Metaphysical Emergence within Physics: Wilson's Degrees of Freedom Account

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Abstract

Metaphysical emergence has often been used to help understand the relationship between the entities of physics and the entities of the special sciences. What are the prospects of using metaphysical emergence within physics, to help understand the relationship between three-dimensional physical entities, and the non-three-dimensional entities that have been recently posited in certain interpretations of quantum mechanics and quantum gravity? This paper explores Jessica Wilson's (2021) analysis of certain cases of metaphysical emergence in terms of degrees of freedom and raises several questions that need to be answered in order to better understand whether this analysis can be used to handle cases of metaphysical emergence within physics.

Keywords: Metaphysical Emergence, Quantum Mechanics, Quantum Gravity.

1. Introduction

In broad strokes, *metaphysically emergent* entities are characterized by being both in some sense *dependent* on some base entities, while also being in some sense *autonomous* from those base entities. Moreover, both the relevant notions of dependence and autonomy are supposed to be suitably *metaphysical*. It isn't enough for the emergent entities to either depend on or be autonomous from the base entities in some merely epistemic or pragmatic sense. Instead, the relevant kind of dependence and autonomy must be understood independently of the kinds of creatures we are, the kind of things we care about, and how we go about investigating the world.

Consider various kinds of special sciences entities—entities that play a role in our best geology and chemistry and biology and so on. On the one hand, the behavior of these entities seems to depend on our best physics; whether you're talking about tectonic plates or chemical solutions or alleles, they are ultimately composed of atoms and subatomic particles (and whatever else physicists turn up in their hunt for a final theory). At the same time, the behavior of entities like tectonic plates and chemical solutions and alleles seems in an important sense

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autonomous from the base entities that physics describes. At the very least, we can reliably predict the behavior of these special science entities without paying much attention at all to the details of our best physical theories—indeed that is what geologists and chemists and biologists spend quite a lot of their time doing. Is this type of autonomy suitably metaphysical? It's hard to say, but if it is, then these special science entities would be paradigm examples of metaphysically emergent entities.

So far, so good, but as the reader can surely tell, there's an enormous amount of philosophical work yet to be done both in spelling out precisely what is meant by dependence and autonomy as conditions of metaphysical emergence, and in clarifying when and where in our philosophical theories examples of metaphysical emergence arise. This is the work taken up in Jessica Wilson's important and timely new book, *Metaphysical Emergence* (Wilson 2021). In addition to putting forward a detailed account of metaphysical emergence, Wilson explores the wide range of philosophical arenas in which one might deploy this concept. There are, of course, the standard examples of special science entities mentioned above, as well as the familiar role that emergence has played in the literature on mental causation and causal overdetermination, but *Metaphysical Emergence* also shows how one might use this concept to help think through philosophical questions about the metaphysics of complex systems, ordinary objects, consciousness, and free will.

In this discussion, I'm going to focus on one particular area of application as a way of illustrating both the importance of Wilson's analysis of metaphysical emergence and raising a number of questions about that analysis. In particular, I will be focused on the ways in which the concept of emergence can be deployed *within* physics (as opposed to being deployed as a way of connecting special science entities with the entities of physics, as in the examples above). Wilson discusses this in her chapter on ordinary objects (Chapter 5). But the topic, as I see it, is much more expansive than she has space to take up there.

In recent years, philosophers of physics have gotten quite comfortable with appeals to emergence. Physicists are exceptionally good at generating mathematical formalisms that allow us to make accurate predictions, but the work of interpreting these formalisms—that is, the work of determining what these formalisms tell us about what the world is like—has become increasingly fraught. Often it is the case that the most straightforward or intuitive interpretation of the formalism tells us that the world is dramatically different than we expect it to be—even with respect to the kinds of entities that have traditionally been within the purview of physics. One example of this trend is found in foundations of quantum theory, where some philosophers of physics have begun to advocate for the view that the quantum formalism describes the evolution of a field in an extremely high-dimensional space—a space of 3×10^{80} dimensions.[1] The obvious question that this view raises is how we are supposed to think about the three-dimensional objects that have been the subject of all prior physics—are atoms and the like just an illusion? One way of resolving this question—or at least gesturing in the direction of a possible resolution—is to bring in the concept of metaphysical emergence, and claim that three-dimensional space and the three-dimensional entities occupying that space are metaphysically emergent entities.

[1] See Albert 1996 for an early version of this view and Ney 2021 for a recent comprehensive defense.

A similar line of thought has been highly influential in recent work on approaches to quantum gravity in which there is no spatiotemporal structure.[2] Obviously the world around us appears to have spacetime structure, so doesn't that make these approaches to quantum gravity non-starters? No, the standard line goes, not as long as one is willing to understand spacetime structure as in some sense metaphysically emergent.

