COMPLEXITY IN SOCIO-ECONOMIC SYSTEMS

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Summary

In socio-economic systems complexity is a natural outcome of the freedom of agents to change their behavior. Because these decisions are governed by the subjective experiences of each agent, then agents cannot know what the other agents will decide, and hence will experience interactions and events that they are unable to predict. This may involve the spontaneous appearance of collective structure with emergent global properties and functionalities. These emergent structures then condition the learning experiences of different individuals, as they evolve and change over time. Instead of a clockwork system simply running forwards until it unwinds, the very dimensions of interaction with the outside world can change, new attributes and functionalities can emerge, and the nature and experiences of its constituent components can transform over time. Creativity, innovation and emergence characterize the real, open, non-linear systems that make up our world. It is the new paradigm of co-evolving complex systems, and it implies, accepts and embraces

the reality of qualitative and quantitative changes over time. This situation is often seen in purely negative terms, as introducing inevitable "uncertainty" (as if this did not exist before), and perhaps meaning that we should not have any long term goals and ambitions. In reality, however, this is a much more exciting world than the one related to mechanical motion.

This paper defines and describes the differences between the old mechanical and equilibrium views of the world, and the new one involving self-organization and co-evolution. It sets out the precise mathematical assumptions that are involved in reducing reality to a mechanical model, and shows the consequences of not making these assumptions. The behaviors of self-organizing and co-evolutionary models are described, and some conclusions are drawn about the mechanisms that are necessary for adaptability and learning. These models have a different aim from those used operationally in many domains. Instead of being detailed descriptions of existing systems they are more concerned with exploring possible futures, and the qualitative nature of these. The reality of complexity within socio-economic systems means that we are concerned not with being but with becoming.

1. Introduction

Today we know that we live in a complex world of emergent behavior and attributes, in which our powers of prediction are limited. This contrasts with the "classical" views that implicitly supposed a mechanical universe, in which knowledge of the laws of interaction would allow us to predict, and to intervene in the world to achieve our ends. Prediction had three basic pillars. First, it could be based on the movement of a frictionless mechanical system along a predefined trajectory as for planetary motion. Secondly, for situations with dissipative forces present the prediction could be modified by adding experimentally determined terms concerning viscosity or friction. Thirdly, for systems with dissipative forces present a prediction could be made about the "final" state of the system as it moved to the predictable state of thermodynamic equilibrium. So, in effect we could predict the behavior of clockwork systems, either running or run-down.

But, with the study of non-linear systems, open to flows of energy, matter and information with their environments, this simple, psychologically comforting myth was exploded. Systems in the real world, on which the sun shines and where structures and differences abound, can respond to their environment in different possible ways. Their configuration and structure can transform itself, resulting in emergent global properties and functionality, and in addition their internal elements can evolve and change over time. Instead of a clockwork system simply running forwards until it unwinds, the very dimensions of interaction with the outside world can change, new attributes and functionalities can emerge, and the nature and experiences of its constituent components can transform over time. Creativity, innovation and emergence characterize the real, open, non-linear systems that make up our world. It is the new paradigm of co-evolving complex systems, and it implies, accepts and embraces the reality of qualitative and quantitative changes over time. In reality this is a much more exciting world than the one related to mechanical motion. But despite this it is often seen in purely negative terms, as introducing inevitable "uncertainty" (as if this did not exist before), and perhaps meaning that we should not have any long term goals and ambitions.

In fact the opposite is the case: *it is because systems can evolve and transform themselves that we can have hopes and dreams of better things*. Obviously, change can also bring worse things, and our aim must be to try to understand the "trade-offs" that different actions, strategies or policies may involve. Without such an attempt, or by continuing to adhere to the inadequate ideas of mechanical thinking, we are left with essentially unexpected emergent structural changes, with qualities and trade-offs that are essentially random. Of course, evolutionary principles ensure that the adoption of random innovations by individuals lead to evolutionary changes in the overall system that tend to increase its entropy production, which may have no obvious benefits for the humans contained within it.

Clearly, if we knew that unguided evolution would inevitably lead to an attractive solution, then we could possibly relax, but history suggests that this is not the case, and therefore that our choices, actions, strategies and policies do really matter. Individuals have intentions and preferences as they go about their business, and hence would like to relate their decision making to the outcomes they will experience. Because of this people are attracted by the possibility of prediction, and are disturbed by the idea that it may not be as simple as their decision support software, or management consultant tells them. We might see the acceptance of the co-evolutionary, complex systems view, with its accompanying acceptance of a level of uncertainty, as being a first sign of adulthood coming upon a reluctant world. The answer will be neither that of "full prediction" nor that of "no prediction", not "total control" nor "totally out of control". As most people have secretly suspected, the answer lies somewhere in between. And now science is coming to this conclusion too.

