The future of the social sciences and humanities in the science of complex systems

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The Future of the Social Sciences and Humanities in the Science of Complex Systems

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Abstract

The modern world is characterised by problems that involve systems with social and physical subsystems. They are entangled systems of system of systems with multilevel dynamics. There is no methodology able to combine the partial micro- meso- and macro-theories that focus on subsystems into a coherent representation of the dynamics of the whole. Policy requires prediction, but the traditional definitions of prediction are not appropriate for multilevel socio-complex systems. Heterogeneous multilevel systems have subsystems that may behave with great regularity over long periods of time, and then suddenly change their behaviour due to weak coupling with other subsystems. Thus systems that are usually highly predictable may be subject to rare but extreme events, and this is highly relevant to policymakers. New ways of thinking are needed that transcends the confines of the traditional humanities, social and physical sciences. Of necessity, this science will be embedded in the design, implementation and management of systems, and therefore the new science will be entwined with policy. Much policy is interventionist experiment. By themselves scientists cannot conduct experiments on socio-complex systems because they have neither the mandate nor the money to design and instrument experiments on the large scale. Policymakers – elected politicians and their officers - design the future, making it as they believe it *ought* to be. New kinds of scientific predictions can inform policy but can only be instrumented and tested if there is good will between policy makers and scientists, where scientists are junior partners. Scientists offer policy makers theories and predictions of social systems based on logical-deductive methods. Policy is generally made on the basis of rhetoric, with the best possible arguments being deployed to support favoured conclusions. To convince policy makers that a particular scientific theory should be used, scientists move from the logical-deductive to the rhetorical. Thus the full theory of a science of complex systems has to provide a logical-deductive metatheory of the rhetorical and logical-deductive systems that make decisions and implement them. Traditional natural and physical science has avoided rhetoric which is much better understood in the humanities and social sciences. Thus it is concluded that the science of complex systems must embrace the humanities and social sciences not just because their domains of study are relevant but also because their methods are necessary to understand how science and policy work together in complex social systems.

1. Introduction

The contemporary world is characterised by problems that involve both physical systems and social systems. Natural phenomena such as earthquakes, hurricanes and droughts can cause great damage to social systems and much effort is expended trying to predict them and mitigate their effects. Over the past century humankind has been surprised to discover that social, economic and political activity impacts on the physical systems of the Earth, with potentially disastrous global consequences. To address the problems faced by individuals, institutions and governments worldwide requires new science able to combine and go beyond the best of the traditional humanities, social, biological, physical, environmental and engineering sciences.

The complicated and messy problems we face cannot be solved alone by any existing body of knowledge from the social, natural, physical and engineering sciences. From the perspective of complex systems science, these problems involve *systems of systems of systems*. Certainly they involve social subsystems, they involve the natural subsystems of the environment, and they involve the artificial subsystems of technology and the built environment. These subsystems and their subsystems such as families, business, the oceans, the atmosphere, the land, houses, shopping malls and transportation are intertwined with many complicated interactions. They will be called *socio-technical systems.*

Cities are entangled systems of systems of systems. Their subsystems include individuals and families at the microlevel, living in individual houses and apartments. These aggregate into wards and districts as political management subsystems. Alongside this are multilevel economic subsystems, from the microlevel of the newspaper vendor to the macrolevel of multinational companies selling products and services (Alexander, 1965). All this is entangled with physical subsystems of roads, parks, buildings, and utilities, themselves entangled with business subsystems and various levels of City Hall. The city itself is a subsystem within its region, and the region is a subsystem within the nation.

Whereas there may be well developed theories and models of subsystems such as ecosystems, finance, welfare, agriculture, transportation, industry, healthcare, oceans, atmospheres, pollution, energy, crime, and conflict - each with their own subsystems – there is currently no scientific method able to combine these into a coherent whole. This lack of scientific theory is a problem because our inability to combine an understanding of the parts into an understanding of the whole makes the predictions that underlie policy unreliable, and may lead to unexpected consequences. The public demand for joined-up government will not be achieved until we have joined-up science.

The behaviour of socio-technical systems is unpredictable in a conventional sense, and new theoretical perspectives are needed for what it means to predict their behaviour. Here it will be argued that *the science of socio-technical systems must be developed through policy and its application through design, implementation and management*. Policy is seen as *designing the future*, and empirical science is necessarily intertwined with policy making and implementation. This too poses many problems on what it means to make a prediction.

It will be argued that a new science of complex systems is needed and that this science will embrace the humanities and social sciences alongside the traditional natural, physical, and engineering sciences within the framework of policy and applications of policy through design, implementation and management.

2. Multidisciplinarity in the Science of Complex Systems

Before going in to the details of the argument that a new science is needed that embraces the humanities and social sciences, it may be useful to explain the great difficulties to be overcome in achieving it.

The science of complex system has two major directions. The first is that systems in domains such as economics, sociology, psychology, biology, chemistry, computing are inherently complex and domain specialists are needed to research and seek detailed understanding of them. These specialists provide deep *vertical* knowledge of their domains. In contrast to this, complex systems scientists take a *horizontal* approach across the particular domains. This is because the same phenomena occur with in different forms across the domains and common methods may be applied. It is also because many systems from many domains interact to form *systems* of *systems* as illustrated by the interaction between economics, climate science, and other domains relevant to the problem of climate change.

Few academics are today trained in a multidisciplinary way. Most universities maintain domain-based departmental structures that act as silos, insulating seniors from ideas outside their domain and inhibiting the spread of knowledge between fields. Even those predisposed to interdisciplinary research usually have depth of knowledge in one or two particular domains, and almost no breadth of knowledge across other disciplines.

Complex systems science is highly interdisciplinary. Generally it is necessary to have knowledge in many disciplines, including mathematics, computing, physics, biology, economics, sociology, psychology, geography, history, and so on. Some complex systems scientists believe that the arts are also necessary for the science. Given this range of domains of desirable knowledge the reality is that almost all of us know almost nothing about almost everything.

Related to this, it is almost impossible for a generalist to know the literature in all possible fields, or even the specialist language used. The interdisciplinary approach requires that those who do know the culture and literature of their own disciplines are generous and tolerant to those who do not. This paper is written in this spirit, and where it can be better informed from other perspectives is point of departure for discussion and synthesis.

3. Prediction

The natural sciences have put a high value on *prediction*, as a way of legitimating their theories and as the basis of applications. This appears in an extreme form in the writings of Laplace in 1814: "We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at any given moment knew all of the forces that animate nature and the mutual positions of the beings that compose it, if this intellect were vast enough to submit the data to analysis, could condense into a single formula the movement of the greatest bodies of the universe and that of the lightest atom; for such an intellect nothing could be uncertain and the future just like the past would be present before its eyes". Today this view is not tenable. There is no formula that can capture everything, and even if there were it could not give predictions in the way Laplace proposed.

