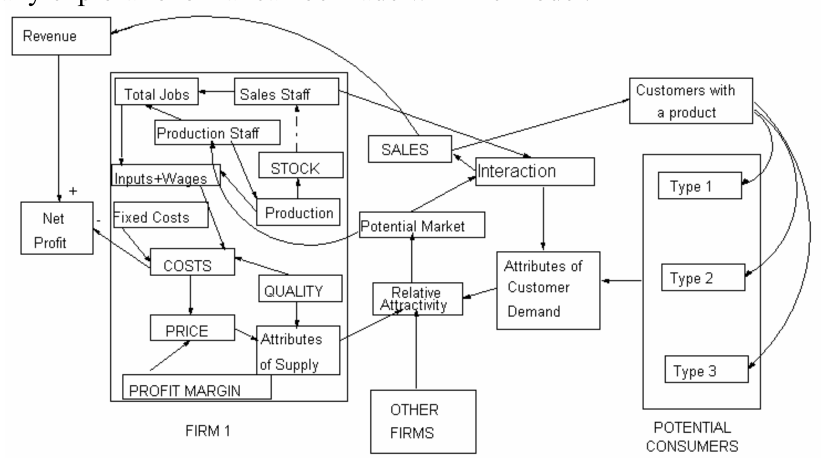


Fig. 5. A model of 6 interacting firms/agents whose choice of mark-up and quality represent their strategies.

The model calculates the relative attractivity of a product (of given quality and price) for a customer of a given type (poor, medium or rich). This results in a calculation of the "potential market" for each firm at each moment, and the sales staff must interact with these potential customers in order to turn them into customers. When a sale is made, then the potential customer becomes a customer and disappears from the market for a time that depends on the product lifetime. The revenue from the sales of a firm are used to pay the fixed and variable costs of production, and any profit can be used either to increase production or to decrease the bank debt if there is any. In this way, the firm tries to finance its growth and to avoid going near its credit limit. If a firm exceeds its credit limit then it is declared bankrupt and is closed down.

A very important issue that arises in the modelling concerning what is driving the manager of the firm in electing to adopt whatever strategy is chosen. In traditional economic theories firms are supposed to act, or to have acted, in such a way as to obtain maximum profit. But, here, we can see that if we used the profit as the driving force for increased production, then the system could not start. *Every new product* *must start with an investment.* That is with a negative profit. So, if firms do start production, and increase it, then this cannot be modelled by linking the increase in production to the profit *at that time*. Instead, we might say that it is driven by the *expected profit over some future time.* But this is clearly wrong, since their expected profits would depend on the behaviour and expectations of other firms. Whatever firms expect, in reality, clearly some of them get it wrong, because a large fraction go bankrupt. In our model therefore we simply have assumed that managers *believe* in their strategy, and hence are driven by their aims and goals, acting in the present *for the future*. They have an interpretive framework, but it may well prove inadequate in which case they may seek other knowledge (evolve their epistemology) and either change their behaviour it according to their adaptive rules, or they go bankrupt. In other words, the ontology will select for agents with aims and goals (axiologies) and interpretive frameworks (epistemologies) that can successfully co-exist. Our model shows that it is the economies and diseconomies of production and distribution that will determine the number, size and scale of the niches that may be discovered.

