The Complexity Revolution

By Greg Fisher

"I think the next century will be the century of complexity."
Professor Stephen Hawking, 23 January 2000.

This is an essay about a revolution in academia, catalysed by the new science of complex systems. To date, the revolution has mostly been limited to the natural sciences; however a few concepts have crept in to our vocabulary, including *tipping points* and *black swan events*, which can be traced back to *complexity science*. This essay tries to describe and explain the revolution behind these terms.

What is complexity science?

Consider a glass of water containing lots of water molecules. In order to understand the properties of the water, academics have until fairly recently had to think about – and model – the water as a single object. They lacked the capability to treat the water as a large number of individual molecules, each bumping into each other. This matters to scientists because many of the properties of water, including "wetness", result from the nature of individual molecules and how they interact. Conventional mathematical techniques are unable to handle the amount of information required to model each individual molecule, and how they interact with each other.

Computer technology changed all of that. With a computer, academics can write a programme in which each individual water molecule is modelled separately; and also how each molecule interacts with others. Our glass or water becomes trillions of individual parts, rather than a single object. At first blush, this does not appear to matter very much; however, academics only began to understand the significance of this new approach after they started to use it. Although it is not intuitively obvious, the change is revolutionary.

There are a huge number of equivalent "systems" in nature, made up of large numbers of constituent parts interacting in some way. The most obvious examples are collections of organisms such as a swarm of bees, or a colony of ants. A complex systems approach helps us to understand the behaviour of the larger group by studying the constituent parts and how they interact. The same is true of our own social systems.

Complexity science emerged in the 1970s after the invention of the microprocessor: computer power suddenly increased (and costs fell dramatically). This allowed academics to switch from using conventional mathematical techniques, which are quite limited when it comes to large, complicated systems; to using computer simulations.

For the purposes of this essay I will define a complex system as *a system containing a large number of constituent parts, all with potentially different characteristics, and each part interacting with others in particular ways*. Using this definition, we can view society is a type of complex system.

So What?

The above description makes complexity science sound like something only for academics to get excited about. In fact, it has profound implications for everybody. It has demonstrated many things that previously we didn't know that we didn't know. It has also made us realise that our own societies, as well as the universe more broadly, are even more complex than we had previously thought.

A complex system, such as human society, is less predictable and less controllable than we have been led to believe by academics and policy makers. It is prone to more extreme events that seem to come from nowhere (e.g. the fall of the Berlin Wall), than is often appreciated (cf Nassim Taleb's *The Black Swan*). Events can occur for seemingly inexplicable reasons, and often our way of rationalizing them is more inaccurate than we would like to think. As individuals this ought to lead us to be more humble, and to accept that the future is far less certain than we would prefer.

If these comments chime with the current economic and financial crises, that is because these extreme events, which were largely unanticipated, reflect society as a complex system.

There are many new and interesting concepts to have matured in complexity science. The most interesting and important is that of *emergence*.

Emergence

In the early days of computer simulations, natural scientists found that if they modelled individual "agents" (constituents of a system) by representing each with a set of algorithms, and then allowed lots of agents to interact freely with others, unexpected patterns began to emerge. After identifying these patterns, which were subsequently labelled *emergent phenomena*, scientists found they were unable to explain their existence by analysing the individual parts of the system. They were left with this perplexing question: if the individual agents (over which the academics had full control) were not programmed to create an observed pattern, how could it possibly have arisen?

This is an important question for academics because Western academia is designed around the idea that "the whole is the sum of the parts" (a concept known as *reductionism*). Academia is divided and sub-divided in to specialised fields in order to analyse parts of the universe, the biosphere, human society, etc. The proportion of academics devoted to understanding multiple subjects, or "the whole", is relatively small. Emergence suggests that Western academia may therefore be over-specialised.

We can look at emergence from two perspectives. Firstly, from the local to the macro level. Most importantly, we cannot be sure what the macro implications of some local action are. A butterfly flapping its wings in the Warwickshire countryside may or may not set off a chain of events that lead to a hurricane in London. This means that there is much greater uncertainty about the broad effects of some localised action in a complex system than we typically believe.

