Emergence Explained (again)

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Abstract.

1. Introduction

Kim (2006)

> Since around 1990, the idea of emergence has been making a big comeback … Indications are that the emergence boom is going to continue, on an upward trajectory, for years ahead.

According to Bedau and Humphreys (2008):

> Emergence relates to phenomena that arise from and depend on some more basic phenomena yet are simultaneously autonomous from that base. The topic of emergence is fascinating and controversial in part because emergence seems to be widespread and yet the very idea of emergence seems opaque, and perhaps even incoherent. …

Other recent definitions include O'Connor and Wong (2006).

> We might roughly characterize the shared meaning thus: emergent entities (properties or substances) 'arise' out of more fundamental entities and yet are 'novel' or 'irreducible' with respect to them. (For example, it is sometimes said that consciousness is an emergent property of the brain.) Each of the quoted terms is slippery in its own right, and their specifications yield the varied notions of emergence that we discuss below.

And Boogerd et. al. (2005)

> The central question then is, in Broad's terms, whether there are properties of systems which cannot be "deduced" from the behavior of parts, together with a "complete knowledge" of the arrangement of the system's parts and the properties they have in isolation or in other simpler systems. Properties that are not deducible in this way we call strongly emergent properties.

Chalmers (2006)

> 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. [...] 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 given the principles governing the low-level domain.

Clayton and Davies (2006).

Weak reductionism recognizes that in practise the only way that the behaviour of many complex systems may be determined is by direct inspection or by simulation. [...]Strong emergence is a [...] position, in which it is asserted that the micro-level principles are quite simply inadequate to account for the system's behaviour as a whole.

Kim.(2006)

Emergentism cannot live without downward causation but it cannot live with it either. Downward causation is the raison d'être of emergence, but it may well turn out to be what in the end undermines it.

supervenience and functional irreducibility are two necessary conditions of emergence.

Supervenience: If property M emerges from properties $N_1, \ldots, N_n$, then M supervenes on $N_1, \ldots, N_n$. That is to say, systems that are alike in respect of basal conditions, $N_1, \ldots, N_n$ must be alike in respect of their emergent properties.

Irreducibility of emergents: Property M is emergent from a set of properties, $N_1, \ldots, N_n$, only if M is not functionally reducible with the set of the Ns as its realizer.

What we have in supervenience and irreducibility, therefore, are two essentially negative conditions, and they do not amount to a *positive* account of what emergence really is. They tell us what emergence is not; they do not tell us anything—at least, not much—about what it is. I believe one pressing item on the emergentist agenda is to provide an illuminating positive characterization of emergence. … Success here includes at least two things: first, the proposed characterization of emergence must explain why emergents so characterized supervene on their base properties and why, in spite of the supervenience relation, the former are not reducible to the latter; second, it must successfully cope with the problem of downward causation.

Somehow the emergentist must devise an intelligible and consistent account of how emergent properties can have distinctive causal powers of their own—in particular, powers to influence events and processes at the basal level.

Wayne

Thus far, I have argued that the presence of a singular limit does not imply explanatory failure at the base level. Whether an upper-level phenomenon can be explained in basal terms depends, rather, on the particular details of the explanatory resources brought to bear after theory breakdown at the singular limit, including initial conditions, boundary conditions and empirical premises in the asymptotic methods used at singularity. The upshot, I want to claim, is that the pre ence of a singular limit fails to be an adequate criterion for eme gence.

The alternative account of emergence I propose is simple: the failure of basal explainability is constitutive of emergence in physics; more precisely, an upper level phenomenon is emergent if and only if it cannot be explained in base-level terms. A consequence of this account is that emergence and reduction are largely decoupled. As I shall argue, in the van der Pol case upper-level phenomena are irreducible yet not emergent.