In the nineteen sixties the weather scientist Lorenz discovered a classic example of what is today called the theory of *deterministic chaos*. When using a computer and mathematical model to calculate the future states of a weather system, Lorenz discovered that a tiny change in the initial conditions of the calculations could make a very large different to the outputs of the model. This system was *sensitive to initial conditions*. Since all measurement has error, even if one had a perfect model, computing the future states of the system will result in wide variation when the system is sensitive to initial conditions. Lorenz showed that even physical systems may not be predictable in the conventional sense that the system will be in a particular state at a particular point in future time.

Let a *prediction* be defined to be a proposition of the form "if a system is in state s at time t and an action or intervention a is applied to the system at time t then the system will be in state s' at some future time within a time interval T. If T is a single point in time, $T = \{t'\}$, the prediction is called a *point prediction*.

As an example, the prediction that "if you are reading this sentence now you will have completed reading it within the next minute" will be empirically true for most readers. As another example, governments around the world recently predicted that "if large sums of money are not given to the banking sector now, then the financial system will collapse within a few years" and acted accordingly. So far this prediction holds. As a third example, "if greenhouse gas emissions are not capped at the current level the climate will change irreversibly by the end of the century". For most of us this prediction is untestable.

These examples show that predictions can be vague about when things will happen, they can be stated in imprecise ways, and there may be no practical way of testing them. In fact some predictions are even more vague by asserting the future state is 'likely' or 'expected but not certain'. When systems are well understood probability theory can represent such uncertainty in useful ways. When systems are not well understood it is difficult to calibrate the probabilities, and in the important case of rare events the probabilities are almost zero and of little operational value.

The laws of physics that determine the behaviour of gases assume that a gas is composed of endlessly moving molecules. The faster the molecules move, the hotter the gas. If the molecules are constrained to a smaller volume, the pressure increases. The microlevel motion of the molecules gives rise to the point-predictive macroscopic *law* that the temperature of a gas multiplied by its volume and divided by its pressure is a constant.

This can be illustrated by the compression stroke of bicycle pump, which gets noticeably hotter as the volume of air decreases and the pressure increases. In this system it is not necessary to know which individual molecule is which, since it is assumed that they all behave in the same way. Contrary to this, individual people do not all behave in the same way in social systems, and the behaviour of individuals at the microlevel can significantly impact on the emergent behaviour of the system at the meso- and macrolevels. For example, if someone other than Archduke Ferdinand had been shot in Sarajevo in 1914 the course of history might have been different.

Consider the movement of people in a busy shopping street. It is very rare that they collide as they walk past each other. Instead individuals take mutually reinforcing evasive action so they miss each other. In a crowd people move according to all the people in their vicinity, and the motions and positions of everyone *emerges* from their local interactions. In general the particular position of any individual is unpredictable through time, but the overall patterns of movement seem to be the same. There are rare and extreme event when crowds panic, and the actions of individuals can result in emergent waves of pressure causing injury and death.

Some emergent behaviour can be predicted from previous experience but often it cannot. Computer simulation provides an important method of predicting behaviour that emerges from the interactions of many things – behaviour that may never have been seen before. Since the systems simulated are usually sensitive to initial conditions, computer simulations often involve distributions of outcomes from many runs with many sets of initial conditions.

Both the physical sciences and the social sciences recognise the multilevel nature of the systems they investigate. The dynamics of cell biological systems is expressed in terms of lower level biochemical subsystems. Somehow cells work together to form subsystems such as organs and these work together to form bodies that have robust mechanisms enabling them to survive in hostile environments. In social science there is a distinction between the study of individuals in psychology and the more aggregate behaviour of groups in sociology, economics and political science.

Despite recognising different levels of organisation in complex systems, *science has no formalism to provide an integrated account of the multilevel socio-technical systems that human beings attempt to plan and manage across the globe*[1].

In December 2009 politicians from all round the world assembled in Copenhagen to seek an international plan to deal with climate change. The meeting ended in failure and recrimination. In part this reflects the complexity of this problem. Each of the many hundred countries present had a more or less clear view of its own needs as a subsystem. Inevitably such a meeting would involve compromise and making deals, and no doubt each national delegation had thought through its strategy to achieve what it wanted by conceding what was necessary. In the event the desired agreement was not achieved. A typical newspaper headline (Vidal *et al* 2009) reads “Low targets, goals dropped: Copenhagen ends in failure - Deal thrashed out at talks condemned as climate change scepticism in action” with the story continuing as “The UN climate summit reached a weak outline of a global agreement in Copenhagen tonight, falling far short of what Britain and many poor countries were seeking and leaving months of tough negotiations to come. …”

One could conclude many things from this, but the most relevant here is that this failure was partly due to a lack of scientific understanding of the process they were engaged in. *All the*

[1] It could be argued that Gidden’s theory of structuration is a counter example to this proposition. Certainly this theory is a good point of departure for a new formalism, but the use of vernacular language to express the theory is not considered here an adequate formalism. In particular from the perspective of complexity science there is the question of how such a theory could be made operational to give ‘predictions’ in particular cases based on data. The challenge is for complex systems science to provide a more general formalism that social scientists would agree has lost nothing of the original.

sciences put together were not able to provide a common understanding of the problem or a common understanding of the political process by which it might be resolved.

The example of the failure of the 2009 climate change negotiations in Copenhagen illustrates the failure of prediction at many levels: the scientific predictions of climate change came under sustained attack, with some success; the predictions underlying the policies to counter climate change were not agreed; and the predictions underlying the negotiations were incorrect. Again this suggests that there is no science able to give holistic predictions of the behaviour of large heterogeneous *socio-technical-politico* systems such as these discussions.

4. The Science of Complex Systems

There is no agreement on what should be the precise definition of 'complex'[2] [3], and there are many reasons as to why a system might be considered complex. These include having:

- many heterogeneous parts, *e.g.* a city, a company, the climate
- complicated transition laws, *e.g.* economic systems; disease transmission.
- unexpected or unpredictable emergence, *e.g.* chemical systems; accidents.
- sensitive dependence on initial conditions, *e.g.* weather systems, investments
- path-dependent dynamics, e.g. qwerty keyboard evolution, international relations
- network connectivities, and multiple subsystem dependencies, *e.g.* ecosystems
- dynamics emerge from interactions of autonomous agents, *e.g.* road traffic, parties
- self-organisation into new structures and patterns of behaviour, *e.g.* ghetto formation
- non-equilibrium and far-from equilibrium dynamics, e.g. fighter aircraft, share prices
- discrete dynamics with combinatorial explosion, *e.g.* chess, communication systems
- adaptation to changing environments, *e.g.* biological systems, manufacturing design
- co-evolving subsystems, *e.g.* land-use and transportation, computer virus software
- ill-defined boundaries, *e.g.* genetically modified crops, pollution, terrorism
- multilevel dynamics, *e.g.* companies, armies, governments, aircraft, the Internet

Many systems exhibit many of these characteristics. Any one of them can make systems appear complex, but together they can make systems very difficult to understand and control.