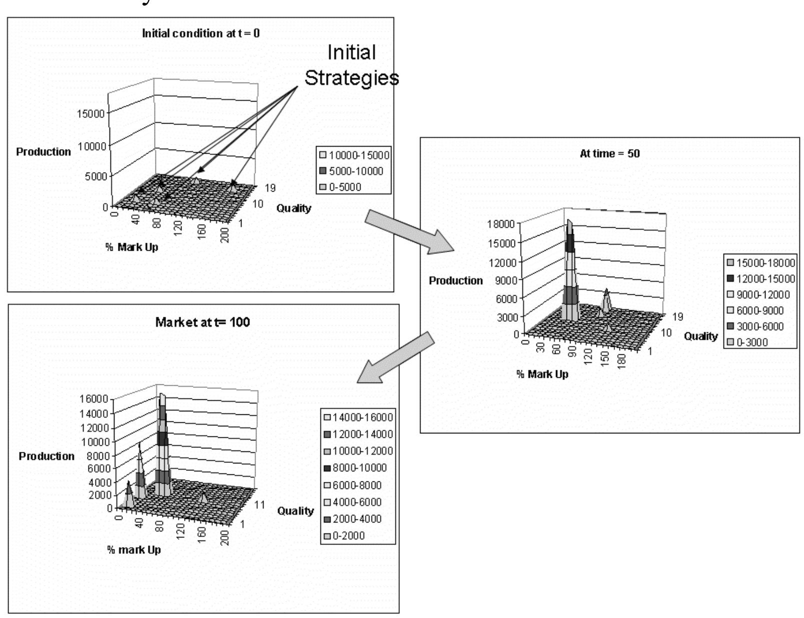
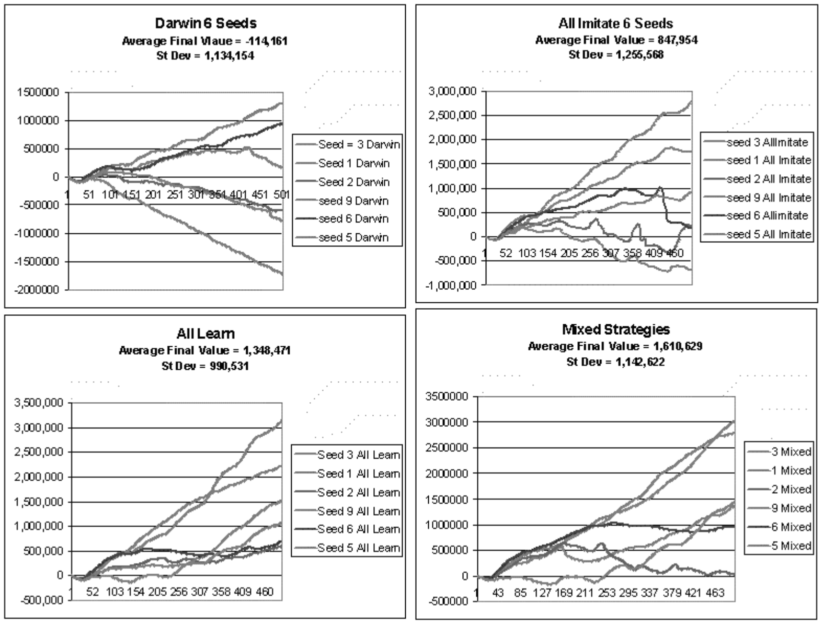


Fig. 6. This shows an evolutionary run where firms are lunched with random price/quality strategies. If a firm goes bankrupt it is replaced by a new firm with a new, random strategy. Each run leads to a different outcome.



Here we see that luck plays an important role in the emergent market structure. Also the learning response of participants to their own comparative performance leads more probably to a more successful market structure.

Fig. 7. Through these multiple simulations we see that Darwinian learning is very ineffective, and the best overall performance is achieved by firms with learning mechanisms.

We can use our model to explore the effect of different learning strategies of firms. The strategy space in view here is that of what % profit to charge and what quality of product to make. Obviously, a lower mark-up will provide larger market share, and lead to economies of scale, but these may not come soon enough to avoid bankruptcy. Alternatively, a firm can have a very high mark-up and make much profit on each unit it sells. However, its sales may be too small to allow survival. The first example of market evolution will be a kind of Darwinian method called “death and replacement”.

1. *Darwinian Learning*: In this case we launch firms with random strategies, and if a firm goes bankrupt, we replace it with a new firm, with a random strategy. In this way, in theory the performance of the market will improve as unsuccessful strategies are eliminated, and only successful ones remain after a long time.

2. *All Imitate*: Here, firms are launched initially with random strategies, but firms adopt the strategy that is winning. In this way, in theory, the reaulting market should evolve to a collection of firms all using a very successful strategy.

3. *All Learn*: In this case, after being launched with random strategies, firms each explore the effects on profits of changing quality and mark up. They then move up the profit slope – if possible. In this way, they demonstrate the effect of a learning strategy.

4. *Mixed Strategies*: Here, after a random launch, we have two Darwinists, two imitators and two learners. This leads to an evolution of the market structure gradually exploring and changing as profit and loss select for the winners and losers.

The results of these simulations are shown in Fig. 7.

The model allows us to test which strategies firms should adopt for the greatest chance of success. It shows us that it is false to believe that firms can simply come to market with Price/Quality strategies that they believe will work, and that their success or failure in the market will effectively lead to efficient economic market structures. The model shows us that average market value achieved by the process, including the cost of bankruptcies, is actually negative. In other words, Darwinism, applied to market evolution, using bankruptcy as the selection process is so costly on average that the industry as whole makes a loss. There is in fact enormous variance in the performance of the market as a whole, with some simulations showing very effective organization by chance, and others with very negative performance following a different sequence of choices.