The second perspective is from the macro to the local level. If some macro event occurs e.g. a financial crisis, how might it have arisen? We often look for explanations that map easily on to the macro phenomenon e.g. in the case of the financial crisis, it was because of greedy bankers, or it was because central banks kept interest rates too low for too long. These, and similar explanations, may well have some explanatory power, however, emergence suggests we may never truly know why a macro event occurs; it may be genuinely novel. There is another lesson here: when it comes to explaining system-wide events across complex systems, we ought to be more humble in believing we have the right explanation.

For a more thorough discussion about new concepts from complexity science, including global cascades, and non-linear change, a separate note is available. See www.gregfisher.me.uk/complexity.

Complexity & Human Cognition

A few great minds in human history, such as Friedrich von Hayek, have made references to complexity (as we understand it today) and emergence. But it is only relatively recently that we have had the technology to understand and explore the concept more formally.

This new understanding appears to have given way to a spectrum of complexity, which is illustrated below.

The Complexity Spectrum

Stability		**Chaos**
Mechanistic World →	Complexity	← Chaos Theory
Structure, certainty, equilibrium, predictability.	Mixture of Stability & Chaos	Instability, risk, uncertainty, disequilibrium, unpredictability.

We can think of the complexity spectrum like the political spectrum – it doesn't really exist but it is a useful way of explaining certain things. Until the end of the 19th Century, physicists looked at the world as if it were at the far left of this spectrum – Newton had developed a simple set of laws which seemed to hold true across all objects. However, over time, physicists began to examine matter at the atomic and sub-atomic level, and began to frame the universe as made up of smaller and smaller constituent parts.

After the microprocessor was invented, chaos theory was developed. This can be seen as the far right of the spectrum, indicative of systems that are unstable and unpredictable. Eventually, complexity science emerged, absorbing chaos theory into a discipline that considers the whole spectrum but which is mostly interested in the region between stability and chaos. Or rather, systems that exhibit both some stability and some chaos.

Importantly, in the grand sweep of history, we have only been aware of this spectrum for a relatively short period of time (about 30 years). We were unable to understand it properly without the aid of computers. Our unassisted brains are not able to grapple with the sheer complexity of the universe, nor human society.

Revolution?

The computer represents a huge leap forward in our ability to process and transfer information. It could be viewed as broadly equivalent to the printing press, which was invented in the 15th Century. The printing press was an enormously important invention because it radically reduced the cost of publishing (previously books cost about a year's wages because they had to be copied by hand). It allowed people to communicate much more efficiently than before, facilitating a greater exchange of ideas, and improving the circumstances for innovation. It is thought the printing press catalysed not only the Renaissance (a broad social revolution) but also the Reformation (a revolution in the church) and the Enlightenment (an academic revolution).

Computers have allowed the transfer of information to become even more efficient. They have also supplemented our own ability to process information. There is a strong argument that these two combined means we are at the beginning of a second renaissance. Perhaps the most obvious illustration of the social impact of computer technology is the use of mobile phone video footage during the Iranian protests following the sham "re-election" of Mahmoud Ahmadinejad as president of Iran. Footage of paramilitary forces assaulting protestors was recorded and distributed within and outside of Iran. Closer to home, a single DVD containing the details of all British MPs' expenses was acquired by the Daily Telegraph, which analysed and published the information.

More generally, the computer has increased transparency and it had allowed people to communicate much more efficiently and openly.

Complexity science represents the academic community making use of computer technology to process information. There is a strong argument that complexity science is leading global society in to a second Enlightenment.

Complexity and Society – the Birth of the Universe to Globalisation

Human global society can be thought of as being at the end of one sequence of emergent phenomena, starting with the Big Bang.

Atoms can be thought of as having properties that are emergent, as a result of the combination of certain sub-atomic particles (also known as *quanta*). Equivalently, molecules (the study of chemists) can be thought of as having properties that emerge from the combination of certain atoms. For example, hydrogen is a gas at room temperature, as is oxygen; but if we combine two hydrogen atoms with one oxygen atom, we get water, which is a liquid at room temperature. Without knowing beforehand, we would not be able to anticipate the properties of combining hydrogen and oxygen in this way.