During the twentieth century it became apparent that many systems could not be investigated using the experimental or theoretical methods of the traditional physical sciences.

The realisation that many systems are sensitive to initial conditions has changed scientists attitudes to what it means to make a prediction. Theory alone tells us that there is a horizon beyond which prediction is not possible. None-the-less, to plan and manage systems it is necessary to be able to predict the consequences of policy interventions. The concept of prediction in social systems is different to that in physical system, *e.g.* in the context of policy predictions are intended to be self-fulfilling prophesies, *e.g.* our policy was to build 1000 homes this year, we predicted that 1000 homes would be built this year, and we have built 1000 homes this year.

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[2] In his paper *From Complexity to Perplexity* Horgan (1995) quotes thirty one definitions of complexity given by Seth Lloyd in 2001. Horgan illustrates the diversity by a selection, including entropy (disorder), information (surprise), fractal dimension, effective complexity (regularity *vs* randomness, hierarchical complexity, grammatical complexity, thermodynamic depth, time computational complexity, spatial complexity, and mutual information (between parts). In his 1999 PhD thesis, Edmonds gives over forty definitions of measures of complexity.

[3] It could be said that the term is contested and therefore a social construct, fitted within an interpretive epistemology that provides one of many possible ways to understand the world with all possessing some degree of truth. However there is much more agreement on the meaning of the bulleted list of more detailed characteristics of complex systems. Furthermore, the existence of many interpretations suggests the possibility of knowledge and science at a metalevel above the particular interpretations, as discussed later.

The science of complex systems attempts to provide methods of understanding the dynamics of systems where conventional methods fail. These methods apply *across* the domains, *e.g.* chaotic dynamics can be observed in biological systems, economic systems, chemical systems, road traffic systems, and many others. There are many systems in which the behaviour of the whole emerges from interactions between the parts, *e.g.* traders in markets, birds in flocks, people in cities, cars on roads, sportsmen in teams, and cells in bodies.

Confining scientific enquiry to one domain can give deep insights, but unexpected things can happen when a subsystem from one domain interacts with a subsystem from another. In 1956, W. Ross Ashby wrote "Science stands today on something of a divide. For two centuries it has been exploring systems that are either intrinsically simple or that are capable of being analysed into simple components. The fact that such a dogma as "vary the factors one at a time" could be accepted for a century, shows that scientists were largely concerned in investigating such systems as *allowed* this method; for this method is often fundamentally impossible in the complex systems."

Thus complex systems science is necessarily interdisciplinary, integrating knowledge from all domains including the humanities, social sciences, natural sciences and the sciences of the artificial[4]. Complex systems science draws on all of these but adds something new. The computer revolution of the twentieth century enabled a new kind of science. For the first time in history it became possible to analyse the dynamic interactions of millions of things explicitly. For example, it is possible to calculate the interactions of millions of drivers in a city and to observe the emergent tailbacks and traffic jams, where the simulated dynamics are close to those observed.

Much of our science is based on extrapolation from what has gone before. It is expected that the planets will move as they always have done. It is expected that the chemical reaction observed yesterday will work the same way today. History provides patterns that can be interpreted as the precursors of conflict, and when similar patterns appear it is tempting to believe that history will repeat itself. Social work is based on patterns of behaviour that are expected to be observed across similar families. This approach to understanding the world and predicting its behaviour is very powerful and works well most of the time. Occasionally it fails to foresee rare but extreme events, with dire consequences. Computer simulation does not have this limitation[5].

Computer simulation is a powerful new scientific method. There are many systems in which the meso- and macro-dynamics emerge from the discrete microlevel interactions of many agents[6]. The resulting dynamics are too complicated to be captured by formulae, but computer simulation allows those dynamics to be played out at the microlevel to produce emergent dynamics at higher levels. Despite having its own methodological problems, computer simulation is giving new insights into many kinds of system. Furthermore new sources of data are emerging about human beings, including the way individuals use mobile telephony and the way people use the Internet for much of their economic and social activities. Never in the history of humankind has so much been known about the

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[4] In his book *The Sciences of the Artificial* Herbert Simon makes a distinction between artificial and natural systems. Artificial systems are man-made and include everything that is designed and intentionally created by human beings. Here natural systems is intended to mean physical systems that are not deigned and man-made such as the weather. There are of course grey areas such climate change which many believe is artificial but created by accident rather than design.

[5] For examples of computer simulations being used to solve practical problems see the article *Practical Business Applications of Complex Science* in the ASSYSTComplexity Newsletter – Number 2, September 15 2009 http://www.rzevski.net/09%209%20Assyst_Newsletter_final_04_JHJ.pdf

[6] The use of the terms 'micro', 'meso' and 'macro' here follow the usual ill-defined usage. In an obvious sense individual people could be said to exist at the microlevel, and nations could be said to exist at the macrolevel, with anything in between said to exist at the mesolevel(s). In Section 5 the terms will be made more precise.

microdynamics of whole populations, with emergent data sources eclipsing and augmenting traditional census, taxation and survey data.

While systems behave in relatively slow ways they appear to be manageable. However sometimes systems manifest *extreme events* with combinations of states and dynamics never seen before. For example, the world financial system recently experienced the extreme event of bank failures, with the possibility of the extreme event of Greece defaulting on its debts and consequent social disorder. Other extreme events include the spread of pandemic flu and terrorist attacks. Simulation using new data sources is possibly the only way of discovering *extreme events* caused by the unexpected interactions of apparently unconnected subsystems.

5. Science and Policy: Designing the Future

Policy can be thought of as being concerned with *artificial systems* designed, created and managed *as they ought to be* (Simon, 1965)[7]. As such it is normative and assumes that, within the constraints of the political systems, the policy maker has a mandate to decide what ought to be and to how try to achieve it.

It can be argued that most policies are unrepeatable experiments. Although they may aim for specific goals there is generally no certainty that the goal will be achieved in the way that is planned. For example, the fisheries policies of Europe over the last quarter century can be seen as an experiment in economics that has resulted in an environmental catastrophe (Booker, 2007), but it is not possible to go back to try polices that might have worked better. Similarly, the near collapse of the world financial system is due to failed experimental ways of reducing risk, but it is not possible to go back try other policies.

