2

Physics and Emergence

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This paper does three things:

- It distinguishes between weak and strong emergence.
- It sketches arguments proposed against strong emergence, and adumbrates a counter.
- It sketches the physical characteristics that strongly emergent systems need to arise.
- It argues that strong emergence is a necessary presupposition for the reality of the academic debate, because, without this presupposition, the debate is meaningless. It argues that strong emergence can arise in systems that involve folding properties, with multiple, non-contiguous micro-realisations of macro-states, sensitive dependence on external conditions, open interaction with an environment, non-linearity, and feedback loops.

What is emergence, and what could the physics of emergence be?

This paper presupposes that emergence, strong emergence, occurs. Not to do so would take away from the reality of the discussion in which it inserts itself, because, without the presupposition of emergence, the intellectual activity of discussion would have no causal reality, and therefore no import.

The term is used often, for example, by Nürnberger (2011:112-145), Kauffman (2008:68-127 et passim) or Clayton (2006:110 et passim) – sometimes, it seems ubiquitous in the description of the development of the world. However it is used in two senses: weak emergence (also called epistemological) and strong emergence (also called ontological) (Welshon 2002:39).

Weak emergence

Emergence as used in this weak sense (e.g. Nürnberger 2011:110, 112; Collier 2013:1) implies that a collective has properties that the parts do not possess in themselves, and constitutes an identity that can be used in modelling or describing behaviour at this level. Such use of higher-level properties is a way of simplifying modelling or description, in the sense of Einstein's dictum: models should always be as simple as possible, but no simpler.

In this sense, every higher level in a sequence in which the constituent parts of a complex entity are analysed is emergent from the previous. And, at each level, the entities emerging have identities that persist through time, have properties that can be described in terms appropriate to that level, and relate to other entities at their level, or adjacent levels, according to laws that are appropriate to the level concerned (Bar-Yam 2013).

Emergence is also used in a diachronic sense, as historical emergence, when the development of novel properties, or concepts – such as the internet, or of cities, or of societies, is called 'emergence' (Rueger 2000b:488, Collier 2013:2).

Objects composed of molecules arranged in crystalline patterns have properties such as hardness, elasticity etc. that the constituent molecules do not have, and which arise out of a combination of the arrangement of atoms/molecules and the properties of the atoms/molecules (Bitbol 2007:294). So, for instance, carbon atoms can be arranged in both graphite and diamond crystals, resulting in significantly different properties (Nürnberger 2011:112).

Weak emergence simply states that it is appropriate to utilise entities that arise out of sub-entities as coherent entities with definite properties and laws that they obey, and that connect them to both the entities below, at, and above their level. The relationships connecting them are robust in the sense that similar variations at lower level result in similar variations at higher level, and general laws can be developed to explain the relationships (Rueger 2006:341, 342). The robustness of such relationships has been analysed by Rueger (2000b).

In weak emergence, it continues to be supposed that the properties of the higher, more complex level can be described in terms of the properties of the lower, more basic level, and connected to these in terms of bridging laws. These bridging laws can be formulated in general terms. The properties of the emergent level can therefore be deduced from the combination of knowledge of the arrangement of the sub-entities and the knowledge of the properties of the sub-entities by applying general bridging laws (Kim 1999:11-12).

This relationship between composite and component level is called ‘supervenience’, and weak emergence is identical to supervenience. In this case, the emergent properties are mere epiphenomena, with the causation truly occurring bottom-up, from the base constituents (Welshon 2002:43).

However, this concept of emergence does not introduce anything substantially new into physical or philosophical discourse. It is of course the case that tables and chairs can continue to be described as tables and chairs, and wood and iron may be described as such, even if we know that they are composed of quarks and leptons bound by strong, weak, and electromagnetic forces.

In this mode of ‘emergence’, the higher-level properties can, in principle, always still be calculated and predicted from lower-level properties. The arrow of explanation continues to point downward.

