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Epistemological Emergence

Emergentist theories begin by breaking the world up into discrete 'levels' within which the laws of different disciplines live. At the basic level is fundamental physics, and layered on top are chemistry, biology, neurology and so forth all the way up to sciences such as psychology and economics. Typically, laws must be internally consistent within a given level and the manner of interaction between the different levels serves to distinguish differing emergentist theories. A paramount concern for emergentist theories is reconciling the different levels at which laws operate. If, for example, some biological phenomenon (cell replication in single celled amoebas perhaps) is already fixed by the lower level physical interactions then does it make sense to speak of biological laws as laws at all? If the biological law is a genuine law of nature, and we accept the physical underpinning then we face the largely intractable problem of massive coincidental over-determination at every instance when a law of the special sciences is instantiated. In this paper, I will argue that metaphysical theories of causation largely fail because they are easily reduced to physicalism, however we can understand epistemological emergence as an important and often underestimated tool in our understanding of the world.

In 1920, Samuel Alexander set forth an early emergentist model in his book "Space, Time and Deity". As Timothy O'Connor narrates, once a basic physical system "attains a sufficient level of structural complexity" (O'Connor 3) it is able to acquire an emergent quality. That is to say, the emergent property is a 'structural property' in the sense that it is constituted by the micro structure of the object, much like the property of 'blueness' is in the macro object but is constituted by the micro structure (O'Connor 5). Another way of framing this is to state that the emergent property is borne out of the relationships between the constituent parts, rather than being intrinsic to any or all of them – such a property (e.g. mass) would be called a 'resultant' property. Emergent properties also display another key feature, namely that they 'resist dissolution' in the sense that they cannot be understood from the micro elements until the emergent property is revealed. In Alexander's own words "Until that constellation is known, what is specially vital may elude the piecemeal application of the methods of physics and chemistry." (Alexander 62). Since a chemist is concerned with chemical interactions, he may study the subject indefinitely without striking upon the secret to 'life', even though life is constituted by not more than those very same chemical phenomena. A more rigorous way to explain this is in terms of 'nomological' versus 'logical' necessity. Emergent properties are only nomologically necessary – that is to say, they only follow given the rules and laws that our particular universe obeys. There is swathe of contextual information needed to extract the emergent property and this context can only be supplied by the relevant special science. This is a relatively weak view of emergence, it suggests that the utility of emergent phenomena is as a 'viewfinder' that tells us where in our fundamental physics to look (O'Connor 8).

It is worthwhile to juxtapose Alexander's naïve notion of emergence with the more refined one put forth by Jerry Fodor. Given some law in the special sciences (eg. S_1x -> S_2x) this can be reduced to an equivalent physical law (P_1x -> P_2x) in circumstances where there are bridge laws creating the following relations (S_1x <-> P_1x, and S_2x <-> P_2x). P_1x and P_2x are understood to be 'physical predicates' meaning they are states, properties or events that are describable in physical terms - for example, the movement of individual particles, or the behavior of electric current as it moves through a solid.

On this view, it seems that everything except the most fundamental laws of physics (which arguably, we are not yet privy to) are relegated to the role of 'special sciences'. Even those rules which we today consider to be ‘fundamental’ are not adequately basic. For example, we can consider the physics of optics, which makes accurate predictions on phenomena such as the reflection of light in a mirror, refraction of light in a transparent medium, and diffraction of waves through a gap. We now know that these phenomena are a result of quantum mechanical behavior (read Feynman's Six Easy Pieces for a great introduction to this), and so it does not make sense to speak of optics as ‘fundamental’ even though it fits under the umbrella of physics. Similarly, if in fifty years quantum mechanics and general relativity become unified under some umbrella theory (string theories perhaps), then even quantum mechanics would be considered derivative rather than fundamental. Therefore, I believe that the most generous reading of Fodor treats his ‘P_1’ clauses as being descriptions of things which are unknown (and perhaps unknowable) genuine fundamental physical truths – our physicalist framework posits that such truths exist.