Compared to policymakers, scientists generally cannot conduct experiments on complex systems such as a city, a national economy or a multinational company. They do not have the mandate and they do not have the money. Scientists do not have the moral or legal authority to make interventions on most systems, and they do not have millions or billions of dollars necessary to make interventions. Scientists cannot build bridges or shopping malls, they cannot impose new policies on health provision, and they cannot set up new factories, sell banks, or buy large tracts of land. To conduct experiments, scientists must align themselves with policymakers, as consultants or advisors. In such partnerships scientists must usually be the junior partner, tolerated as long as they are useful.

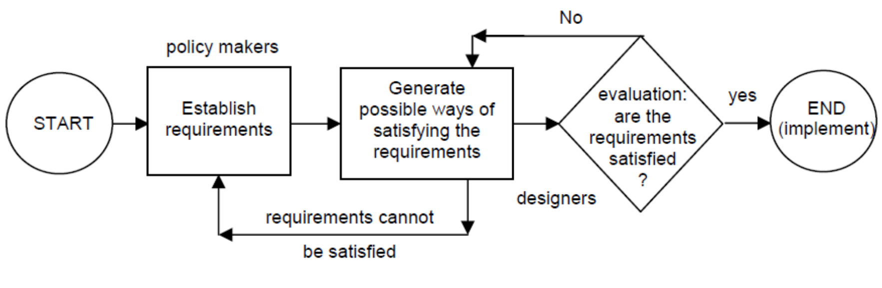


Fig. 1 The simplified requirements-generate-evaluate model of the design process

Artificial systems are *designed*. As shown in Figure 1, the process begins with the establishment of needs or requirements and proceeds with the generation of possible ways to satisfy those requirements. These are evaluated, and the design solution is either accepted or new and better solutions are generated. This process is *open ended* and in general there are many possible ways of satisfying the requirements. Some solutions are better than others, but generally the requirements conflict and a compromise has to be reached. For example, a city

[7] By definition, the interventions of policy deliberately attempt to change what exists and create artificial systems.

might want to build new public housing to a high standard with a sports centre for a hundred families with a budget of a five million dollars. The cost constraints suggest that any design solution will have to lower the standards, reduce the number of families, have a more modest sports centre, or increase the budget. If it can be found, such a solution is said to *satisfice* the constrains, giving an acceptable compromise. However sometimes no solution can be found and the requirements must be revisited. In this case it might be decided that providing a sport centre is not practice, and this constraint may be removed. This creates a different problem that may be much easier to solve by finding a an acceptable satisficing design.

The iterative nature of generating and evaluating designs in the context of changing requirements underlies a co-evolution between the problem and its solution. The design process is one of learning about the system being created, including its possibilities which may not have been apparent when the process began[8]. The process begins by sketching out possibilities is a very general way and proceeds by vague possibilities being instantiated with concrete specifications. The coevolution between specified requirements and the creation of a design to satisfy them is illustrated in Figure 2. At every stage of the design process decisions are made affecting the requirements and the final outcome, and for this reason it is essential that the policy maker remains in the loop.

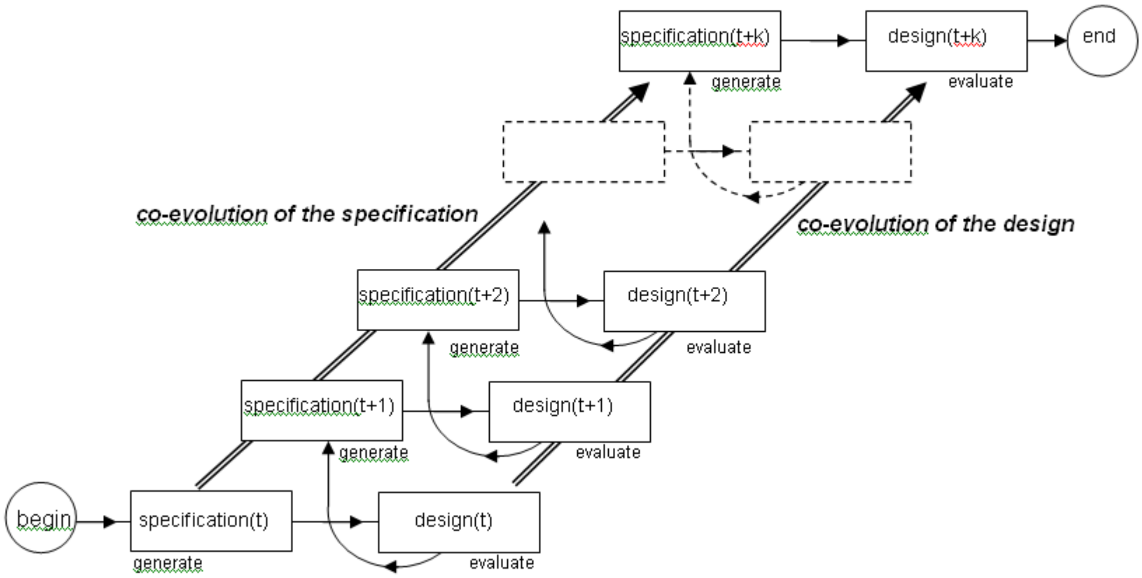


Figure 2. The co-evolution between specification and design through a generate-evaluate spiral

The design itself involves predicting how the parts and the wholes in the new system will behave. At its simplest, design involve identifying a appropriate set of components and specifying has they can be assembled to form parts and eventually the whole multilevel system. For example, rooms are built of bricks, doors and windows; houses are assemblies of rooms of various types; and estates are assemblies of houses, roads and other services.

The design of a big system such as a housing project would not be designed bottom- up from the minutiae of the bricks and window frames, but would start with a sketch in which, for example, individual house might be represented by hastily drawn rectangles. At this stage the designer might confirm their hypothesis that the desired number of houses can be fitted into the site according to constraints such movement and privacy. Following this the type of house be instantiated at a lower level in the representation, some having two bedrooms, some having three and some having four. As the lower levels are instantiated with more concrete things,

[8] It will be argued that the process of formulating and executing policy is exactly analogous to design, with the possible exception of learning from failure.

the top-down assumptions and hypotheses may be shown to be incorrect. Perhaps it is not possible to fit the desired mix of more precisely specified houses on the site, requiring the higher level hypotheses to be revisited. The instantiation of the detailed plumbing may reveal unexpected cost problems that could compromise the whole project, requiring the analysis to be revisited at a higher level of abstraction, with possibly a hypothesis that the project could be saved by a lower cost roof construction.