2. Socio-Economic Systems and Complexity

2.1. Freedom and Choices

Complex systems are systems that can respond in more than one way to their environment, which means that there is some internal freedom, and some measure of autonomy within them. This autonomy leads to an important difference between the old classical scientific approach and that which is relevant to socio-economic systems. In classical science, the aim was to seek for the unchanging laws of nature that governed events. Knowing these laws did not change the laws themselves, nor the behavior of the objects described by them. People could use this knowledge, however, to change their own behavior, tools, organizations and so on through science and technology to change their surroundings according to their desires. On the contrary, however, any laws or rules of behavior that are discovered in the socio-economic realm will lead to changes in behavior of those "knowing" that will in turn "decrease" the validity of those laws. The laws of socio-economic systems are really about the responses of agents and actors to the situation that they perceive, and this is produced by their beliefs about it. In social phenomena firm knowledge would still be limited to the physical laws involved in the situation. Other "knowledge" about how people may respond will all be subjective, and in fact correspond to "beliefs" about what will happen based on the experiences of the individual concerned. Once we "observe" that people respond to a piece of news in a certain way then we may adopt this as our belief about "causality" in the situation. However, in reality, this "knowledge" will prove to be only of temporary value, since as further news comes in, people will not necessarily react in the same way, since their experiences will lead them to anticipate the response, and change their behavior.

In human systems "knowledge" is a spur to action, and the actions make the "knowledge" obsolete. Indeed much "knowledge" is actively sought with a view to action, and the action and the responses that it can provoke mean that the world is changed in ways that our previous "knowledge" does not know! This is quite different from a scientific endeavor to discover the "laws of nature" in which the laws, once discovered, are not changed. Of course, there may be theoretical developments as further experiments continue, but the new laws must always encompass and confirm the old ones, but be extended into new regions.

This allows us to understand why complexity is important in understanding and dealing with socio-economic systems, though relatively unimportant in understanding planetary motion. Socio-economic systems are driven by the actions and decisions arising from the interacting subjectivities of individuals and groups. These individuals and organizations strive for knowledge to guide their actions, and equipped with some local perspective, change their behavior and responses accordingly. This affects other individuals and organizations as well as the physical structure and patterns of flow in the system, and there is therefore a response to this changed situation, according to the perceptions those affected, thereby altering the basis of the knowledge of the initial agents. In socio-economic systems then, we could only formulate a mechanical basis for decision making providing we knew fully the future plans and decisions of every single agent in the present and future system (and indeed how we may choose to change the boundaries of the "system" itself). Since this is clearly impossible, our actions must always be taken on the basis of incomplete representations and imperfect knowledge. This may sound like bad news, but in reality, it is what makes us "free" and what makes life worth living. It also brings in the science of complexity, since this deals with situations in which multiple agents and organizations of agents interact, but have internal freedom concerning their aims and ethics, their understanding of the options available, and their option evaluating process that eventually leads to actions. The whole system is replete with uncertainty.

The acceptance of the new ideas allows us to reflect on our social organizations and our economic and political institutions and reassess them in the light of these new ideas. In particular, the issues of intentionality and of the relation between the individual and society have always been thorny ones. We normally accept that individuals try to achieve their ends but that society should be concerned mainly with helping them do that. This would naturally see an evolutionary process as being the simple, value-free outcome of individual strivings at a lower level. Yet clearly, there are asymmetries of initial endowments, of power, of information, of relationships, as well as of inherent capacities, and therefore the particular social system does affect outcomes. The "winners" are not simply inherently superior. The outcome is affected by luck and by their precise location and path within the social system. Less controversially, we can consider the question of competing firms within an economic market. The intention of each firm may be to make profits and to grow, but only some will succeed in doing so. The strategies, decisions and product designs of each company will turn out to have either successful or unsuccessful pathways, and the question that we need to address is whether a company can "know" enough to do better than random. It is like buying a stock on the equity markets with the intention of making money. Can we do better than a random choice? Our intention is to do so, but what knowledge can we have that could make it so? Particularly as all the other investors are also trying to achieve similar ends. We immediately see the paradox. If markets are efficient, there can be no privileged individual knowledge, and a random choice among them would be justified. Yet a vast industry of financial management exists and on the whole most of us would prefer to consign our life savings to an established company rather than to a series of dice throws.