A stronger case for Emergence is O’Connor’s own view. He argues that emergent phenomena must exhibit three key characteristics (a) supervenience (b) non-structural (c) novel causal influence. (a) and (b) entail that the emergence is interesting in the sense that it is not simply a sum of the component parts – as the mass or size of an object would be. (c) is interesting because it requires that an emergent phenomenon which exists in a higher strata is able to ‘go down’ and influence something at a more fundamental level. This would be like a chemical reaction having causal impact on the atoms involved, independently of the physical details of those atoms. Upon first reading, it seems O’Connor is attempting to provide a metaphysical account of causation which makes the bold claim that supervenience and downward causation are compatible – or that a system on a level ‘n’, which is itself completely internally determined and gives rise to events on level ‘n+1’, can then be influenced by those same events. How can such a system still be internally consistent on its own level? However, O’Connor goes further and clarifies:

> “Suppose … that physicists had come to an understanding of a set of (fundamental level) laws L, that accurately described the processes of matter for all systems whose levels of complexity were lower than n, but failed fully to govern these complex systems of level n. In such a scenario there would be good reason to surmise that here we had an emergent property (or properties at work).” (O’Connor 16)

So clearly O’Connor is not quite as ambitious as it first seemed and he is content with a merely epistemological account of emergence. The interesting difference between O’Connor and Alexander is that the latter focuses on that which can be known by studying a subject while the former places emphasis on explanation, and how well one thing can be understood. He states later that even an eventual reduction of the emergent phenomenon to fundamental physics would be inadequate because the phenomenon “demands explanation in terms of the properties of the object exhibiting the strange [emergent] behavior, an explanation that the postulation of an emergent property seems to provide." (O'Connor 17).

In some parts of this paper I will take an exaggerated stance on what it means to describe something 'physically' – imagining that such a description consists in tracking individual molecules and using the dynamics of the standard model and the four fundamental forces (gravity, electromagnetism, strong and weak nuclear forces). Even though physicists often work on scales larger than the atomic scale (e.g. physicists can work with large objects by treating them as point masses) I will assume that such laws are 'special' laws, not fundamental ones. Newton's law of gravitation can be used on large objects only because it works on the fundamental particles that those objects are constituted by, and so this is a form of supervenience.

COMPLEXITY

'Emergent' phenomena in a classical, intuitive, non-rigorous sense are visible everywhere. A simple example is that of collective behaviour (or 'eusociality') exhibited in some primitive organisms such as ants and bees. An ant colony is comprised of tens of thousands of individual ants. No single ant knows what the temperature of the colony ought to be, or where to go out foraging for food. However, provided a sufficiently large number of these very simple players are playing according to very simple rules it is possible to arrive at a complex system which is capable or feeding itself, regulating its temperature and achieving many other complex, "intelligent" effects.

Similarly, we might consider the viscosity of a liquid to be an 'emergent' phenomenon because the viscosity (or some finite fraction of the viscosity) is not found in any of the individual particles but rather arises out of the interactions between the constituent parts (Sapolsky). This type of 'emergent' behaviour stands in contrast to 'resultant' phenomena, where the macro result is actually just an aggregation of the individual parts - a good example is the mass of an object as the sum of the masses of its component parts.

Thus, this 'intuitive' sense of emergence requires the following:
(1) The 'emergent' phenomenon is not 'contained within' any of the constituent parts.
(2) The emergent phenomena only exists once a certain 'critical mass' has been reached.

The clear rebuttal to this line of argument from the hardcore physicalist stands as follows: emergent phenomena arise out of the physical interactions between simple component parts. It is correct that these emergent properties do not manifest themselves on smaller scales, but this does not mean to say that the emergent, macro properties exist as anything over and above the fundamental micro properties. To make such a claim would be simply to confuse the concepts of 'emergence' and 'complexity'. It is likely that macro systems are highly complex, and because our physics vocabulary and capacity for computation is still relatively infantile, we opt for the convenient solution of using 'emergent' language to describe those things that we understand to be complex physical systems. Thus emergence can easily be reduced to 'complexity'.

However, a good case study to talk back to this criticism is that of cellular automata – the most famous variation of which is Conway's Game of Life. The game board comprises of some N by M grid with each square or cell inside the grid being either "alive" or "dead" (black or white). Within the universe of the cellular automation, time exists in discrete intervals and at each 'time-step' the state of a given square is determined by the cells that are directly around it. For example, in Conway's game of life, a cell will die unless it has two or three neighbors (as if by over or under population), and a 'dead' cell can be born if it has exactly 3 neighbors (as if by reproduction). The interesting thing is that any given cell only "knows" about the small neighborhood of cells close to it, and operates according to a finite set of very simple rules. It seems therefore, that the system lacks any kind of fundamental complexity, and could be described as a simple, rather than complex system.