These examples show that the concept of metaphysical emergence has the potential to play an important role in philosophy of physics. At the same time, the rules of the game in such debates are very unclear. There is little consensus on the definition or proper analysis of metaphysical emergence among philosophers of physics, or on the more general benefits and challenges of accepting this concept as a part of our overall metaphysical toolbox. Wilson's book therefore should be thought of as providing an important resource to help philosophers of physics think through these issues in a rigorous way that connects with the broader philosophical literature.

2. Wilson's DOF-based Account

As with any account of metaphysical emergence, Wilson's account has two parts: an analysis of the sense in which metaphysically emergent entities are dependent on some base entities, and an analysis of the sense in which metaphysically emergent entities are autonomous from those base entities. The latter is relatively simple (although see more on this in section 5). According to Wilson, the dependence aspect of metaphysical emergence is understood in terms of *cotemporal material dependence*. In paradigm cases (e.g. the special science cases) this involves the base entities *composing* the emergent entity.

The autonomy aspect of metaphysical emergence, on Wilson's view, is understood in two further, distinct ways. In some cases, autonomy is understood in terms of emergent entities having novel *powers* with respect to the base entities. In other cases, it is understood in terms of emergent entities having a proper subset of the powers had by the base entities. Thus we get two types of emergence:

> *Strong Emergence*. What it is for token feature S to be Strongly metaphysically emergent from token feature *P* on a given occasion is for it to be the case, on that occasion, (i) that S cotemporally materially depends on P, and (ii) that S has at least one token power not identical with any token power of P (Wilson 2021: 53).
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> *Weak Emergence*. What it is for then feature S to be Weakly metaphysically emergent from token feature P on a given occasion is for it to be the case on that occasion, (i) that S cotemporally materially depends on P, and (ii) that S has a non-empty proper subset of the token powers had by P (ibid.: 72).

This classification is all well and good, but I fear that it doesn't help clarify when emergence occurs and when it does not unless we have a settled understanding of powers—when an entity has a power, when it does not, and what precisely powers are. And this, I strongly suspect, is a debate that many philosophers of physics will wish to avoid. With that in mind, it's also important to note that Wilson discusses various "implementations" of weak and strong emergence as defined above, and that one of these—the implementation of weak emergence in

[2] See, for instance, Wüthrich et al. 2021.

terms of degrees of freedom (DOF)—draws on a concept (degrees of freedom) that is already familiar in both physics and philosophy of physics.

Here's how the DOF-based implementation of weak emergence works. As always, the emergent entities need to cotemporally materially depend on the base entites. And then the autonomy condition is understood in the following way:

> […] at least one state of a Weakly emergent entity can be specified using strictly fewer degrees of freedom (independent parameters needed to specify states relevant to an entity's law-governed properties and behaviors) than are needed to specify the corresponding state of the system of entities upon which it cotemporally materially depends (ibid.: 18).[3]

The central example of DOF-based weak emergence, for Wilson is the relationship between the ordinary macrophysical objects that make up the world as we experience it, and the entities described by the quantum formalism. As Wilson writes, "Certain quantum DOF are…eliminated in the classical (macroscopic) limit. For example, entities of the sort treated by classical mechanics are ultimately composed of quantum entities, but the characteristics states of classical-mechanical entities do not functionally depend on the spins of their quantum components" (ibid.: 179).[4]

At least at first, this DOF-based implementation of weak emergence seems highly promising as a tool for understanding emergence within physics. But there are a number of questions that it inspires. In what follows, I'll discuss three of these questions, before returning to briefly discuss Wilson's notion of dependence.

3. The Limits of DOF-based Emergence

Perhaps the most obvious type of question that the introduction of the DOF-based implementation inspires, are questions about the limits of this way of understanding of emergence. First and foremost, we might wonder about the relationship between the DOF-based implementation and Weak Emergence as originally stated. Wilson's presentation of the concept suggests that DOF-based weak emergence only applies in particular cases, where as Weak Emergence is a more general concept. But why, exactly? What are the limits of DOF-based weak emergence? If we wanted to *exclusively* understand weak emergence in terms of the elimination of degrees of freedom, could we? If not, why not?

One way to try to figure out the answers to these questions is by looking at cases where Wilson posits weak emergence without any explicit discussion of degrees of freedom. One especially illuminating example is her application of weak emergence to free will. She writes,

> The prospects [for there actually being free will of the weakly emergent variety] are good. Though free choices are not taken to be part of a higher-level system of laws

[3] Note that Wilson says that the above description is rough. She gives a more thorough, technical definition in chapter 5.2.4. As far as I can tell, however, the details of the technical definition do not affect the discussion here.