The next block of simulations looks at the performance of the market when the players all imitate any winning strategy. This does perform better than Darwinian learning on average, with an average final value of over 800,000 compared to -114,000. But the strategy seems to provide the most unstable trajectories, with some examples of market crashes and severe set-backs in the general pattern of improvement.

In the third set of simulations, all the firms adopt an "experimental" strategy of probing their "profit" landscape and moving in the direction of increase. The simulations could be used to examine particular cases, and could offer advice to particular firms engaged in market competition, however, here we are really more interested in investigating the general properties of evolutionary markets. Our model shows us that the basic process of "micro-variation" and differential amplification of the emergent behaviours is the most successful process in generating a successful market structure, and is good both for the individual players and for the whole market, as well as its customers (Metcalfe, 1998, 1999).

The important result that emerges is that, for the same potential demand, for the same technology, the same strategies and the same interactions, chance can still allow great variation in the market structures that emerge. In general the Darwinian method (death and replacement) is so poor that the cost of learning exceeds the total profits of the sector in two of the four cases! Although firms actually believe that their goal should be to beat other firms, here we see that in reality it is how to find strategies of price and quality that enable profitable co-existence. This immediately recalls the issue of ecology, where a successful species is not one that tries to eat all the others, but one that can find a niche that fits its capabilities.

Since each computer run has different outcomes, what we can say is that evolution does lead to some collective structure which is "good enough", that does not mean that it is very good. This evolutionary process is one of satisficing not optimizing, as it operates by the elimination of those that do not survive, and not the excellence of the chosen few. We find that Adam Smith's "invisible hand", the foundation of the belief in free markets, is in reality highly capricious, since there is not a single, universal collective structure that emerges. Instead, the outcome and the costs of learning are highly contingent and history dependent.

This just shows that markets are really theatres of interaction where beliefs clash, and there is some outcome. Luck is important, but so also can be a strategy of learning response.

Having looked at the level of the market place, we can now look at the problem at the level below, inside the competing firms. How do they gain their capacities to produce and deliver products and services sufficiently effectively to survive?

EVOLUTION OF MANUFACTURING ORGANISATIONS

The previous sections demonstrate theoretically how micro-diversity in character space, tentative trials of novel concepts and activities, will lead to emergent objects and systems. However, it is still true that we cannot predict what they will be. Mathematically we can always solve a given set of equations to find the values of the variables for an optimal performance. But we do not know *which* variables will be present, as we do not know what new "concept" may lead to a new structural attractor, and therefore we do not know *which* equations to solve or optimise. The changing patterns of practices and routines that are observed in the evolution of firms and organisations can be looked at in exactly the same way as that of "product" evolution above. We would see a "cladistic diagram" (a diagram showing evolutionary history) showing the history of successive new practices and innovative ideas in an economic sector. It would generate an evolutionary history of both artifacts and the organisational forms that underlie their production (McCarthy, 1995; McCarthy, Leseure, Ridgeway, & Fieller, 1997; McKelvey, 1982, 1994). Let us consider manufacturing organisations in the automobile sector.

Table 2. 53 characteristics of automobile manufacturing organizations.

1. Standardization of parts	27. TQM sourcing
2. Assembly Time Standards	28. 100% inspection sampling
3. Assembly Line Layout	29. U-shaped layout
4. Reduction in Craft Skills	30. Preventive Maintenance
5. Automation	31. Individual Error correction
6. Pull Production System	32. Sequential dependency of workers
7. Reduction of Lot Size	33. Line Balancing
8. Pull Procurement System	34. Team Policy
9. Operator based machine maintenance	35. Toyota Verification Scheme
10. Quality Circles	36. Groups vs. Teams
11. Employee innovation Prizes	37. Job enrichment
12. Job Rotation	38. Manufacturing Cells
13. Large Volume Production	39. Concurrent engineering
14. Mass Sub-Contracting by sub-bidding	40. ABC Costing
15. Exchange of workers with suppliers	41. Excess capacity
16. Training through socialization	42. Flexible Automation of product versions
17. Pro-active Training Programme	43. Agile automation for different products
18. Product Range reduction	44. In-Sourcing
19. Automation (machine paced shops)	45. Immigrant workforce
20. Multiple sub-contracting	46. Dedicated automation
21. Quality Systems	47. Division of Labour
22. Quality Philosophy	48. Employees are system tools
23. Open Book Policy with Suppliers	49. Employees are system developers
24. Flexible Multi-functional workforce	50. Product focus
25. Set-up time reduction	51. Parallel processing
26. Kaizen change management	52. Dependence on written rules
	53. Further intensification of labour