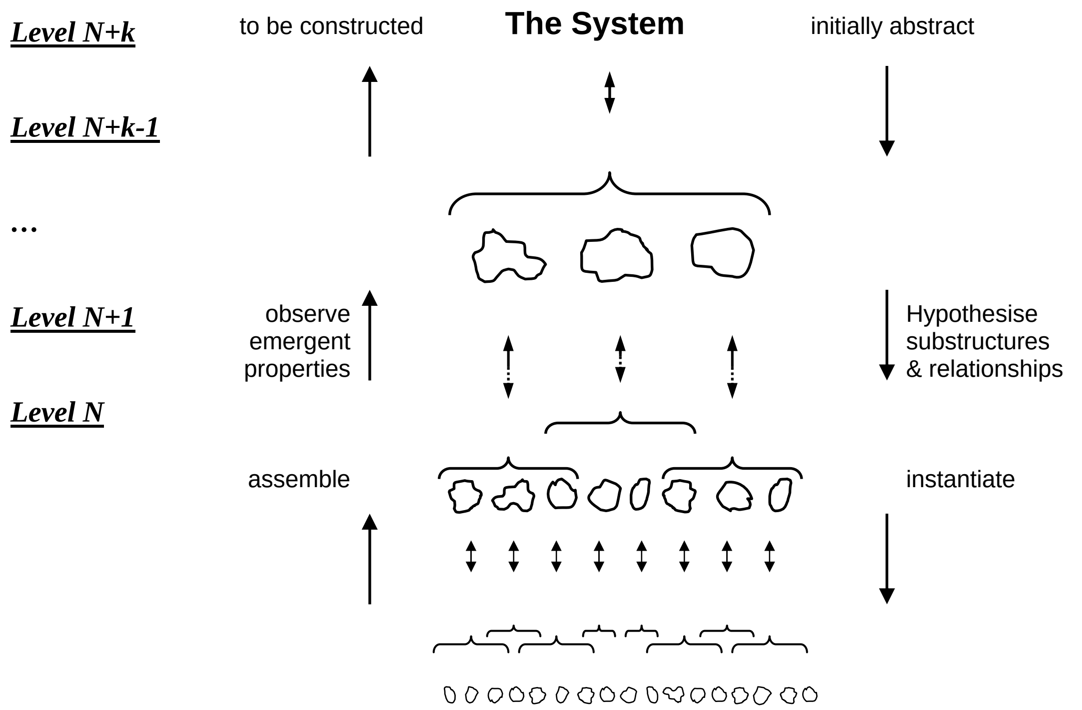


Figure 3. Design as bottom-up construction and top-down hypothesis, generation and reasoning

Thus design is an iterative process of top-down reasoning and hypothesising bottom-up construction as more details are added lower down the multilevel representation, as illustrated in Figure 3.

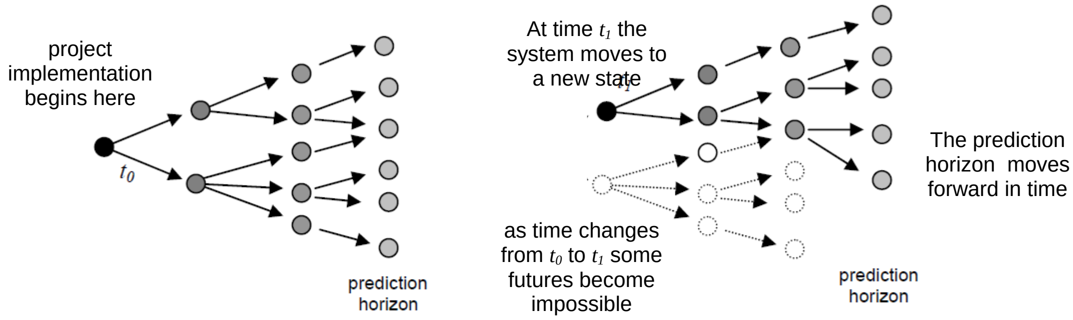
In large complex systems the top-down hypotheses of how the system might behave can be very complicated and require the specialist analysis of the whole or subsystems by a scientist. When an entirely new system is being designed, the designers are the first scientists of the theory of that new system. For example, aeronautical science began with the iterative designs of the Wright Brothers and others, while architectural science began much earlier with the trail and error design and construction of increasingly larger and more complication buildings.

Designers can be masters of complexity. They deal with clients who don't know what they want or what is possible, they have to know the regulations that constrain what is allowable and negotiate permissions with the authorities, they have to create new systems that will satisfice the client's requirements, they have to manage many processes during the fabrications stage, and they have to manage the dynamics of finance and their client's finances. More formally, the interplay between design and complexity has been characterised by Alexiou *et al* (2009):

- designing complex systems requires a scientific understanding of their dynamics
- design processes can be complex, e.g. manufacturing processes, supply chains
- the environment of design can be complex, e.g. regulation, fashion, economy
- design is a complex collaborative cognitive process

Design and the implementation of design to create systems are dynamic processes that involve predications of how the system will behave. As shown in Figure 4, the prediction horizon moves forward in time as the plan is implemented.

For example, consider again the implementation of a social housing project. At time t_0 there could be two possible states involving the purchase of the site. Once the site is purchased at time t_1 some things that would have possible with another site become impossible, and many future trajectories get pruned. With the abstract concept of site being instantiated the prediction horizon moves forward as it becomes possible to see new future states. In this case the instantiation of the site would lead to a period of more detailed planning when it would become clearer how many dwellings of which types could be accommodated. Thus one can imagine the project moving forward in time, with the decision on the more site detailed layout being made, designs for the individual building being made, and contractors being appointed to do the work. In an ideal world decisions will be made with the prediction horizon smoothly moving forward until the construction of the project is finished, and the system moves in to a management regime. Of course projects do not always go smoothly. When the contractors start digging the may uncover interesting archaeological remains. Then the designers and managers accept the delay and costs over-runs caused, or they may completely revise the design to incorporate the new and unexpected component in the design



(a) future trajectories fans out from the present

(b) The horizon moves forward with time

Figure 4. Predictions in complex socio-technical systems fan out and have horizons

The design and implementation of projects has been characterised here as selecting trajectories within an ever unfolding time horizon, where *prediction* involves hypothesising that certain future states are possible, and that taking a particular action will send the system to one of a set of particular future states. This is shown graphically in Figure 5, where the system is given an intervention 'kick' with the expectation (prediction) that it will end up at some target state. From a traditional scientific perspective this becomes a simple experiment that can be used to test the underlying theory: give the system the kick and see if the predicted state emerges, as shown in Figure 5.

Figure 5: Experiment as predicting that an intervention kicks will result in a future target state

Of course the reality is much more complicated than this. The kick that initiates the housing project may be taken in complete ignorance of events that will knock the system off trajectory. For example, the discovery of archaeological remains can completely knock a building project off trajectory, possibly killing the projects or requiring it to be replaced by another. Figure 6 illustrates a project that is continually being knocked of trajectory, by unexpected political decisions, unexpected financial problems, and even 'acts of God' such as a lightening strike.

