Emergence

Emergence is all the rage these days. It has been used to explain everything form the weather to consciousness and the origin of life. But emergence appears to be a hard concept to define and a cursory survey of books and the internet will reveal many different definitions. Broadly speaking, however, they all boil down to the observation that many systems which are made of large numbers of smaller entities seem to have properties that the smaller entities do not themselves possess. In short, the whole is often more than the sum of its parts

(For a comprehensive list of definitions see: http://www.vub.ac.be/CLEA/ dissemination/groups-archive/vzw_worldviews/publications/wvdefemerg.pdf)

Many authors have also sought to distinguish 'strong emergence' from 'weak emergence' e.g. David J. Chalmers; http://www.consc.net/papers/emergence.pdf:

> *We can say that a high-level phenomenon is* ***weakly emergent*** *with respect to a low-level domain when the high-level phenomenon arises from the low-level domain, but truths concerning that phenomenon are unexpected* [but still, in principle, derivable] *given the principles governing the low-level domain.* (My addition in brackets)
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> *We can say that a high-level phenomenon is* ***strongly emergent*** *with respect to a low-level domain when the high-level phenomenon arises from the low-level domain, but truths concerning that phenomenon are not deducible even in principle from truths in the low-level domain.* (My emphasis)

Now the die-hard reductionist will claim that *all* systems, however complex they are, must, in principle, be reducible to the properties of their component parts and that it ought always to be possible, in principle at any rate, to deduce or predict the properties and behaviour of the complex system given the properties of its components. On this view, strong emergence is impossible. If you know the chemical properties of atoms and molecules, you should be able to predict the properties of anything made of atoms including viruses, bacteria, fungi, plants, animals and even humans. Opponents of this view, including Chalmers, claim that there are indeed systems of such complexity that their properties are not predictable, even in principle. The most significant example of such a system is, in their view, the conscious human brain.

The distinction between reducible systems and non-reducible systems is, I believe, so important that we should give them more distinctive names than just strong and weak emergence. Systems which have properties which *transcend* the properties of their components i.e. systems which are strongly emergent, should be called *transcendent* systems.

So, leaving aside for the moment the problem of human brains, are there any other truly transcendent phenomena? Or are the die-hard reductionist right after all? Lets consider a few possibilities. First some straightforward examples of (weak) emergence:

- The behaviour of ideal gases can simply be deduced from the behaviour of atoms and molecules moving under the influence of Newton's laws.
- All the properties of solids and liquids can also (in principle) be deduced from information obtained by the application of quantum theory to the behaviour of atoms.
- The movements of a shoal of fish or a mumuration of starlings can be easily simulated by a computer program obeying some simple rules such as follow your leader but don't get too close to your neighbours.
- Even if its precise strength and course may be unpredictable in practice, the properties of a hurricane can be reduced to and deduced from the properties of masses of air of which it is

formed.

- The aerodynamic performance of a jet aircraft is a direct consequence of the way its components are put together and can be calculated before a single prototype is built.
- A really complex computer program like the chess program Deep Thought or a large neural network can produce behaviour which was unforeseen by the programmer (and may even be, in some sense, impossible to predict *even in principle*); but that does not mean that the program was somehow transcending the laws of physics. Any phenomenon which is *computable* is emergent not transcendent.

All these examples suggest a powerful means of identifying emergence. If you can simulate it on a computer, then you are dealing with (weak) emergence.

But what if you can't even simulate it on a computer? Take, for example, the economic law of supply and demand which asserts that if supply exceeds demand, prices will fall and vice versa. Just as the gas laws follow from a consideration of the behaviour of molecules, this law follows from certain assumptions about the behaviour of individuals buying and selling; but unlike molecules which obey well known physical laws, we cannot reduce the behaviour of individuals to simple physical laws. It is not that individuals behave in ways that *transcend* the laws of physics, it is just that the gap between the laws of physics and the phenomenon in question is just too vast to bridge.

This suggests that we need a third category between Chalmers' weak and strong emergence which could be defined as follows:

> *We can say that a high-level phenomenon is **empirically emergent** with respect to a low-level domain when the high-level phenomenon arises from the low-level domain, but truths concerning that phenomenon are deducible <u>in principle but not in practice</u> from truths in the low-level domain.*

Here are some more examples of empiric emergence:

- Insular dwarfism – the observation that isolated populations of large animals tend to evolve into smaller versions.
- The Cepheid variable law which relates the periodicity of the star to its absolute luminosity.
- Children with Down's Syndrome have certain characteristic physical features such as slanting eyes and small ears etc.
- The rings of Saturn are caused by the gravitational interaction of a number of small 'shepherding moons' with billions of lumps of ice and rock.
- Men tend to be more aggressive than women

There is absolutely no suggestion that any of these observations transcend the laws of physics. They are simply empirical observations which are sufficiently widely accepted as to form an adequate basis on which to build more general theories. To take just one example: we do not know exactly why Cepheid variables behave in the way that they do because we do not know enough about their internal structure. But this does not stop us from using the law to deduce important information about the size and structure of our universe.