With these characteristics (Table 2) as our "dictionary" we can also identify 16 distinct organisational forms: (a) ancient craft system, (b) standardised craft system, (c) modern craft system, (d) neocraft system, (e) flexible manufacturing, (f) Toyota production, (g) lean producers, (h) agile producers, (i) just in time, (j) intensive mass producers, (k) European mass producers, (l) modern mass producers, (m) pseudo lean producers, (n) Fordist mass producers, (o) large scale producers, and (p) skilled large scale producers.

Cladistic theory enables us to calculate backwards the probable evolutionary sequence of events Fig. 8. It considers which organizational forms are most similar, and calculates the shortest pathways to common ancestors, leading to a reconstructed evolutionary tree. In our approach we look at the pair-wise interactions between each pair of practices, in order to examine the role of "internal coherence" on the organisational performance. In this "complex systems" approach, a new practice can only invade an organisation if it is not in conflict with the practices that already exist there. In other words, we are looking at "organisations" not in terms of simply additive features and practices, but as mutually interactive "complexes" of constituent factors. We see that this a more precise way of talking about the practices involved in creating "dynamic capabilities". In auto manufacture, the most "evolved" organisational form is that of agile manufacturing. This is what wins in sophisticated, mature markets but there still can be a place for mass production and maximum economies of scale in developing markets.

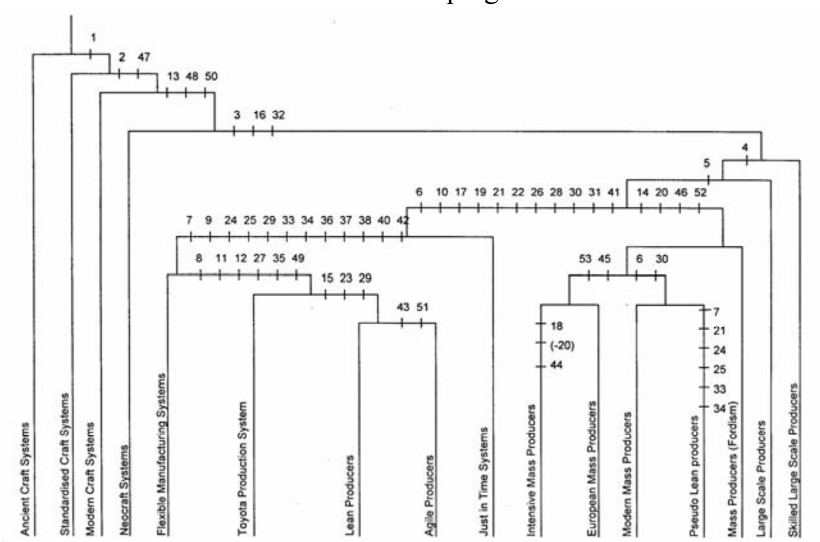


Fig. 8. The cladistic diagram for automobile manufacturing organisational forms (McCarthy, et al., 1997).

From a survey of manufacturers (Baldwin, Allen, Winder, & Ridgway, 2003) concerning the positive or negative interactions between the different practices, a matrix of pair interaction was constructed allowing us examine the "reasons" behind the emergent organisational forms, with successful forms arising from positive mutual interactions of constituent practices. This is shown in Fig. 9.

We have then been able to develop an evolutionary simulation model, in which a manufacturing firm attempts to incorporate successive new practices at some characteristic rate. The matrix shown in Fig. 9 provides the information about pair interactions of practices, and so it is possible to calculate the "synergy" of the practices present in an organization and the invadability of the organization by some new practice. The growth has a logistic form that is modified by the amount of synergy in the practices, which changes the potential market (saturation level) of the performance (production level) of the firm. There is an incredible range of possible structures that can emerge, however, depending simply on the order in which they are tried. But, each time a new practice is adopted within an organization it changes the "invadability" or "receptivity" of the organisation for any new innovations in the future. This is true illustration of the "path dependent evolution" that characterises organisational change. Successful evolution is about the "discovery" or "creation" of highly synergetic structures of interacting practices.