[4] Note that although the discussion of ordinary objects being weakly emergent with respect to fundamental particles is the focus of just one subsection of the book (6.1.1), this example is repeatedly mentioned when DOF-based weak emergence is discussed. See, e.g., sections 3.2.3 and 5.2.4.

> on either compatibility or libertarian accounts, a compatibility account is one manifesting the usual Weak emergentist characterization of special science goings on as comparatively insensitive to lower-level physical details, in the sense that an agent's reasons for action in a given case float free of many such details (and in particular, are sensitive only to facts about 'relevant' causal antecedents) (ibid.: 274).

There's no explicit discussion of degrees of freedom here. Why not? One guess is that the mention of laws in the quote above is important. Perhaps on Wilson's view the DOF-based implementation is only possible when the emergent behavior is law-governed. Further support for this guess can be found in Wilson's definition of degrees of freedom. See the quote in section 1 from page 18 and also the following:

> Call states upon which the law-governed properties and behavior of an entity E (object, system, or other particular) functionally depends on the 'characteristic states' of E. A DOF is then, roughly, a parameter in a minimal set needed to describe an entity as being in a characteristic state (ibid.: 177).

From these quotes it looks as though it follows from Wilson's definition of degrees of freedom that if a certain kind of behavior isn't law governed then it won't have any associated degrees of freedom.

This restriction explains the thought that DOF-based weak emergence will only encompass a subset of the cases of weak emergence, but it is a somewhat surprising restriction to make. A fairly standard definition of degrees of freedom is that they are simply the number of independent parameters needed in order to specify a system's state. Of course we tend to only be interested in certain states of certain systems—and therefore we tend to only be interested in certain degrees of freedom. One such group is the states of systems that factor into the laws governing those systems behavior. But there are other salient groups—for instance the states of systems that factor into the explanation of those systems behavior, even if those explanations don't involve laws. And if we have this more expansive understanding of degrees of freedom—where degrees of freedom can be described for any behavior that has an explanation, even if it isn't law-governed—then we should be able to understand compatibilist-style free will as explicitly involving the elimination of degrees of freedom.

All of this by way of discussing how DOF-based weak emergence is related to weak emergence more generally. Another important question about the limits of the DOF-based implementation is whether it can be extended to help us understand strong emergence as well. In the book, Wilson presents this implementation exclusively as a variety of weak emergence. But it seems as though there ought to be a straightforward DOF-based implementation of Strong Emergence, along the following lines:

DOF-based Strong Emergence. There is (i) cotemporal material dependence of the emergent entity on the base entity and (ii) least one state of the emergent entity must be specified using strictly more degrees of freedom than are needed to specify the corresponding state of the system of entities upon which it cotemporally materially depends.

Moreover, at least at first glance, there are some relatively straightforward examples of DOF-based strong emergence in philosophy of physics. For instance, on at least some interpretations of the quantum formalism, when two (or more) particles become entangled one needs strictly speaking more degrees of freedom in order to specify the behavior of the system than one needs when specifying the behavior of the individual components of the system. For instance, if there are two particles whose spin states are entangled, it may be that all we can say about the behavior of the particles individually is that particle 1 has a .5 chance of having spin up in the z direction and a .5 chance of having spin down, and particle 2 has a .5 chance of having spin up in the z direction and a .5 chance of having spin down. But when it comes to the behavior of the system as a whole, there is an additional important pattern that comes to light, which is that when particle 1 has spin up, particle 2 has spin down. We capture this fact by saying that the wave-function of the system as a whole takes a certain form, from which it can be derived (using Born's rule) that the probability of the particles having the same spin is 0. A natural way of thinking about this situation is that the entanglement of the particles' spin states results in there being emergent entity—the quantum system—whose state must be specified using strictly more degrees of freedom than are needed to specify the states of the individual particles.

4. Ordinary Objects as an Example of DOF-based Weak Emergence

Another way to try to better understand DOF-based weak emergence is to train a closer eye on some of the examples that Wilson provides. The central example, as mentioned above is ordinary, microphysical objects, which Wilson argues are weakly emergent (in the DOF-sense) from quantum parameters. Here's a bit more of what Wilson says about ordinary objects being weakly emergent.

> What I will call 'classical' objects are ordinary objects of the sort whose static and dynamic behaviors are appropriately treated by classical or Newtonian mechanics, understood as comprising, roughly, Newton's three laws of motion and the gravitational and electromagnetic force laws (ibid.: 192).
>
> The characteristic states of classical objects do not functionally depend on the spins of the quantum components of these entities. Hence notwithstanding that the values of quantum parameters may in some cases lead to macroscopic differences—for example, readings on a measurement apparatus, and the like, as in the case of Schrodinger's cat—it remains the case that DOF such as quantum spin are eliminated…from those needed to characterize entities of the sort appropriately treated by classical mechanics (ibid.: 194).