Most of these approaches to emergence try too hard. They attempt to define a meta-property (emergence) that can be used to categorize phenomena into the emergent and the non-emergent. It's not clear why one would want to do that—or expect that one could. Emergence, if it is at all meaningfully applied to naturally occurring phenomena, is clearly very broad. It applies to phenomena as unrelated as entanglement in physics and the distinction between the living and the non-living in biology. It is a meta-property because it attempts to categorize phenomena on the basis of their relational properties, which themselves are human-defined characteristics. It is something like attempting to define animals that fly or animals that live in the water as a category. Presumably one could do it in a fashion, but there is no reason to expect that the results will be pretty. The problem is that the property of flying is itself not well defined (are squirrels, trap-jaw ants, baby spiders, or air-borne bacterial included?) and doesn't map naturally onto anything fundamental.

If one had an agreed-upon list of phenomena that were considered emergent and one wanted then to characterize what is common among them, that might be worthwhile. But that isn't the case. There is no agreement about what is emergent and what isn't. How then would one expect to define a property that divides all phenomena into the emergent and the non-emergent?

Most attempts at defining emergent focus on supervenience and irreducibility. See, for example, Kim. As Kim points out, there is general (but not universal) agreement that for anything to qualify as emergent it must supervene on some base but be irreducible to properties of the base. As Kim also points out, this is a negative requirement. It excludes rather than defines. Anything that does not meet those requirements is excluded from being considered emergent. I believe that this focus on irreducible supervenience has been a distraction and that we should return to more fundamental considerations.

Consider an airplane—or more simply an airfoil, i.e., a material body that produces lift when in motion relative to air. Presumably the property of being able to produce lift is emergent. The property is emergent because it is independent of the properties of the materials that make it up. There is nothing about steel, aluminum, wood, plastic, or whatever materials are used in the construction of the airfoil that have anything to do with producing lift. An airfoil produces lift because of its aerodynamic shape. It is the shape that creates the property, not the materials.

Presumably one could trace the mechanism whereby an airfoil produces lift to properties of the material that make up the airfoil. But it doesn't make much sense to do so. The properties that are relevant in the materials those that enable it to be shaped into an airfoil. Water, for example, can't produce lift (unless frozen) because as a liquid it can't be made into an airfoil.

The notion of multiple realizability is often raised with respect to emergence. That too is a distraction. Certainly an airfoil is multiply realizable, but it is not its multiple realizability that makes an airfoil lift producing property emergent. It is the fact that it is the shape of the ensemble and not the properties of the ensemble components that produce the result.

This is such a simple concept that one wonders why so much effort has been put into looking for emergence in other places.

Kim (1999) recognizes this type of emergence and finds it unremarkable.

> I fall from the ladder and break my arm. I walk to the kitchen for a drink of water and ten seconds later, all my limbs and organs have been displaced from my study to the kitchen. Sperry's bird flies into the blue yonder, and all of the bird's cells and molecules, too, have gone yonder. It doesn't seem to me that these cases present us with any special mysteries rooted in self-reflexivity, or that they show emergent causation to be something special and unique. For consider Sperry's bird: for simplicity, think of the bird's five constituent parts, its head, torso, two wings, and the tail. For the bird to move from point $\underline{p}_1$ to point $\underline{p}_2$ <u>is</u> for its five parts (together, undetached) to move from $\underline{p}_1$ to $\underline{p}_2$. The whole bird is at $\underline{p}_1$ at $\underline{t}_1$ and moving in a certain direction, and this causes, let us suppose, its tail to be at $\underline{p}_2$ at $\underline{t}_2$. There is nothing mysterious or incoherent about this. The cause -- the bird's being at $\underline{p}_1$ at $\underline{t}_1$ and moving in a certain way -- includes its tail's being at $\underline{p}_1$ at $\underline{t}_1$ and moving in a certain way. But that's all right: we expect an object's state at a given time to be an important causal factor for its state a short time later. And it is clear that Sperry's other examples, such as the water eddy and the rolling wheel, can be similarly accommodated.

What's strange is how offhandedly Kim dismisses these examples. It is as if he would dismiss the example in which an airfoil (and consequently the molecules of which it is composed) moves upwards as a result of the generated lift. Is it trivial that as an airfoil move upwards one would expect its molecules to do so since that's what it means for an airfoil to move upwards. Yet the molecules by themselves can't move upwards. They do so only because they are part of the airfoil.