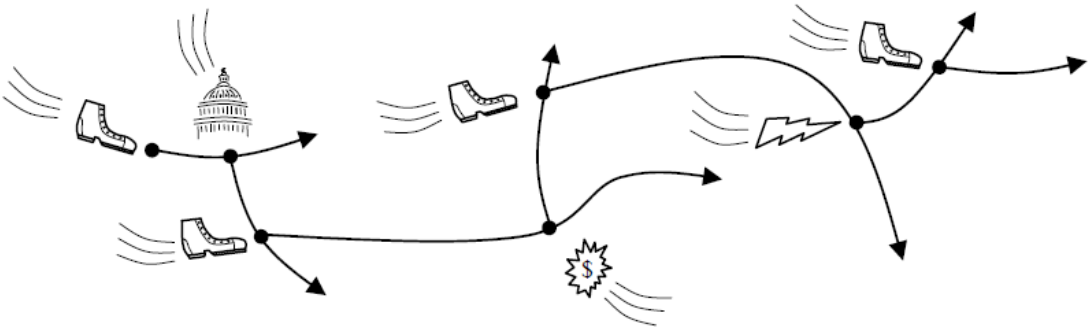


Figure 6. What does 'prediction' mean when the system is continually knocked of trajectory

In this context policy can be characterised as giving the system a kick in the hope that it will reach the target, but with the expectation that unpredictable events will knock it off trajectory before the system can reach the target. What does it mean to make a prediction when the final state that characterises the prediction will never be reached? How can predictions be tested when the target is hard to define in any meaningful way?

In Figure 6 perhaps the predictions can be tested to the point that the system is first knocked of trajectory by political decisions? After the second restorative kick, perhaps the prediction behind it can be tested at the point that finance knocks it off trajectory? And after the third restorative kick, perhaps the prediction can be tested at the point that lightening strikes?

Thus prediction in policy and design is more complicated than conventional experiments which can be both contrived and simple. This discussion suggests difficulties in what means to *test* a prediction? How can the 'correctness' of designs be tested statistically in this dynamic environment? Furthermore, what does it mean to make a prediction in a multilevel system? Does it mean predicting some particular system states at micro-, meso- or macro levels? Or does it mean predicting all system states at all levels, since in complex systems microlevel individuals can have massive effects at meso and macro levels.

For systems that are sensitive to initial conditions a single point prediction has almost no information. In general it is necessary to consider distributions of outcomes from the initial conditions. This suggests that statistical tests will have to be multilevel, and that there is a completely new approach to statistical analysis waiting to be discovered and developed.

6. The logic of science and the metalogic of policy

As a gross simplification[9] it will be supposed that policy making involves identifying something as desirable and taking an action to achieve it. The logic of this is that 'if we do A then B will be a desirable consequence', so we will make policy intervention A.

Complex systems science is based on well defined principles of logical argument established thousands of years ago. A central idea is that one can have propositions, and that these can be

[9] For the purpose of exposition the roles of policymakers and scientists are separated. Policymakers - elected politicians supported by their apolitical officers - are mandated by the electorate and have the moral authority to change society. Scientists do not. This is a clear distinction. Of course the reality is that many officers and scientists are political (possibly abusing their favoured position) and the nitty-gritty of policy is much more messy than suggested here.

true or false. Some propositions are empirical, and some are deduced from others *e.g.* the Aristotelian Darii syllogism gives a way of generating new propositions from existing knowledge: ‘all men are mortal’ and ‘Socrates is a man’, implies that ‘Socrates is mortal’.

The logical operators of conjunction (*and*) and disjunction (*or*) allow propositions to combined into larger propositions, *e.g.* ‘all men are mortal’ is a proposition and ‘Socrates is a man’ is a proposition, while ‘all men are mortal *and* Socrates is a man’ is a compound proposition which is true if both parts are true. Negation flips the *truth value* of a proposition, so that ‘this house is inhabited is true” when “this house is not inhabited is true”.

Entailment is at the heart of science, that something implies something else. For example, it is argued that ‘not reducing greenhouse gas emissions’ implies ‘the climate will change catastrophically’. One of the simplest rules of entailment is *modus pones* which has the form “if A implies B is true, and A is true then B is true’. For example, if ‘the switch is down’ then ‘the light will be on’ is true, and ‘the switch is turned down’, then ‘the light will be on’ is true.

In terms of policy *modus pones* can be applied as follows. ‘The theory tells us that A implies B is true’, we want B, we will take action to make A true. Then we will have “A implies B” is true and ‘A is true’ so that ‘B is true’. For example, suppose that theory tells us that ‘if the children are inoculated then they will not get the illness’ is true and that ‘they will not get the illness’ is a policy aim. Then the policy can be to inoculate the children to achieve the policy objective that ‘the children will not get the illness’ is true.

This example illustrates the different roles of the scientist and the policy maker. The scientist’s job is to provide theory that provides entailments relevant to the objectives of policy makers, such as ‘A implies B’. The policy maker’s job is decide whether B is desirable or not, and whether or not it is desirable to take action to induce A with the expectation that it will induce B.

One argument in this paper is that scientists generally do not have the moral authority to assert that either A or B are desirable, and generally they do not have the financial resource or moral authority to induce A. If a scientists wants to test the hypothesis that ‘A implies B’ they will have to convince the policy makers that ‘A implies B’ is true in the context of the policy makers judging that B is desirable and that it is desirable to induce A in order to induce B.

As the climate change example shows, scientists may not be successful in persuading politicians that ‘A implies B’, since putting in place A (consuming less energy, higher taxes, making payments to poor countries, etc) is such an unattractive policy option while B (catastrophic weather events, flooding, population movements, conflict, etc) seems unlikely or hard to imagine and so very far off (2050).

Thus we see that the logic of decision making is not the same as the logical process of science. Decision making is almost always conducted in vernacular language. The chains of entailment used by decision makers may not obey the same logical standards as science, and sometimes they seem perverse. This is because the propositions and entailments that policy makers use depend upon their values and belief systems. Politicians are not required to give logical justifications for their action – in democracies they are judged at the ballot box.

In logic, when a proposition refers to something, that something is considered to be at a ‘lower’ level and the proposition at a meta-level. For example, consider the statement that “women have fewer teeth than men”. Bertrand Russell[10] wrote “Aristotle maintained that women have fewer teeth than men; although he was twice married, it never occurred to him to verify this statement by examining his wives' mouths.” Russell’s statement is at a metalevel above the original statement because it is saying something about the statement.