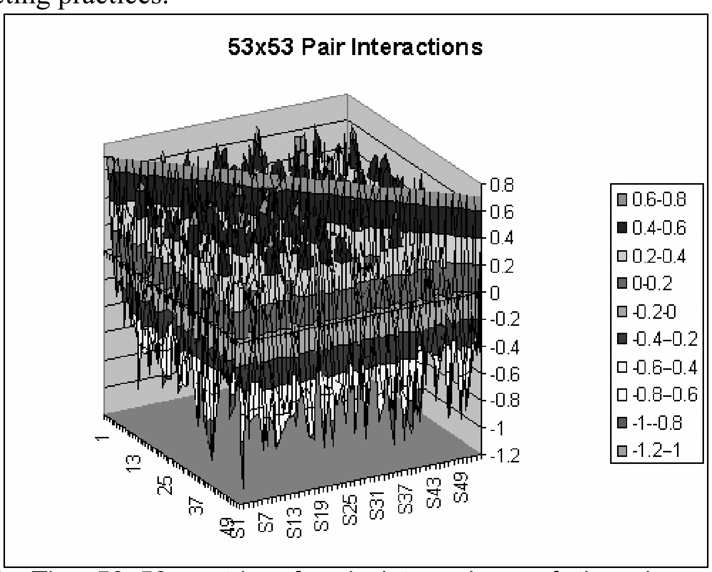
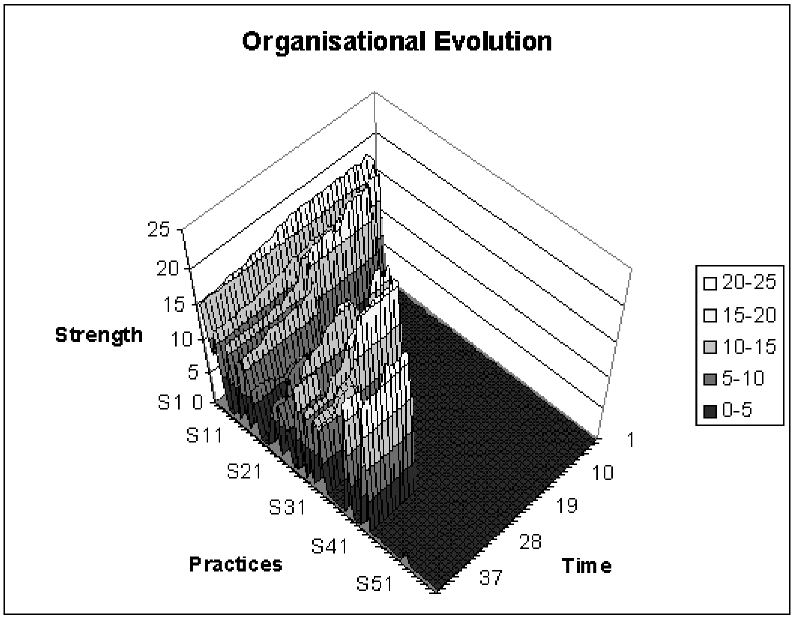
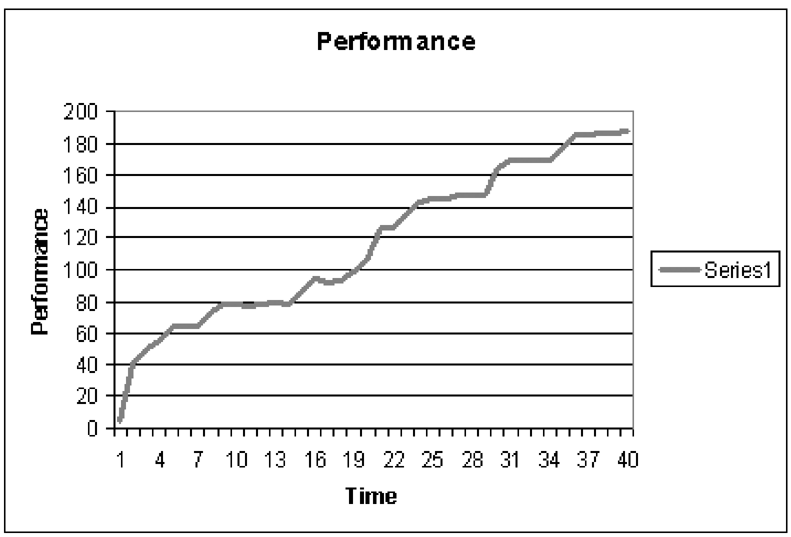


Fig. 9. The 53x53 matrix of pair interactions of the characteristic practices. It allows us to calculate the net attraction or conflict for any new practice depending on which ones are present already.