No one disputes this mode of emergence or its pervasiveness: the properties of the space-time manifold arise out of symmetry-breaking in the multidimensional original manifold; the properties of quarks and other leptons arise out of strings or whatever else is foundational to them; the properties of protons and neutrons arise out of those of their constituent quarks; the properties of atoms arise out of their constituent protons, neutrons and electrons; the properties of molecules arise out of their constituent atoms; the properties of gases, metals, crystals, and liquids arise out of the properties of the molecules that constitute them; the properties of stars arise out of the balance of gravitational attraction, electro-chemical repulsion, and nucleosynthesis of the gas contained in them; the properties of galaxies arise out of the stars, gas-clouds, dark matter and dark energy associated in them – the list goes on (Nurnberger 2011:110).

However, in all these cases, the property of the composite can be predicted from the properties of the constituent parts thereof. The properties of the atom – its size, ionisation energies, electrochemical properties, such as electro-positivity or -negativity, reaction energies of atoms with each other, and the orientation of chemical bonds the atom is likely to form can be predicted from quantum-mechanical calculations of the wave-functions of its constituent nucleus and electrons – even if this is only in approximations of perturbation theory. In this sense, it is true that chemistry is but applied quantum mechanics (Mitchell 2012:172).

In the case of weak emergence, therefore, the historical strategy of Physics – analysis and synthesis – is still fruitful. The composite system can be analysed into simpler subsystems, the interactions of which can be studied and reduced to regularities and laws, and the properties of the composite system can then be re-established out of a theoretical synthesis of the laws and structural arrangement of the subsystems.

In the sense that the composite system shows a coherent identity, with predictable behaviour and predicatable properties, it can be regarded as an entity. So a quark or lepton will still be regarded as an entity even if the properties of either can be derived from superstring theory. A neutron, or a pi meson, or a proton, is regarded as an entity, even if it is known that they are systems of quarks. An iron atom is regarded as an entity, even if it is known that it is a system composed of 26 protons and electrons and 30 neutrons.

It is more appropriate, in terms of simplicity of expression, to express systems in terms of their proper level of emergence in terms of weak, or epistemological, emergence – but this kind of emergence does not conceptually limit physics, nor does it introduce something new.

Its use should not be confused with the claims of strong emergence.

Strong emergence

A stronger concept of emergence is also often claimed to hold for some complex entities such as life processes of bacteria, or the mind processes of the brain, or societies, ecosystems or economies (Nurnberger 2011:116-145, Clayton 2004:110, Kauffman 2008:68, Collier 2013:4).

This form of emergence is both controversial and interesting (Bitbol 2007:294).

It is controversial, because it is not universally accepted. The arguments against it will be sketched and debated later.

The term ‘emergence’ is used strictly, or in the strong sense, when the ‘emergent’ properties in the weak sense cannot be predicted or explained by reference to the lower level properties, not only because of limitations in our current knowledge, but in principle (Kim 1999:3; Newman 1996:251). Strong emergence is linked to non-reductionism and top-down causation (Kim 1999:4, 6).

In the case of a system exhibiting strong emergence, the system cannot be reduced to its sub-components, structure, and general bridging laws in the sense that the behaviour of the system cannot be theoretically predicted or synthesised from these (Kim 1992:124-125, Kim 1999:6; Hüttemann & Terzidis 2000:276, Kauffman 2008:41, Beckermann 1992:102).

This does not mean that a mysterious, non-physical component is presupposed that needs to be added to the system for the ‘strong’ emergent properties to occur. Indeed, it is assumed that the emergent system is composed of purely physical subsystems that interact in accordance with the general laws of physics (Kim 1992:124, Kim 1999:7; Campbell & Bickhard 2011:37). It can be analysed into its components. However, the theoretical synthesis of the system from the components in terms of general bridging laws that enable a scientist to predict the properties of the emergent system from the properties and configuration of the component subsystems fails (Kim 1992:125, Kim 1999:8; Hüttemann & Terzidis 2000:276).