My argument, of course, is that the molecules implement the airfoil and as long as they continue to do so they are constrained to move as the airfoil moves. The important relationship is the implements relationship.

This is upward and naturally occurring emergence. Downward emergence occurs when we conceptualize the properties we want an ensemble to have and then construct one to have those properties. Nature doesn't conceptualize. So nature's emergent properties are not as neat and clean-cut as ours.

2. *Examples of emergence*

> One of the best ways to get a feel for emergence is to consider widely cited core examples of apparent emergent phenomena. The examples involve a surprising variety of cases. One group concerns certain properties of physical systems. For example, the liquidity and transparency of water sometimes are said to emerge from the properties of oxygen and hydrogen in structured collections of water molecules. As another example, if a magnet (specifically a ferromagnet) is heated gradually, it abruptly loses its magnetism at a

specific temperature—the Curie point. This is an example of physical phase transitions, which often are viewed as key examples of emergence. A third example involves the shape of a sand pile. As grains of sand are added successively to the top of the pile, the pile forms a conical shape with a characteristic slope, and successive small and large avalanches of sand play an important role in preserving that shape. The characteristic sand pile slope is said to emerge from the interactions among the grains of sand and gravity.

Life itself is one of the most common sources of examples of apparent emergence. One simple case is the relationship between a living organism and the molecules that constitute it at a given moment. In some sense the organism is just those molecules, but those same molecules would not constitute an organism if they were rearranged in any of a wide variety of ways, so the living organism seems to emerge from the molecules. Furthermore, developmental processes of individual organisms are said to involve the emergence of more mature morphology. A multicellular frog embryo emerges from a single-celled zygote, a tadpole emerges from this embryo, and eventually a frog emerges from the tadpole. In addition, evolutionary processes shaping biological lineages also are said to involve emergence. A complex, highly differentiated biosphere has emerged over billions of years from what was originally a vastly simpler and much more uniform array of early life forms. The mind is a rich source of potential examples of emergence. Our mental lives consist of an autonomous, coherent flow of mental states (beliefs, desires, memories, fears, hopes, etc.). These, we presume, somehow emerge out of the swarm of biochemical and electrical activity involving our neurons and central nervous system.

A final group of examples concerns the collective behavior of human agents. The origin and spread of a teenage fad, such as the sudden popularity of a particular hairstyle, can be represented formally in ways similar to a physical phase transition, and so seem to involve emergence. Such phenomena often informally are said to exhibit ‘‘tipping points.’’ Another kind of case is demonstrated in a massive traffic jam spontaneously emerging from the motions of individual cars controlled by individual human agents as the density of cars on the highway passes a critical threshold. It is interesting to speculate about whether the mechanisms behind such phenomena are essentially the same as those behind certain purely physical phenomena, such as the jamming of granular media in constricted channels. …

3. One version of emergence

The version of emergence that I want to formulate differs from most others in that it includes an explicit intermediate construct. In many formulations of emergence one imagines that lower-level functionality is somehow directly (or mysteriously) transformed into higher-level functionality. This approach leads to the sort of dilemmas that Kim has repeatedly pointed out.

My suggested alternative is to suggest that lower level functionality (and entities) may create compound entities and that those compound entities may often have properties and capabilities that are acceptably autonomous from those at the lower level. As an example consider an object that floats in water. An object floats when the water it displaces weighs at least as much as the object itself. Some objects are naturally buoyant because they are made of materials that are less dense than water. But let's consider only objects that are made of materials that are more dense than water but that still float—objects with a concave shape that exclude water from an empty interior space and use that interior space as part of their displacement volume.

How does one relate the properties of the (lower level) materials of which such an object is made to the object's ability to float? Since the construction materials are denser than water, one can't map any sort of lower level buoyancy to the buoyancy of the floating object. So the ability to float is not in any traditional sense directly reducible to lower level properties. The object floats (a) because of its shape and (b) because of the ability of the materials of which it is made to exclude water from its interior.

The ability of such an object to float is, I would claim emergent. It is a property of the object (as a higher level construct), and that ability is not directly attributable to properties of the materials of which it is composed. That is, there is nothing about the component materials that would suggest that a construct made of those materials will float. Some definitions of emergence require that emergent properties be not be deducible, "even in principle" from lower-level properties. Chalmers put it this way.