[10] Bertrand Russell, Impact of Science on Society (1952)

Even if a scientist believes that they have immutable proof that 'A implies B' is true, a politician may choose to assert that for policy purposes 'A implies B' is false. In deciding the truth value of 'A implies B', the proposition 'A implies B' becomes an object in a meta-level discussion. Scientists would like this metalevel analysis to go as follows

"Eminent scientists have told us that 'A implies B' is true. Everything that eminent scientists tell us is true. Therefore 'A implies B' is true."

Of course this argument is flawed. Throughout history eminent scientists have been telling politicians things that are not true. For this reason the meta-proposition that 'Everything that eminent scientists tell us is true' is known to be false. At best scientists can hope for the meta-proposition that 'Some things that scientists tell us are true' or even 'most things that scientists tell us are true'. But the logic is that 'some things that scientists tell us are false' and that 'A implies B' may be one of them. Unfortunately the metalevel argument can also include "scientists themselves disagree about 'A implies B' so we will not use this as an assumption in our policymaking".

In any logical analysis, inconsistency is fatal. Inconsistency means that the assumptions made allow some proposition to be demonstrated as being both true and false, When this happens it is possible to show that any proposition in the system is true or false.

Politicians generally have core sets of beliefs that they are very unwilling to change. For example, if a politician believes that the death penalty is desirable, they cannot admit any set of assumptions that would lead to the conclusion that the death penalty is undesirable. For example, the proposition that miscarriages of justice may happen combined with the irreversibility of the death penalty convinces many people that the death penalty is undesirable in general. Despite this a politician might argue that although miscarriages of justice can happen, there has been no miscarriage of justice in a particular case and that in this case execution is desirable.

Administration and policy can be deeply normative, with the decision maker seeking an argument to support a conclusion that they think is desirable. Thus the conclusion of the argument is reverse engineered to find premises that will support it. This is exactly the opposite to science which works from premises (known facts) to conclusions. Science could be said to be based on a form of logical argument based on shared principles of inference and interpretation of data[11], while policy could be said to be based on *rhetoric* where arguments are formed to be the most persuasive.

Addressing the question of why we need rhetoric, an article in the Stanford Encyclopaedia of Philosophy[12] on Aristotle's Rhetoric suggests the following:

> It could still be objected that rhetoric is only useful for those who want to outwit their audience and conceal their real aims, since someone who just wants to communicate the truth could be straightforward and would not need rhetorical tools. This, however, is not Aristotle's point of view: Even those who just try to establish what is just and true need the help of rhetoric when they are faced with a public audience. Aristotle tells us that it is impossible to teach such an audience, even if the speaker had the most exact knowledge of the subject. Obviously he thinks that the audience of a public speech consists of ordinary people who are not able to follow an exact proof based on the principles of a science. Further, such an audience can easily be

[11] Clair O'Farrell writes "A scientific practice, in Foucault's account, is a particular set of codified relations between a precisely constructed knower and a precisely constructed object, with strict rules which govern the formation of concepts. Foucault was interested in science for a number of reasons. One of these was that 'science' had set itself up as the ultimate form of rational thought. With the Enlightenment, scientific reason became the privileged way of accessing truth. According to this view for knowledge to acquire value as 'truth', it had to constantly strive to become 'scientific', to construct and organize concepts according to certain rigorous criteria of scientificity. Foucault argues that scientific knowledge is not inherently 'superior' or more 'true' than other forms of knowledge." (http://www.michel-foucault.com/concepts/index.html 2007). The argument given here does not imply that science is the only form of knowledge. Even within science as defined here there are alternative descriptions of systems. However it will be later suggested that all descriptions and forms of knowledge may be unified at an appropriate metalevel.

[12] http://plato.stanford.edu/entries/aristotle-rhetoric/, viewed 19th March 2010.

> distracted by factors that do not pertain to the subject at all; sometimes they are receptive to flattery or just try to increase their own advantage. And this situation becomes even worse if the constitution, the laws, and the rhetorical habits in a city are bad. Finally, most of the topics that are usually discussed in public speeches do not allow of exact knowledge, but leave room for doubt; especially in such cases it is important that the speaker seems to be a credible person and that the audience is in a sympathetic mood. For all those reasons, affecting the decisions of juries and assemblies is a matter of persuasiveness, not of knowledge. It is true that some people manage to be persuasive either at random or by habit, but it is rhetoric that gives us a method to discover all means of persuasion on any topic whatsoever.

But it is not just policy makers who are faced with a public audience. For scientists the policy makers are also a public audience not able to follow an exact proof based on the principles of science. To persuade a policy maker that the scientific fact that 'A implies B' may require rhetoric rather than science. Thus complex systems scientists may need to use rhetoric at the metalevel in order to persuade the policy maker to do experiments that contribute to science.

Since complex systems science is entangled with policy, the science is incomplete without a theory of the dynamics of policy and how decisions are made. For example, the science of climate change is incomplete without a theory of how scientists and politicians can work together to design and implement policies that can lead to desirable futures. The failure in Copenhagen in 2009 suggests that such a theory does not exist. This is a challenge for complex systems science.

In the field Artificial Intelligence there has been much interest in automated proof and there are systems that can accept sets of propositions and generate their logical consequences. There is interest in applying such systems in law to determine the validity of arguments that are made in court. It is possible that the distinction between formal logic and rhetoric may be clarified using such systems, and this may help to better understand metalevel reasoning.

7. The future of the humanities and social sciences in the science of complex systems

The main argument in this paper is that humanities and the social sciences will merge with the science of complex systems, synthesised into a science that does not have the traditional 'two cultures' divide. This will not be a comfortable process but already the movement can be seen. Many social scientists are already embracing complex systems science and enriching. *e.g.* (Urry, 2005). Complex systems scientists increasingly appreciate that all human activity is spatially referenced, and the methods of geography and demography are increasingly adopted by complex systems scientists, including the use of digital maps within Geographical Information Systems, and an understanding that population data is different the kind of data traditionally collected in the physical sciences. Cities can now be considered as exemplars of complex systems[13], including transportation and settlement patterns such as the emergence of ghettos (Schelling, 1971).

While the humanities and social sciences give deep insights into the complex world that we try to design, plan and manage, the many failures of policy show that they are at best incomplete sources of knowledge for understanding the future[14]. The science of complex systems has its roots in the natural, physical and engineering sciences, with strong connections to mathematics, physics, biology and computer science. These scientists readily accept the relevance of the domains of psychology, sociology, political science, geography, history, but they do not easily understand their method of data collection and synthesising what is known into theory. The methods of complex systems science bring new ways of looking across these domains, and there is a debate to be had with the specialists in those domains on the most appropriate ways to investigate them. This debate takes place in the

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[13] http://www.assystcomplexity.eu/video.jsp?video=55 *Evolution, cities and planning*, Plenary talk by Michael Batty, European Conference on Complex Systems, ECCS'09, University of Warwick, Sept 2009.