This also means that the description of the behaviour of the system needs laws, or more broadly speaking, modes of understanding, *sui generis*. These modes of understanding need to be developed from induction on the observation of the system – if such laws can be found at all. Effects such a system would have on lower-level entities would not be predictable in terms of the effects of the subcomponents of the system (Kim 1992:125, Kim 1999:10; Clayton 2004:39). If, however, we can come to an understanding of the behaviour of the higher-level system as an entity in itself, we would be able to understand effects it has on lower-level entities in terms of the higher-level system. All strongly emergent systems would therefore be examples of top-down causation (Kim 2006:557; Bitbol 2007:294; Welshon 2002:41; Campbell & Bickhard 2011:42, Ellis 2012:6).

Arguments against strong emergence

When could this be possibly true?

Some answer "Never!"

They argue in two ways:

Hüttemann & Terzidis (2000) ask whether the concept of emergence categorises systems in interesting ways, and deny this. They argue that, if emergence is used in the weak sense, as composite systems exhibiting properties their subsystems do not, then this is true of all composite systems. As far as the strong concept of emergence is concerned, they argue that for truly novel, irreducible properties to arise in emergent systems, these systems must exhibit top-down causation, which goes against the grain of explanation in physics, and will therefore be seen as an anomaly to be overcome, rather than a state of affairs to be accepted (Hüttemann & Terzidis 2000:275. 279).

This argument seems to be very much a *petitio principi*. It is precisely the change in the explanatory direction that emergence proposes to make (Kauffman 2008:33).

Kim (2006:558) argues against top-down causation as follows: each higher-level 'Emergent' state E will correspond to a set of lower-level state descriptions L_i. Indeed, he presupposes that E is fully determined by this set, such that, if L_i are exactly copied, a new copy of E, with exactly the same behaviour, would arise (Kim 2006:552). This assumption is termed 'mereological supervenience'. If this state E then causes a subsequent state E*, equivalent to substates L_i*, where L_1 is changed to L_1*, we would talk of top-down causation. However, since E is equivalent to the combination of L_i, and E* equivalent to the combination of L_i*, one could as easily state that the L_i cause L_i*, and the higher, emergent level therefore is otiose (Kim 2006:559; Welshon 2002:42; Campbell & Bickhard 2011:41).

However, this argument misses the role that multiple representibility (Davidson 1980, 2001:216, Kauffman 2008:25, 59) and small perturbations, and sensitive dependence thereon, may play. If one includes small perturbations in the analyses, and the system is sensitive to these, one needs to work, not with individual macro states, but with ensembles or groups of both macro-and microstates. If the set of, closely similar, {E} corresponds to a set of {L}, which need not, actually, because of folding properties, necessarily be closely similar, or located in a contiguous phase-space realm, (vs Collier 2013:7). This is in contrast to the assumption made by Rueger (2000: 468), and corresponds to the critique of Kim (1999) by Mitchell (2012:176). If each L_i, according to the laws governing its operation, results in L_i*, then {E} could result in any member of {E*} – which, due to folding and sensitive dependence, could be a rather large and divergent set (Bitbol 2007:297). Only one of these, E*, corresponds to L_i*. However, the choice between the macro-level outcomes is not uniquely determined by the lower-level description, owing to sensitivity to perturbations and multiple representation of the lower system. Among the higher-level outcomes, one is chosen. If the system is embedded in a larger whole, or is of a nature where the macro-structure thereof determines the choice of E*, then, the choice, at the macro-level E, causes the choice at the lower level L.

So, for instance, not every reaction I have in responding to a reading makes logical sense – I have to select that which is most logical on a higher level from a number of automatic responses that could present themselves. It is the fact that such responses are selected at the higher level of logic that makes them deliberate and meaningful, in place of automatic and simply happening.

Further argument against Kim's denial of top-down causation, and therefore actuality of high-level, emergent states, is made by Welshon (2002) and Campbell & Bickhard (2011). Both critique the assumption of mereological supervenience.