Now for a few slightly confusing examples:

- An image of the Queen made out of a collage of tiny individual faces. When you look closely at the image, all you see are the individual faces but when you stand back, the well-known image of the Queen's smiling face 'emerges'. Is this weak or strong emergence? Well it is true that the whole is more than the sum of its parts because if you were to put the parts together in a different way you could end up with a completely different image but this is not the kind of emergence that a physicist is talking about. The image of the Queen and the individual photographs really have nothing to do with each other. This is a classic case of what I call **disjoint emergence**.

- I think you will agree that a five pound note has some very desirable properties which are in some way a result of the way a collection of atoms and molecules are put together. But it would be wrong to say either that the value of a £5 noted *emerges* from or even *transcends* the laws of physics. This is another example where the monetary value of the note really has nothing to do with the atoms and molecules of which it is made.
- What about Beethoven's 5th symphony. Does the symphony *emerge* from the notes written on the page or from the vibrations of the air produced by the orchestra? Isn't it just another case of disjoint emergence?

Now what about some real candidates for transcendence:

- The second law of thermodynamics is an incredibly useful law which tells us, amongst other things, exactly how much useful work you can possibly get out of a given engine. It does this by using a well defined property of a system called entropy. On the face of it, the second law of thermodynamics appears to have the same status the gas laws law and entropy the same status as temperature. Now while it is not difficult to demonstrate using just Newton's laws of motion that, for example, the pressure of a gas is proportional to its absolute temperature but it turns out that it is quite impossible to deduce the second law of thermodynamics in the same way. Ludwig Boltzmann spent many years of his life trying to do this and the failure of this enterprise may well have contribute to his suicide. The reason for his failure is simple: Newton's laws of motion are symmetric with respect to time but the second law of thermodynamics is not and it is logically impossible to deduce an asymmetric law from a bunch of symmetric ones. It is fair to say that in Boltzmann's day, the second law of thermodynamics *transcended* the laws of physics as they were then understood. But does this mean that the second law is a genuinely transcendent phenomenon? Is there a department in heaven whose sole function is to make sure that entropy increases irrespective of the laws of physics? No scientist – not even David Chalmers would subscribe to this.

When faced with a situation like this where we do not have a satisfactory reductionist explanation of a phenomenon we have to do one of two things: either we accept the phenomenon as a fundamentally new one and add it to our list of fundamental laws, or we simply look harder for an explanation. (In the case of the second law of thermodynamics I believe that we do have a satisfactory explanation once we have added two further premises to Newton's laws. The first is that according to quantum theory there is a tiny element of randomness in any collision between two molecules and the second is that our universe is not infinitely old and began in a very low entropy state. This is where the temporal asymmetry comes in.)

Here is a contemporary case where we are in precisely this situation:

- In 1986 Bednorz and Muller discovered the first material which is superconducting at 30K and soon after several materials were discovered that superconduct at the temperature of liquid nitrogen (77K). No completely satisfactory explanation of these phenomena exists. Most scientists believe that this is simply because the problem has (so far) proved to be extremely difficult and that, like all other properties of matter, the phenomenon is emergent and that eventually an explanation will be found. It may, however, turn out to be the case that the laws of physics as we currently understand them are inadequate to explain the phenomenon. In which case the phenomenon transcends the currently known laws of physics. But does this mean that we should class the phenomenon as transcendent?

And what about the really big issues:

- Is the origin of life emergent or transcendent? Are the laws of physics adequate to explain how life evolved or not?

And finally:

- Is consciousness merely an inevitable consequence of the way 100 billion neurons are wired together or is it a completely new phenomenon which transcends the laws of physics?

Almost all scientists who study the conscious brain tacitly assume that consciousness is an emergent phenomenon wholly reducible to the workings of neurons and other cells in the brain. But a number of mathematicians and philosophers are of the opinion that the brain can do things which no (classical) computer could ever do. If this is true then consciousness cannot just be weakly or even empirically emergent – it must be a genuinely transcendent phenomenon. If this is the case, Chalmers argues, consciousness must be added to the fundamental constituents of the universe on a par with matter and energy – a view which leads him to believe that all objects including bacteria and thermostats possess consciousness in some degree. For what it is worth, I do not subscribe to this view. I believe that, as with high temperature superconductivity, our current laws are inadequate to explain consciousness but I hold out the hope that as and when we fully understand the quantum nature of the world we live in we shall come to see how consciousness can indeed emerge from that enhanced understanding.

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