> 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.

It's not clear to me what it means to say that that some truths are not deducible (even in principle) from other truths. Chalmers explains in a footnote that he means "that strong emergence requires that high-level truths are not conceptually or metaphysically necessitated by low-level truths." I'm afraid I still don't understand. Is the ability of our example object to float deducible from truths about the materials of which it is made along with truths about water, buoyancy, etc.? Naively I would think so. After all the object does float—and we can explain why. So it must be deducible from truths about its components, etc.

On the other hand, in order for our object to float it had to have been constructed in such a way that it enclosed space that was used to displace water. Is the concept of such a construction among the truths of the lower level, or is it available for use in a derivation of the higher level truth that the object does float? If not, then the ability of the object to float is presumably not deducible (even in principle) from the lower level truths.

Another way to approach this issue is to note that the physics of buoyancy is independent of the truths about the lower level domain. So in that sense also once can't derive the ability of the object to float from truths about the lower level domain alone. One must add the physics of buoyancy, which has nothing to do with the lower level domain.

For either or both of the two reasons just examined (that the construction of the object and the physics of buoyancy are not part of the lower level) I suspect—but obviously don't know—that Chalmers would say that the ability of the object to float isn't deducible from lower level domain truths. Consequently it satisfies Chalmer's definition of (strongly) emergent.

Does the ability of the object to float satisfy Kim's requirements for emergence: supervenience and functional irreducibility? Certainly the object supervenes on its components. Change the components and the object changes. So it seems to me that supervenience is not an issue. What about functional irreducibility? The question of functional irreducibility seems to me to raise the same issues as those raised by Chalmer's requirement of non-deducibility. What does it mean for something not to be functionally reducible to something else? Kim doesn't provide a definition. So it's hard for me to say. I would guess that it means that there is no composition of lower level functions that are equivalent to the target higher level function. Kim gives as an example that "Number theory is irreducible to hydrodynamics and vice versa." Since both number theory and hydrodynamics are independent, it's not clear to me why they are not mutually reducible. After all each can be constructed *ab initio*. So it is no harder to construct each theory if one starts by assuming the other. Perhaps what is intended by reducible in this context is that one theory is dependent on the other. Just as number theory doesn't depend on hydrodynamics the physics of buoyancy does not depend on the properties of materials. So in that sense the ability of the object to float satisfies Kim's requirements for emergence.

Like Kim and Chalmers, Howard (2007) also suggests that irreducibility and supervenience are central to emergence. Howard is more explicit with respect to what he means by irreducibility. He adopt Nagel's (1961) formulation as follows.

> *Intertheoretic reduction* is a *logical* relationship between theories. In the classic formulation owing to Ernest Nagel, theory T_B, assumed correctly to describe or explain phenomena at level *B,* reduces to theory T_A, assumed correctly to describe or explain phenomena at level *A*, if and only if the primitive terms in the vocabulary of T_B are definable via the primitive terms of T_A and the postulates of T_B are deductive consequences of the postulates of T_A. As normally formulated, this definition of reduction assumes a *syntactic* view of theories as sets of statements or propositions.

But Howard goes on to say.

> Thinking about the relationship between different levels of description in terms of intertheoretic reduction has the advantage of clarity, for while it might prove difficult actually to determine whether a postulate at level *B* is derivable from the postulates of level *A*…, we at least know what we mean by derivability and definability as relationships between syntactic objects like terms and statements, since we know by what rules we are to judge. The chief disadvantage of this way of thinking about interlevel relationships is that one is hard pressed to find a genuine example of intertheoretic reduction outside of

> mathematics, so to assert emergence as a denial of reduction is to assert something trivial and uninteresting.

It was of course my intent that the ability of the object to float be considered emergent. I selected this example exactly because I wanted a case of emergence that was easy to talk about. I hope that the preceding discussion has accomplished that objective.

Even though there are many ways to build an object that has the ability to float, this isn't a matter of multi-realization. Whether or not there are multiple ways to realize the ability to float is not relevant. What is relevant is that lower-level elements combined to form a higher-level entity that had that new property.