(a)



(b)

Fig. 10. (a) One evolutionary run showing organizational evolution as new practices are launched over time according to a random sequence. (b) The increasing performance over time as the organization evolves.

In Fig. 10, we see the changing internal structure of a particular organisation as it attempts to incorporate new practices from the 53 possible. In the simulation, we see the development of the evolutionary tree of the FIRM as new practices are tried out and either succeed in "invading" the organisation, or are repulsed. The "landscape of "receptivity" is changed every time a new practice succeeds in invading.

The model starts off from a craft structure. New practices are launched with an "experimental" value of 5. Sometimes the behaviour declines and disappears, and sometimes it grows and becomes part of the "formal" structure that then conditions change which innovative behaviour can invade next. Overall performance is a function of the synergy of the practices that are tried successfully. The particular emergent attributes and capabilities of the organisation are a function of the particular combination of practices that constitute it.

This shows how an "organization" can be seen as a set of interacting practices. These arise historically and diversity is produced because of the ignorance of the participants as to what would be best - and selection on this diversity leads to a successful and varied industry.

The model based on the opinions of the manufacturers surveyed shows us that synergy does indeed increase in the more evolved organizational forms, reaching very high values in the "Japanese" style agile manufacturing. However it in no way says that in real life there are not all kinds of practices introduced, or mergers attempted, without any knowledge or understanding of the possible synergy or conflicts that may be unleashed. Indeed, the purpose of the model is precisely to awaken ego-ridden CEOs to the probable failure of many suggested mergers. The model shows us what historical pathways can be successful in the long run – not what CEOs may actually do. The model is attempting to establish a real basis for the assessment of possible organizational innovations or mergers, since we know that the majority of mergers do not achieve their avowed aims (Allen, Ramlogan, & Randles, 2003).

Different simulations lead to different structures, and there are a very large number of possible "histories". This demonstrates a key idea in complex systems thinking. The explorations/innovations that are tried out at a given time cannot be logically or rationally deduced because their overall effects cannot be known ahead of time. Therefore, the impossibility of prediction gives the system "choice". In our simulation we mimic this by using a random number generator to actually choose what to try out, though in reality this would actually be promoted by someone who believes in this choice, and who will be proved right or wrong by experience, or in this case by our simulation. In real life there will be debate and discussion by different people in favour of one or another choice, and each would cite their own projections about the trade-offs and the overall effect of their choice. However, the actual success that a new practice meets with is pre-determined by the "fitness landscape" resulting from the practices already present and what the emergent attributes and capabilities encounter in the marketplace. But this landscape will be changed if a new practice does successfully invade the system. The new practice will bring with it its own set of pair interactions, modifying the selection criteria for further change. So, the pattern of what *could* then invade the system (if it were tried) has been changed by what *has already* invaded successfully. This is technically referred to as a "path dependent" process since the future evolutionary pathway is affected by that of the past – i.e. its historicity.

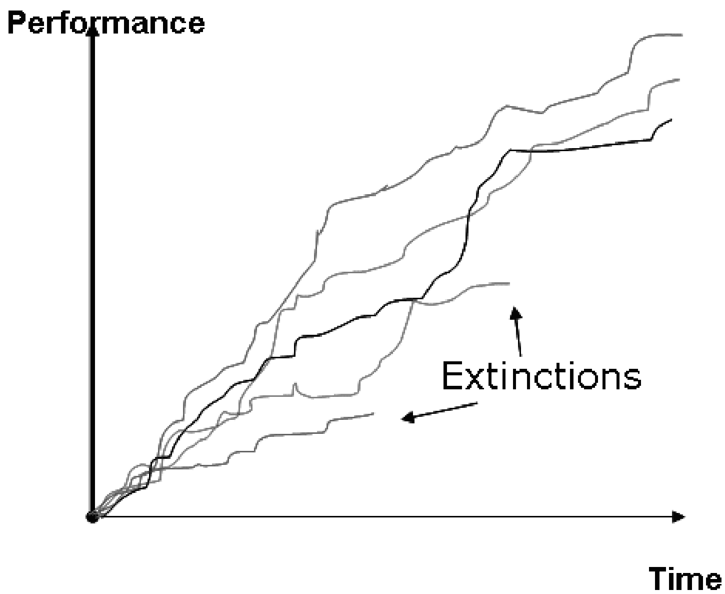


Fig. 11. Different firms follow different historical pathways (different sequences of organizational evolution), and selection occurs.