Of course, even a financial market consisting of actors that assign money randomly to different stocks would still exhibit a sensible evolution over time, since the companies that received investment and also had viable products and organization would survive while those that lacked one or both of these would not. And this is interesting because it shows us that with or without intention at the individual level, an evolutionary process can still occur, and produce a seemingly "rational" result. The question really is whether the intentions of individuals can successfully beat the "random" strategy or not. Of course, we also have the problem that sometimes, just by luck, a random strategy will do really well – better than average, and so we shall also have to decide on what will be meant by "doing better than".

2.2. Knowledge and Uncertainty

Knowledge is not what we thought it was. Knowledge about the socio-economic parts of systems (not necessarily the physical) is about the interpretive frameworks that emerge within individuals and organizations and lead them to respond and to act in the way that they do. Their actions however, change the system, and later lead to changes in the interpretive frameworks as a complex, multi-level co-evolutionary process of "inside" with "outside". We are just participants, sometimes "doing" and sometimes "done to" in a complex, co-evolutionary system with multiple spatial and temporal scales of interaction, where learning and transformation are occurring, reflecting the fundamentally irreversible nature of the universe. Our predicaments result from the co-evolution of the multi-level complex systems of which we are part, and these are expressions of the Second Law of Thermodynamics, which says that today is not necessarily like yesterday, and tomorrow will not necessarily be like today.

The paradox of greater knowledge leading to greater uncertainty really results from the limitation of the traditional scientific view of the world as a mechanical system, rather than an evolutionary one. It is based on the misconception that all systems, even social and economic ones, can be broken down into interacting, stable components, whose coupled working can be completely understood. The effort required to make humans appear to conform to this mechanical image led to assumptions of "rationality" and of "Homo Economicus", which were artificial constructs designed to have a predictable (mechanical) response in a given set of circumstances. These ideas have permeated much of society with the evolution of mass production, in which production work was broken down into a series of functional steps, so that the factory (and the unfortunate people in it) could be like a production machine. In this way human work and labor was reduced to a set of mechanical operations, which then lent themselves to easy replacement - initially by machines and later by computers. This is now extending from production lines into fields such as education, banking, customer services of all kinds, as the interaction between client and worker is reduced to a "tick-box" set of steps, a pre-ordained set of pathways, which can only cater for a world with pre-defined possibilities.

But this is inadequate, as the world will always find ways of going beyond any set of pre-determined possibilities. Our societies are changing, and with it the categories and typologies on which any such rigid system is based. Technology is changing, needs are changing, and people’s values are changing. The traditional "engineering" approach to a problem or a constraint has always been produce a piece of technology, a mechanism or structure, which could "better" turn the inputs into outputs according to the local "cost/benefit" criteria. But the very success and growth of these technological solutions changes the context in which they exist: both from the input side - the raw materials and production structures that are required, and the output side, meaning the impacts on society and on the biosphere.

The institutional structures of society, particularly with their present heavy emphasis on economic variables and short-term profit, mean that the failure to foresee the limits of technology and the growth of environmental and social problems was almost inevitable. This myopia stems from the traditional philosophy of science since the enlightenment, rooted in Newtonian concepts, that saw mechanics as the key to understanding. In this reductionist view, improving (according to local criteria) the "separate pieces" of something would necessarily make the whole perform better. But if we really inhabit a Complex System in which each part, and indeed different levels of structure and organization are coupled together and co-evolve, we need a new vision and understanding on which to base our policies and decisions. We need to see ourselves as inhabiting a nested set of co-evolved, hierarchical structures linking, through intermediate levels of organization, the biosphere to the atoms and molecules at a particular place. In reality, the climate, the ocean currents, the landscapes, the settlement patterns, the cities, firms and each individual are all linked, in a complex web of interaction, some apparently stable and some evolving. Since our actions affect this system in ways that we cannot know, then knowledge, such as it is, is necessarily ephemeral, and what we need is to keep generating new knowledge and questioning old. Physics triumphed when dealing with planetary motion for reasonable times, the trajectories of cannonballs or in understanding and anticipating electromagnetic radiation. But, its extension into the realms of human transactions and behavior has been singularly unsuccessful. Today, we must try to develop a more useful approach based on an acceptance and understanding of the ideas underlying Complex Systems.

3. Complexity and Simplicity

In order to bring greater understanding to the socio-economic systems that we inhabit, we need to bring the insights coming from the new science of complexity. But what are these? We know that a mechanical system is not complex because its parts move according to a trajectory given for all time if we know the interactions between the components. The cog’s don’t learn, or get bored, or rebel. They just run. Socio-economic systems however, are full of learning, nobility, deceit, intention, emotion and so on and they do not just run. In order to understand the basis on which such things can occur, we need to understand precisely how a mechanical description differs from reality. And this is deeply rooted in our need to simplify situations, and to reduce them to manageable numbers of elements, with characteristic behaviors.