4. Four + 1 categories of emergence

	Naturally occurring	Human Designed
Static	Atom, molecule, solar system	Table, boat, house, car, ship, geo-stationary satellite, …
Dynamic	Hurricane, biological organism or group	Designed social group such as a country government, a corporation, a poker club, ship of Theseus, geo-stationary satellite,

Besides the previous, computers offer an environment within which entities can be created without having to worry about energy or resources. The environment provides them. In all cases the entities are emergent through the implementation of persistent patterns of existing entities.

5. Seven questions about emergence

From Bedau and Humphreys.

> The study of emergence is still in its infancy and currently is in a state of considerable flux, so a large number of important questions still lack clear answers. Surveying those questions is one of the best ways to comprehend the nature and scope of the contemporary philosophical and scientific debate about emergence. Grouped together here are some of

the interconnected questions about emergence that are particularly pressing, with no pretense that the list is complete.

1. How should emergence be defined?

A number of leading ideas appear in different definitions of emergence, including irreducibility, unpredictability, conceptual novelty, ontological novelty, and supervenience. Some definitions combine a number of these ideas. We should not presume that only one type of emergence exists and needs definition. Instead, different kinds of emergence may exist, so different that they fall under no unified account. Emergent phenomena might well come in fundamentally different types that should be distinguished along various dimensions. A further issue is whether emergence should be defined only relative to a theory, or a level of analysis, or a system decomposition. The controversy about how to define emergence is exacerbated by the casual way that terms such as ''emergence'' and ''emergent'' often are used. At least two separate issues are important here: controversies about the proper definition of emergence, and controversies about the proper way to test and evaluate definitions of emergence. Perhaps the proper definition of emergence can be attained only in the context of a comprehensive theory of emergence, resulting in a definition that is implicit rather than explicit. Another possibility is that the concept of emergence is best characterized by a cluster of features such as novelty, holism, irreducibility, and so on, but that the features drawn from the cluster differ from case to case, and that what counts as novel, for example, differs with different subject matters. Given the high level of uncertainty about how to properly characterize what emergence is, it should be no surprise that many other fundamental questions remain unanswered.

My answer is that emergence shouldn't be defined. Emergence should not be a predication to be attained; it is descriptive of certain phenomena. I believe that I have described the phenomena that should be considered emergent. It isn't' clear yet whether one can come up with a formal characterization that captures those and only those phenomena. The point, though, is that it's the phenomena that matter, not the definition of the category. As in all science we adjust our definitions to fit our observed cases; we don't create definitions *a priori* and then attempt to fit observations into such a pre-defined framework.

My definition of emergence is the phenomenon whereby a constraint on a system produces new entities (and entity types) and relationships among those entities (and types). Emergence can be naturally occurring, man-made, or some combination of the two. This definition is much more operational than the traditional definitions that define emergence in terms of properties of phenomena. I define emergence by how it is produced rather than by what is looks like. I think that's important because for me emergence is a matter of implementing one level of entity by using other pre-existing entities. So emergence for me is necessarily an operationally defined process.

2. What ontological categories of entities can be emergent: properties, substances, processes, phenomena, patterns, laws, or something else?

Within the literature on emergence, different authors say that different categories of entities are emergent. There should be no presumption that these different categories are mutually exclusive; it could be that emergence applies to many or even all of them. But it is important to be clear about which of these candidates is under discussion in any given context. Emergence in one of these categories sometimes entails emergence in another, but that is not always the case. For example, it seems clear that emergent laws can link nonemergent properties, whereas a genuinely new emergent property would seem to require new, and probably emergent, laws.

3. What is the scope of actual emergent phenomena?

This question partly concerns which aspects of the world can be characterized as emergent. The examples of apparent emergence above show the prevalence of the claim that emergence captures something distinctive about consciousness and about other aspects of the mind. Another common idea is that emergence is one of the hallmarks of life. But examples of apparent emergent phenomena also include the behavior of human social organizations and of nonhuman social organizations. In addition, certain kinds of physical aggregations are commonly cited as examples of emergent phenomena. The question of the scope of emergence also concerns the question of how widespread emergence is. For example, many contemporary philosophers think that emergence is a rare and special quality found only in extremely distinctive settings, such as human consciousness. Others think that emergence is quite common and ordinary, applying to a myriad of complex systems found in nature. For those who think that nothing is truly emergent, the question still arises whether this state of affairs is simply an accident or whether the very idea of emergence is incoherent.