The evolution through the tree of forms corresponds to a gradual increase in overall "synergy". That is, the more modern structures related to "lean" and to "agile" organizations contain more "positive" links and less "negative" links per unit than the ancient craft systems and also the mass-producing side of the tree. Here, new aims and goals are defined within the organization, and new ways of achieving them are created and tried out. Reality selects for those aims and goals, and those practices that can successfully co-exist together in a synergetic structure. Of course, some firms find particular niches which allow them to stay where they are, as for example Morgan Cars may be essentially artisanal in its organization, but it finds enough customers to keep going year after year.

So, the exploration produced by the different types of emergent capability respond to the needs of different parts of the market, and this becomes visible post-hoc. Obviously, the market itself is evolving, as for example the taste of the US, Europe and Japan appeared to have tipped the balance in favour of agile and lean manufacturing, but with the rise in the Chinese and Indian economies, the market for ultra-cheap, mass produced cars may well grow enormously. In this way organizational evolution and industrial patterns co-evolve with the changing aims and goals of different potential customers, and with their changing circumstances. The exploration afforded by ignorance in knowing the precise order in which new ideas should be tried out, leads to an ability to co-evolve and innovate new forms and new capabilities.

Our work also highlights a "problem" with the acceptance of complex systems thinking for operational use. The theory of complex systems tells us that the future is not completely predictable because the system has some internal autonomy and will undergo path dependent learning. However, this also means that the "present" (existing data) cannot be proven to be a *necessary* outcome of the past – but only, hopefully, a *possible* outcome. So, there are perhaps so many possible structures for organisations to discover and render functional, that the observed organisational structures may be only 16 of several hundred that are possible. In traditional science the assumption was that "only the optimal survive", and therefore that what we observe is an optimal structure with only a few temporary deviations from average. But, selection is effected through the competitive interactions of the other players, and if they are different, catering to a slightly different market, and also sub-optimal at any particular moment, then there is no selection force capable of pruning the burgeoning possibilities to a single, optimal outcome. Complexity tells us that we are freer than we thought, and that the diversity that this freedom allows is the mechanism through which sustainability, adaptability and learning occur.

This picture shows us that evolution is about the discovery and emergence of structural attractors (Allen, 2001a, 2001b, Allen & Strathern, 2004) that express the natural synergies and conflicts (the nonlinearities) of underlying components. Their properties and consequences are difficult to anticipate and therefore require real explorations and experiments, to be going on, based in turn in diversity of beliefs, views and experiences of freely acting individuals.

CONCLUSIONS

There are several important points about these results. The first is that the model above is very simple, and the results very generic. It shows us that for a system of co-evolving agents with underlying micro-diversity and idiosyncrasy we *automatically* obtain the emergence of structural attractors.

A structural attractor is the emergence of a set of interacting factors that have mutually supportive, complementary attributes – meaning that they have the possibility of emergent capabilities which can access resources from their environment. This addresses the question of why any particular system exists. Systems arise by chance and persist for as long as they successfully access the resources needed for maintenance and growth. Darwin's finches, and the different permutations of finch that inhabit different size islands, are illustrations of natural "structural attractors". These are complex systems of interdependent behaviours whose attributes are on the whole synergetic. They correspond to the emergence of hypercycles in the work of Eigen and Schuster (1979) but recognise the importance of emergent collective attributes and dimensions. The sequence of structural attractors (or complex system) that emerge and dissolve over time reflect the particular historical pathway that has occurred. It results from the particular local, idiosyncratic deviations and peculiarities that occurred to perturb the pattern of positive and negative interactions of the structural attractors that emerged. Evolutionary Drive (Allen & McGlade, 1987) describes how underlying micro-diversity drives systems forward through successive structural attractors.

What are the implications of these structural attractors:

1. Search carried out by the "error-making" diffusion in character space, made possible by local "ignorance" of global implications, leads to successful performances of the emergent structures. Instead of a homogeneous system, characterised by intense internal competition and low symbiosis, the development of the system leads to a much higher performance, and one that decreases internal competition and increases synergy. This is different from a classical dynamic attractor that refers to the long-term trajectory traced by the given set of variables.