[14] It could be argued that policy failures are inevitable because we may never understand the future due the nature of prediction as performative or constituitive. This may be so, but need not be conceded until the idea of metelevel resolution as proposed in this paper has been reufuted.

context of a lack of scientific knowledge on how to understand, design, plan and manage systems of systems of systems, which remains a challenge to all disciplines.

The social and physical sciences share the experience that a system may change its behaviour when observed. This is perplexing in quantum physics but obvious in social systems, *e.g.* if an adult observes children playing the behaviour may be different to what it would have been if the adult were not there. At the macrolevel physical systems are more tolerant to being observed, and physical scientists assume an objectivity about their observations which is not always the case in social systems. For example, at the mesolevel the 'Hawthorn' effect, that a social system may improve its performance just by being observed[15], is well known in management science. The effect of observation at the macrolevel in social systems is illustrated by Governments restricting the activities of foreign journalists. Thus the instruments for data collection in social systems have difficulties not experienced by many coming from the physical sciences. For this reason anthropology and ethnography are being embraced in complex systems science.

Surprisingly some scientists believe that art can contribute nothing to science, *e.g.* in a recent radio programme[16] the eminent biologist Lewis Wolpert proclaimed with great certainty that "art has contributed zero to science historically. … There are all sorts of images from science that can give artists something to work on, but it does not go the other way. … The artist couldn't tell us a thing in that particular area". Many would disagree with this.

In the same radio programme Christopher Frayling gave a counter-example from the natural sciences: "Fred Hoyle, [was] beginning to work in Cambridge in the late forties, on his theory of a cyclical cosmology that things don't move in a linear way, they move in circles. He goes to see a film in nineteen forty eight made by Ealing Studios called Dead of Night. Dead of Night begins with someone pulling up at a country house – it ends with the same scene of someone pulling up at a country house. In between all sorts of things have happened but the entire movie is cyclical. It ends where it begins. It begins where it ends. And he went home and wrote in his diary 'My God! It's a cosmology. Maybe there's something in this cyclical cosmology.' The art had reinforced the idea in Fred Hoyle's mind and off we go with Hoyle's cosmology of the fifties." Frayling's example concerns art as *inspiration* for science.

Art can play a more direct role in science, as illustrated by the work on organisations by Mitleton-Kelly (2003): "During the analysis our resident artist, Julian Burton, will capture some of the themes, dilemmas and underlying assumptions in a picture. This has several advantages: many related aspects that are difficult to think about at the same time, can be captured in one picture; and very sensitive issues that are difficult to talk about, can be presented diagrammatically to workshop participants, before the presentation begins. Once they recognise what is being shown they may laugh and thus break the tension and open the issue(s) to discussion."

One such drawing shows a tower block with cracks running through it, people on the top spinning plates. The impression is that this organisation is in danger of falling to pieces while everyone is over-busy attending to immediate tasks. In the terminology of knowledge engineering, this use of art is a means of *knowledge elicitation*. The implications are (i) that art can capture information that cannot be captured in other ways, such as tape recording, interview notes, or a questionnaire, (ii) that art can be used in a dialogue that elicits information in other ways, including subjects confirming or correcting the interpretation of previous interviews, (iii) that the work of art can be a way of enabling subjects to see their social situation in new and otherwise threatening ways, and that (iv) that the work of art can be part of a social dynamic, enabling subjects to interact better with the social scientist and therefore being willing to provide information that they might otherwise withhold. In this case art becomes part of a scientific *instrument*, and is part of the scientific process.

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[15] http://en.wikipedia.org/wiki/Hawthorne_effect

[16] http://www.bbc.co.uk/radio4/science/thenewtwocultures.shtml Mark Lythgo, *The New Two Cultures*, BBC Radio 4, 25/4/2007.

Contemporary art is oriented more towards exploration than traditional aesthetic. As such it provides a means of exploring the search space of possible worlds. We have asserted that policy makers and scientists design the future, creating and predicting the behaviour of new systems that have never existing before. Art can be viewed as the blue sky research laboratory of design, and therefore of science and policy. Art gives glimpses of the unknown unknowns.

The “dismal” social science of economics is in the process of being revolutionised by concepts from complex systems science. The premises of conventional economics include indefensible notions of equilibrium that are particularly inappropriate for the multilevel dynamics of economies and financial systems. Complex systems science is already providing new ways of modelling economic systems through agent based simulation and game theory. In his article on ‘Meltdown Modelling’ Buchannan (2009) writes “At Yale University, for example, economist John Geanakoplos, working with physicists Doyne Farmer of the Santa Fe Institute and Stefan Thurner of the Medical University of Vienna, has constructed an agent-based model exploring the systemic consequences of massive borrowing by hedge funds to finance their investments. In their simulations, the funds frequently get locked into a self-amplifying spiral of losses … much as realworld hedge funds did after August 2007.”

In sociology and political science the values of the scientist may be reflected in the premises of their arguments, with some social scientists adopting overtly political positions. In this respect there may be a spectrum between the logical-analytic and the rhetorical that can inform the essential science-policy duality suggested here.

8. Conclusions

Complex social and socio-technical systems have been characterised by various properties that make them intractable to both the conventional physical and social sciences. The main reasons for this are that (i) the macroscopic dynamic behaviour of systems emerges bottom-up from the dynamic interactions of autonomous individuals at microlevels, where this is constrained top-down by emergent macrolevel properties, and (ii) the dynamics at all levels are be sensitive to initial conditions so that unavoidable errors in measurement ensure that the predicted trajectories will diverge from those observed, and there is a horizon beyond which point-predictions have almost no information.

The approach of the science of complex systems to modelling the dynamics of social systems includes the use of computer simulation as its main tool. The theory underlying simulation must be an eclectic synthesis of knowledge from traditional social and physical science, augmented by the spectacular new data sources now available through telecommunications, powerful networked computation, and human interaction through the Internet.

The traditional physical science concept of prediction is almost irrelevant in the science of complex systems. Point predictions that a system will be in a particular state at a particular point in time convey little information when systems are sensitive to initial conditions. Complex systems science seeks a new understanding of prediction, including new theories of stochastic dynamics and path-dependent dynamics. It is argued that scientific theories of large complex systems can only be tested through policy and its application through design, implementation and management. In this context prediction is complicated by the final results of interventions (experiments) will rarely being seen due to the trajectory of executing the plan always being disturbed by unexpected events. This requires a new formulation of the concept of prediction, possibly with new statistical procedures for testing predictions.

The main argument of this paper is that the emerging science of complex systems will embrace the humanities and conventional social sciences in the same way that it has embraced concepts from the natural sciences. This will involve a synthesis of knowledge from the different scientific traditions, and a synthesis of those traditions into a new science applicable at all metalevels of human affairs.

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