Instead of (as has been classically done) perceiving systems as aggregates of individual particles with defined properties, which are then recombined per bridging laws to constitute a system, Campbell & Bickhard (2011:52) point out that none of the supposed 'particles' are atoms – undivisable. Instead, all are the consequence of configurations of smaller entities, which, at the lowest level, lose the characteristics of identifiable particles owing to quantum mechanical effects, and should rather be conceived of as fields-in-process. Reality at its lowest level, therefore, should be conceived of as determined not by particles, but in terms of configurations of fields that develop (Campbell & Bickhard 2011:47, Castellani 2002:264-5). It is therefore the configuration, the arrangement, the structure that gives actuality, rather than the components thereof – and therefore, in the case of emergent systems, which are open to their environment (such as a candle flame or a living organism) the process and structure of interaction is definitive, rather than accidental to the system (Kauffman 2008:59, Campbell & Bickhard 2011:52). Campbell & Bickhard (2011:55) therefore argue for a revised ontology which makes strong emergence possible by discarding mereological supervenience in favour of a conception of reality as composed of fields-in-process.

Physical conditions for emergence

From the argument above (for top-down causation, and therefore for *wirk-lichkeit*), the actuality of the emergent system, and the conditions for the physical nature of such systems, can be developed. These conditions concur with those developed by Campbell & Bickhard (2011:53).

Clearly, systems in which the behaviour of the dynamics of the aggregate systems is narrowly constrained to approach one specific behaviour by known laws to which its subsystems are subject cannot show emergence because, in such cases, properties and behaviour can be theoretically synthesised, and maybe quantitatively or at least qualitatively predicted. Where the bridge laws between micro- and macro states can be explicated, no strong emergence occurs (Kim 1999:8, 12) This may apply even to complex systems – such as computers and cell phones – where the design ensures reproducibility and predictability of results (Collier 2013:8).

This criterion also probably eliminates equilibrium systems, because of the tendency of equilibrium systems to a unique value, where small perturbations are damped out. Emergent systems are therefore likely to be systems far from equilibrium, driven and damped, and therefore reliant on input from, and open to, an environment (Campbell & Bickhard 2011:50; Collier 2013:11, 14).

In order for the bridging laws of the structure to be inexplicable, the development of the aggregate system must allow for different consequences to result from states that are close to each other, initially, in value (Newman 1996:256). Sensitive dependence on initial conditions, and multiple configurations with little energy difference between them, are therefore to be expected in most systems that show strong emergence (Mitchell 2012:181). Emergent properties are therefore associated most closely with systems in which the arrangement of the constituent parts is of definitive importance (Campbell & Bickhard 2011:49).

In order for there to be high-level selection among the possible high-level states that can result, emergent systems would most likely include feedback loops, structured on the higher level, that can perform such selection (Collier 2013:8, 14-15). This is even more so if the behaviour of the system can include modification of its own structure, thereby accumulating information (Ellis 2012:5, Kauffman 2008:69). In these cases, the future kinds of behaviour, as governed by the arrangement of the system, depend on options taken in terms of sensitive dependence, which were unpredictable. In such cases, the unpredictable history of development of the system can lead to different configurations of the system, which then give the system different responses to new stimuli. Such systems would therefore be historically conditioned and have a measure of individuality, and would have a historically self-referential history (Ellis 2012:5; Kauffman 2008:35).

Such systems would therefore need to combine both sufficient flexibility for changes in the structure to arise, and the ability to retain the formation of structures for some time. On the basis of this argument, it seems to me that emergence is most likely on what is termed the edge of chaos (Kauffman 2008:40). The above analysis corresponds with the arguments put forward by Glansdorf and Prigogine (1978:xx, 82, 222, 287) and De Wolf and Holvoet (2004:9).

These properties seem to be verified by those systems that are most often referred to as candidates for emergence: living entities with their transmission of inherited, neural networks that show the capacity to learn by feedback loops through interaction with their environments, and ecosystems, in which organisms evolve and accumulate genetic information through the feedback loops of evolution.

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