It is the "creative destruction" of the "incoming" non-prototypical elements that drives evolution.

2. The whole process leads to the evolution of a complex, a "community" of agents whose activities, whatever they are, have effects that feed back positively on themselves and the others present. It is an emergent "team" or "community" in which positive interactions are greater than the negative ones. There will still be conflictual interactions, but they are outweighed by positive ones. The structural attractor will not be optimal, but only sufficiently good to have emerged, and nobody will really know how it actually works, or how much better or worse it could

Structural attractors are emergent sets of prototypes that can establish interacting processes that succeed in temporarily stable persistence - that can get adequate resources from the environment.

be made by modifications to the behavioural rules

3. The structural attractor represents a particular sub-set of activities from all those possible in principle. It reflects the "*discovery*" of a subset of agents whose attributes and dimensions have properties that lead to an emergent capability to have brought it into existence.

Successful and sustainable evolutionary systems will clearly be ones in which there is freedom and encouragement for the exploratory search process in behaviour space. Sustainability in other words results from the existence of a capacity to explore and change. The free evolution of the different populations, each seeking their own growth, leads to a system that is more *co-operative than competitive*.

If we think of an artefact, some product resulting from a design process, then there is also a parallel with the emergent structural attractor. A successful product or organisation is one in which the "bundling" of its different components creates emergent attributes and capabilities that assure the resources for its production and maintenance. However, the complication is that the emergent attributes and capabilities are not simply an additive effect of the components. If a change is made in the design of one component it will have multi-dimensional consequences for the emergent properties in different attribute spaces. Some may be made better and some worse. The landscape of projected "fitness" of the product is rugged and therefore a rational, single pathway into the future is not possible, and this in turn gives rise to diverse possibilities and the need for exploration, evaluation and selection. Successful "products" are therefore also structural attractors whose components work in overall synergy, creating emergent performances that are the result of the path dependent processes that occurred in the product definition and development phases. From all the possible designs and modifications firms seek structural attractors having dimensions and attributes that work well together.

Throughout the economy, and indeed the social, cultural system of interacting elements and structures we see a generic picture at multiple temporal and spatial scales in which *uncertainty about the future allows* actions that are exploratory and divergent, which are then either amplified or suppressed by the way that this modifies the interaction with their environment. Essentially, this fulfils the early vision of dissipative structures (Nicolis & Prigogine, 1977; Prigogine & Stengers, 1987), in that their existence and amplification depend on the internal agents or elements "learning" how to access energy and matter in their environment, and this brings intentionality, whether well-informed or not, into the dynamics of micro-diversity generation. The question is whether or not a particular perturbation, deviation of exploration leads to a self-reinforcing loop of mutual advantage in which entities and actors in the environment wish to supply the resources required for the growth and maintenance of the disturbance in question. Or more correctly, the system will evolve each time that a disturbance is tried that has this self-reinforcing property. Over time, then, such events will occur and the system will evolve structurally. In this way, structures emerge as multi-scalar entities of co-operative, self-reinforcing processes. This also provides us with a basis for understanding the evolution of organisms and individuals that actively strive to survive. Because evolution selects for micro-diversity generating explorations, then it automatically either looks like "striving", or actually is. Not only that, we see how the theory also shows that evolution is about systems that devote some fraction of their effort to exploring outwards from this in ways that eventually lead to instability and structural reformation

In effect, the successful working of the ecosystems, markets and social systems requires the constant generation of underlying heterogeneity. This can be in the aims and goals (axiologies) of the agents, in their attempted interpretive frameworks (epistemologies). The resulting heterogeneous ontology selects over time for synergy and co-operativity amongst all this. Uncertainty about the future, ignorance, leads naturally to the freedom to think and aim for different things and hence to propose different ways forward. These then compete and co-operate between themselves leading to a selection of a compatible sub-set. Selection from the level above leads to the retention of systems with such dynamic capabilities that allow transformation and restructuring to occur within. Evolution selects for an evolutionary capability, and so the outcome is that we live in a world for which there is no "correct" axiology, epistemology or ontology, since this is always changing, as part of an evolving heterogeneous whole.

Evolution has ontological priority over apparent structure and organization. These latter are temporary emergent features of the on-going evolutionary process. The entities involved include the internal "models" and "values" of the interacting elements.

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