In his lecture titled "Complexity and Emergence", Stanford professor Robert Sapolsky explains some key features of cellular automata. Most notably, we recognize the fact that the vast majority of initial conditions and rule systems create patterns which are 'boring' – i.e. all cells go extinct or exist in some uninteresting static form. Of the relatively few configurations that produce interesting patterns (symmetries, or oscillatory patterns), they are largely similar to each other, implying that similar states can be converged upon form different initial conditions. This is important because once two systems have converged to being identical it is impossible to distinguish them – this is a manifestation of the 'multiply-supervening' effect.

There are also examples of more complex setups. A 'glider' for example is a particular arrangement of 5 cells that appears to propagate indefinitely along a straight line. The rule configuration means that the shape of the glider moves along a fixed line, almost like a bullet being fired. It is also possible to create 'guns' to fire these gliders, the most famous of which is the Gosper Glider Gun.

Now, the key point here is that the cellular automata system is so chaotic that even with a complete understanding of the low level rules and initial conditions in play, one would not be able to predict which rule sets or scenarios would result in a beautiful pattern except by stepping through one moment at a time. Meaning there are no high level patterns that can be observed by studying the system at a high level. One set of initial conditions may lead to a mass extinction while a very similar set would create a beautiful thriving set of stable ecosystem. However, an "expert" who sees an image of a Gosper Glider Gun would be able to recognize it as such and 'predict' with remarkable accuracy exactly how it will behave and the frequency with which it will fire gliders. This seems to be a concrete case in which the high level 'special science' reveals more than the low level incremental advancement of time. The defining feature of emergent phenomena therefore, is that they reveal information about the system which cannot be gleaned at a more fundamental level EXCEPT by stepping through, one time interval at a time.

I propose therefore, that laws of special sciences and other emergent phenomena ought to be understood as a mechanism of 'leapfrogging' over the much more narrowly spaced chain of causes in the physical description. So while a physical law will teach us to process through a chain of events (or 'states' of the universe) as t_0, t_1, … t_100, a law in a special sciences may enable us to jump from t_1 -> t_50 in one broadly applicable rule. In this way, emergence is understood to be 'only' an epistemological idea but nonetheless an immensely powerful one. Emergent phenomena are ways of characterizing observed patterns in physical systems which go over and above that which can be extracted by studying the physics alone.

They provide a way to describe causal relations in terms that more closely capture the essence of the thing being described. If I throw a ball in the air, it seems more adequate to describe the ball as a single entity moving through space rather than as a lattice of 10^24 individual quarks bound together by the strong nuclear force and each travelling along a line in "the fabric of space time". The point here is that even though 'God' may dictate that the individual atoms move according to fundamental physical rules, for a human being such a description usually serves only to completely obfuscate what is going on. The special sciences therefore (and emergent phenomena) can be seen as a way to leapfrog over many of the small details that fundamental physics must step through, and thus provide human beings with a more intuitive description of the physical phenomena.

Another problem that this form of emergence is able to overcome is that of a scarcity of information. In order to make predictions from basic physical models (e.g. describe the trajectory of a bullet in terms of its constituent particles), the number of required parameters is huge compared to those required to make predictions on a macro scale. One way to interpret such a discrepancy is to say that the microscopic description is more accurate, or somehow closer to the truth. While such a claim is true to a degree, in the case of the bullet the macro scale prediction is so close to reality that the correct interpretation is that the micro scale model incorporates large volumes of redundant or unnecessary information. This also makes the low-level system significantly more fragile. If for example, we only know the positions of 20% of the particles in the bullet, the laws of motion applied to only those pieces will give us drastically flawed results. Instead we will need to postulate that the additional 80% of particles exist and exist in specific places, but doing this is equivalent to 'modelling' the entire bullet as a single point particle of mass, m, which is precisely what we are trying to avoid with our fundamentalist description.

Works Cited:

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