Biologists are interested in complex molecules, which are the combination of simpler molecules, and often these also have properties that could be considered as emergent. We can take this a stage further – biological organisms have emerged on earth from the combination of these complex molecules. Over time, increasingly complex organisms have emerged, which can be thought of as comprising complex sub-systems. For example, our brains can be thought of as complex systems themselves, as can our respiratory and vascular systems. The human being can therefore be described as a complex system that has emerged from – and represents – a combination of multiple complex sub-systems, which interact.

Taking emergence a final stage, society can be seen as having properties (e.g. values, language) which have emerged out of the complex interplay of human beings over millennia.

Once again, we can reverse the perspective. Society is a type of complex system; and if you accept that a single human being is a complex system, society ought to be viewed as a complex system of interacting complex system. Global society is the ultimate complex system, which can be thought of as containing several interacting civilizations, or as several billion interacting individuals each having complex sub-systems within complex sub-systems…

Implications and Conclusions

Apart from emergence, this essay has said little about the new concepts that have developed in complexity science. For our understanding of human nature and society, I would argue that complexity science offers a means to frame more holistically a number of subjects that were previously segregated.

This includes the evolution of instincts and emotions, morality / ethics, and social institutions. These are complicated subjects but they are worth exploring briefly.

Historically, evolutionary biologists tended to think of evolution only at the level of the individual organism. Darwin himself made glancing references to mechanisms, including morality, which allowed groups of people to improve their collective survival. So as not to alienate himself from his Christian-based community, Darwin took this work no further.

We can think of instincts in the most primitive of animals (e.g. reptiles) as providing mechanisms that facilitate group behaviour. The most obvious is the parent's instincts to protect their offspring, a simple form of attachment. These instincts can be thought of as having emerged to facilitate behaviour that appears altruistic at the level of the individual but efficient at the level of the group. It enhances group survivorship because there are situations in which it makes evolutionary sense for individuals to cooperate.

In a more evolved way, mammals have an emotional capacity that is more sophisticated than simpler instincts. Emotions provide mammals with an ability to empathise with others that may not be kin. In a sense, they allow for a larger group of individuals to coexist (e.g. a pack of wild dogs) and to behave in ways that are constructively for the group's survival. It is more complicated than this, however, because individualistic survivorship traits work in parallel, generating a tension between competition and cooperation. Consider a pack of wolves hunting together but each wolf also competing for the best mate.

If emotions gave us the capacity for empathy, we humans have taken this a stage further in evolving the capability to learn and perpetuate moral values. This capacity has allowed a larger group of people to coexist within a community (e.g. a tribe, or village). Religion was crucial for developing the types of moral teachings that increased survivorship bias in those groups. Our ability to learn and apply certain moral values was combined with a particular set of moral rules (e.g. the Ten Commandments). This meant that, in the absence of credible law, societies based on particular religious beliefs had a greater survivorship bias than those lacking those beliefs.

Social institutions can also be thought of in the same way. Criminal laws in many countries reinforced pre-existing moral rules because they imposed more direct costs on anti-social behaviour than social disapproval, or the threat of eternal damnation. There are also many other social institutions e.g. money and laws requiring minimum safety standards, which can be thought of as forms of coordination between people within society.

Natural scientists have made good use of the new science of complex systems to understand both the universe and the earth's biosphere. However, social scientists have been oddly reluctant to take on board the generic lessons it has taught us. Time is of the essence. The world is approaching capacity constraints in many areas, including climate change, fresh water and fertile soil. These constitute global coordination failures among people at a time when the most politically powerful nation, the US, is the most suspicious of global governance. For me, one of the key lessons of complex systems is that human society suffers from substantial coordination failures, which necessitates cooperation. Forms of cooperation require an accurate analysis of the problem and governance structures that facilitate them. Currently we have neither.

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