4. Is emergence an objective feature of the world, or is it merely in the eye of the beholder?

Does emergence characterize only models or descriptions or theories of nature, or does it apply also to nature itself? Is emergence only a function of how something is described or viewed or explained? Question 4 is connected to the issue of whether emergence is defined only relative to a theory or model or representation. Some maintain that emergent phenomena are real features of the world, while others maintain that emergence is merely a result of our imposing certain kinds of representation on the world, or a result of our limited abilities to comprehend correctly what the world is like. Candidates for emergent phenomena in the real world include the physical process called spontaneous symmetry breaking. A simple case of this can occur when a uniform body of liquid has a flat surface. If the bottom of the liquid is heated uniformly and sufficiently, the fluid breaks up into a field of different convection cells in which the liquid continually cycles between the bottom and top of the fluid. An example of emergence that might reflect merely our limited ability to understand the world is the stable patterns that emerge in John Conway's Game of Life. If the Game of Life is initialized with the now-famous R-pentomino pattern of 5 active cells, it takes 1103 iterations of the rules to arrive at a final stable pattern. The discovery of this final pattern occurred only after the game was implemented on a computer; exploring the rules of the game ''by hand'' was insufficient.

5. Should emergence be viewed as static and synchronic, or as dynamic and diachronic, or are both possible?

This is a major division between accounts of emergence. In synchronic emergence, the emergent feature is simultaneously present with the basal features from which it emerges. By contrast, in diachronic emergence, the base precedes the emergent phenomenon which develops over time from them. If mental phenomena emerge from neural phenomena, this is generally thought to be synchronic, there being no time gap between a recollection of one's fifteenth birthday and the brain state that gives rise to the memory. The development of the traffic jam over time is a good candidate for a diachronically emergent pattern. Discussions in the philosophical literature usually focus on synchronic emergence, while those in the scientific literature often concern diachronic emergence. A further question about diachronic emergence is whether and how it applies to both discrete and continuous systems.

6. Does emergence imply or require the existence of new levels of phenomena?

A great many discussions of emergence use the terminology levels, with the levels having three characteristic features. First, the hierarchy of levels has no precisely defined order, but instead is determined implicitly by the organizational complexity of objects. These levels tend to coincide with the domains of individual sciences. Second, each level is assumed to contain at least one kind of object and one kind of property that is not found below that level. Third, at each level kinds exist that have novel causal powers that emerge from the organizational structure of material components. Pressing questions thus include whether this framework of levels corresponds to an objective hierarchy in the world, whether appeal to these levels is useful or misleading, and whether there are clear criteria to identify the levels.

7. In what ways are emergent phenomena autonomous from their emergent bases?

Emergent phenomena are Janus faced; they depend on more basic phenomena and yet are autonomous from that base. Therefore, if emergence is to be coherent, it must involve different senses of dependence and independence. A number of different kinds of autonomy have been discussed in the literature, including the ideas that emergent phenomena are irreducible to their bases, inexplicable from them, unpredictable from them, supervenient on them, and multiply realizable in them. In addition, emergent phenomena sometimes are thought to involve the introduction of novel concepts or properties, and functionally characterized properties sometimes are thought to be especially associated with emergent phenomena. Another important question about the autonomy of emergent phenomena is whether that autonomy is merely epistemological or whether it has ontological consequences. An extreme version of the merely epistemological interpretation of emergence holds that emergence is simply a sign of our ignorance. One final issue about the autonomy of emergent phenomena concerns whether emergence necessarily involves novel causal powers, especially powers that produce ‘‘downward causation,’’ in which emergent phenomena have novel effects on their own emergence base. One of the questions in this context is what kind of downward causation is involved, for the coherence of downward causation is debatable.

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