Understanding "reality", creating apparent "knowledge", requires us to reduce the real complexity of any particular situation to a simpler, more understandable one, by making specific simplifying *assumptions.* When facing a situation the hope is that there exists a representation that, while being sufficiently simple to be understood, remains sufficiently "realistic" to be useful. Of course, it is not at all certain that such a representation exists, but in our struggle to survive, we cling to the hope that it does. Gaining useful knowledge requires that we know what simplifications can be made and which are a step too far. In other words, we need to construct an interpretive framework through which to make sense of what is going on, and this framework is not given *a priori*, but is something that we must construct and adapt over time. For example, it may be convenient to assume that we are in a stable environment, and what is happening is only due to the interaction of certain types of people, who act entirely according to their assigned roles. From this we may make predictions, and adjust our actions accordingly. Of course, we may also simply rely on "trial and error" to teach us practical heuristics. Ordinary wisdom will often be of this kind, and in an unchanging world this may be adequate. However, if the world is changing, then how can we gain knowledge to help decide what to do? What simplifications can we still make?

In order to understand what precisely is the "difference" between a complex system and a mechanical system, and how complex systems obtain their freedom to evolve and change, we need to specify exactly the assumptions that are necessary in order to represent some piece of reality as a mechanical system. If we make this explicit, then we shall identify at the same time the source of the "vitality" of a complex system, with its creative, co-evolutionary behavior.

3.1. Four Steps to Reduce Complexity to Simplicity

What are these steps?

1. Define a boundary between the part of the world that we want to "understand" and the rest. In other words, we assume first that there is a "System" and an "Environment", and that we can understand the workings of the system on the basis its components, working in the context of the environment. For this to be useful we would also assume either that the environment was fixed or how it would change. Since the boundary chosen directly affects the "knowledge" that emerges, these steps should be considered as "exploratory" and subject to revision and repetition as we try to discover the structures that we inhabit and affect, and whether the resulting perspectives are helpful or not.

2. We have rules for the classification of objects that lead to a relevant taxonomy for the system components, which will enable us to understand what is going on. This is often decided entirely intuitively. In fact we should always begin by performing some qualitative research to try to establish the main features that are important, and then keep returning to the question following the comparison of our understanding of a system with what is seen to happen in reality.

3. The third step concerns the level of description *below* the level of classification (the components) we have chosen to describe the situation. We assume "homogeneity" inside our components, or at least an average composition, with some normal distribution around it. In this way the real micro-diversity *inside* the components is eliminated, and as a result any "evolutionary" or "learning" effect is neglected since the components cannot adapt or change their behavior without selective forces operating on an underlying micro-diversity.

We create a "stereotype" based simplification of reality, whose "typology" of functioning remains fixed and does not evolve. When we make this simplifying assumption, although we create a simpler representation, we lose the capacity for our model to "represent" evolution and learning within the system.

4. We describe the overall behavior of the variables as the statistically smoothed *average rates* of individual interaction events. So, for example, the output rate for a group of employees in a business would be characterized by their average output rate. This assumption (which will never be entirely true) eliminates the effects of "luck" and of randomness and noise that are really in the system.

The mathematical representation that results from making all four of these steps is that of a *mechanical system* that appears to "predict" the future of the system perfectly.

A fifth assumption that is often made in building models to deal with "reality" is that of stability or equilibrium. It is assumed in classical and neo-classical economics for example, that markets move rapidly to equilibrium, so that *fixed relationships* can be assumed between the different variables of the system. The equations characterizing such systems are therefore "simultaneous", where the value of each variable is expressed as a function of the values of the others. Traditionally then, "simple" equilibrium models like this have been used to try to describe economic markets. Although these can be useful at times, today, with much greater computing power available, we are no longer so forced to only look for analytical solutions to problems, but we can also run models that demonstrate complex behavior and provide new insights into the social reality that we inhabit. This means that we can set about understanding the behavior of people, and of social systems using evolutionary and dynamic models that do not "reduce" complexity to the simplicity of a mechanical system. Instead, we can study adaptive evolutionary systems, with interacting, learning agents and actors, that transform themselves and the system over time.

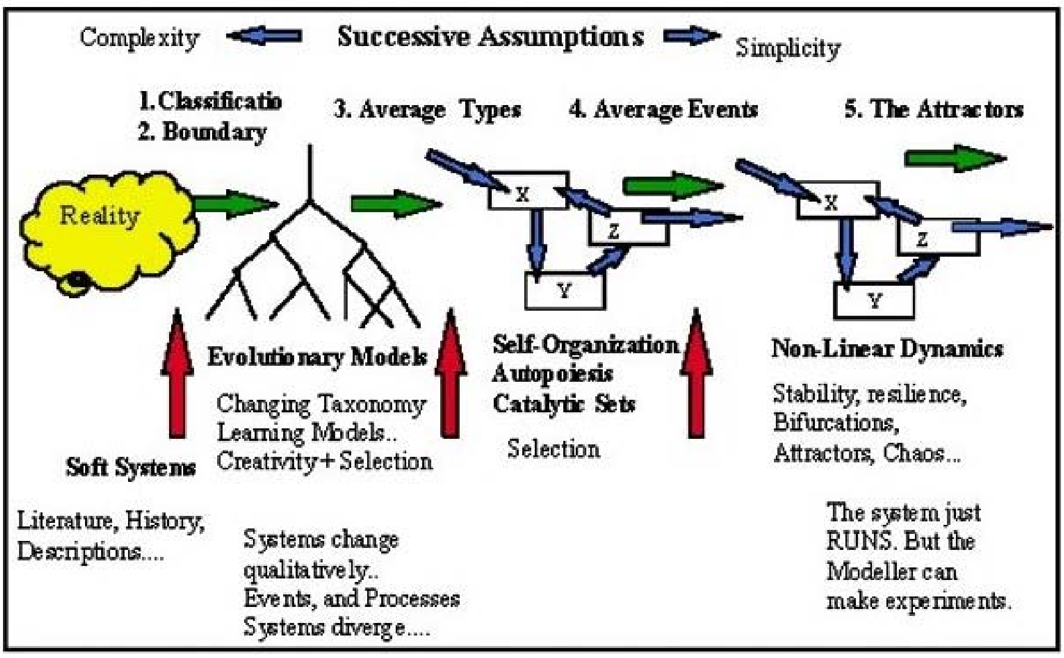

Figure 1: The steps taken in reducing the real complexity of a situation to a simplified mechanical representation.

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Bibliography

Allen P.M. and McGlade J.M., 1987, "Evolutionary Drive: The Effect of Microscopic Diversity, Error Making and Noise", *Foundations of Physics*, Vol.17, No.7, July. Pp.723-728 [The original statement of the "Evolutionary Drive" idea]

Allen P.M., 1988 "Evolution: Why the Whole is greater than the sum of its parts", in *Ecodynamics*, Eds Wolff, Soeder & Drepper Springer Verlag, Berlin. [Original article where the difference between mechanical and complex systems was presented]

Allen P.M. 1997, *Cities and Regions as Self-Organizing Systems: Models of Complexity*, Gordon and Breach, Reading, UK. [A summary of all my urban and regional work that developed and used the ideas]

Nicolis G and Prigogine I. 1977, *Self-Organization in Non-Equilibrium Systems*, Wiley Interscience, New York. [The original book that laid out much of the foundations of what would become complex systems thinking]

Prigogine I. 1980, *From Being to Becoming*, Freeman, New York. [One of the most important statements of the century]

Biographical Sketch

Professor **Peter M. Allen** is Head of the Complex Systems Management Centre in the School of Management at Cranfield University. He is the o-coordinator of NEXSUS, the ESRC Priority Network in Complex and Dynamic Processes. His research is directed at better understanding and dealing with change in complex systems. He has a Ph.D. in Theoretical Physics, was a Royal Society European Research Fellow 1970-71 and a Senior Research Fellow at the Université Libre de Bruxelles from 1972-1987, where he worked on self-organizing systems with the Nobel Laureate, Ilya Prigogine. Since 1987 he has been at Cranfield University. For almost 20 years Professor Allen has been working on the mathematical modelling of change and innovation in social, economic, financial and ecological systems, and the development of integrated systems models linking the physical, ecological and socio-economic aspects of complex systems as a basis for improved decision support systems. A range of dynamic integrated models has been developed in such diverse domains as industrial networks, supply chains, river catchments, urban and regional development, fisheries and also economic and financial markets. Professor Allen has written and edited several books and published well over 150 articles in a range of fields including ecology, social science, urban and regional science, economics, systems theory, and physics. He has been a consultant to the Canadian Fishing Industry, to Elf Aquitaine, to the United Nations University, the European Commission and the Asian Development Bank. He has managed a number of large European and UK research contracts.