It is supposed to follow from all this that ordinary objects satisfy the DOF-based account of weak emergence.

The first thing to note about this example is that the details may be dependent on the interpretation that we give of the quantum formalism in fairly complicated ways. Just as one example, in Bohmian mechanics, you can talk about the spin properties of a particle, and use such talk to make predictions, but when you look more carefully, all of the behavior of a quantum particle is explained by its initial position, its initial wavefunction (in the position basis), and the two dynamical laws (the guidance equation and Schrödinger's equation). So it's not entirely clear how to think about the elimination of spin states as a degree of freedom on that interpretation. Was it ever really a degree of freedom to begin with? At the very least there seems to be room for some interesting additional work to be done in sorting through how this example incorporates the details of various dynamical and ontological interpretations of the quantum formalism.

It's also interesting to note that it isn't immediately obvious why we need to discuss quantum parameters here at all. Consider the fact that ordinary objects like my coffee mug do not unexpectedly lift into the air and float around the room. This behavior is both predicted and explained by classical mechanics. One way of predicting and explaining it is by applying Newton's laws directly to the coffee mug. Another way is to use thermodynamics to predict and explain the behavior of the system involving the coffee cup, the table it is sitting on, and the air around it. Either way, note that you do not need to specify the position and momentum of each individual particle that is a part of the system.

It looks to me like this means that the coffee mug is a weakly emergent entity (on a DOF-based account). The mug cotemporally materially depends on the particles that compose it, but the state of the mug can be specified using strictly speaking fewer degrees of freedom than are needed to specify the states of the individual particles that compose the mug.

Call the argument just given the *classical argument for ordinary objects being weakly emergent* and Wilson's argument described above would be a *quantum argument for ordinary objects being weakly emergent*. At least at first glance it seems that the classical argument works just as well as the quantum argument for Wilson's purposes. And perhaps that's all to the good, since it means we don't have to sort through various interpretations of the quantum formalism in order to conclude that ordinary objects are in fact weakly emergent.

Of course, one thing that seems important about the classical argument is that our best physics says that classical particles with precise positions and momenta are not fundamental. But note first that it wasn't stated in the definition of DOF-based weak emergence that the base entities needed to be themselves fundamental. And second, as mentioned above, it is also controversial whether the quantum entities that instantiate properties like spin and which compose classical objects are themselves fundamental--those who think that the quantum formalism represents a field in a high-dimensional space, for instance, will disagree. So I don't think the non-fundamentality of classical particles is a good reason for treating the classical argument differently from the quantum argument unless you're willing to take a controversial stand with respect to quantum ontology.

4. When Is a Degree of Freedom Eliminated?

It's worth emphasizing the following complication in both the quantum and the classical arguments for the weak emergence of ordinary objects. In terms of the laws governing the base entities, it is *possible* for my coffee cup to lift up off the table and float around the room (or for it to, e.g. quantum tunnel through the table)—it's just very unlikely.

This is importantly different from the example that Wilson gives when discussing what it means for a degree of freedom to be eliminated. In Chapter 5, she writes:

> A case in point is that of a spherical conductor of the sort treated in electrostatics, which has DOF that are eliminated relative to the system of its composing entities; for while the E-field due to the free particles depends on all charged particles, the

> E-field due to a spherical conductor depends on the charges of particles on its surface. Certain quantum DOF are also eliminated in the classical (macroscopic) limit (ibid.: 179).

The case of the spherical conductor is one where degrees of freedom that are in other circumstances relevant to the behavior of the composing entities make *no difference at all* to the behavior of the electric field created by the conductor.

In the classical argument, the degrees of freedom that are in other circumstances relevant to the base entities (i.e. the exact position and momentum of each particle) are *very likely not to affect* the movement of the coffee mug. But there is some probability of them making quite a significant difference. The sense in which quantum degrees of freedom are eliminated in the coffee mug's behavior will also be merely probabilistic. (The exact details of the way in which they are probabilistic will depend on the interpretation one gives of the quantum formalism, but I will try to avoid going too far into the weeds here.)

So one of the key questions facing the DOF-based account is whether that is all that is necessary in order to say that a degree of freedom is eliminated—that it is *very likely not to* have an effect on the behavior of the emergent entity? Another way to put the same point: if a parameter is very likely not to have an effect on the behavior of some entity, is that sufficient to say that the behavior of that entity is *functionally independent* of that parameter?

In part this is just an interesting question to ask about this account. But it also gives rise to an interesting observation, namely that weak emergence might come in degrees, depending on the probability of the "eliminated" degree of freedom actually having an impact on the behavior of the emergent entity. For instance, in both the classical and the quantum case, the probability of a micro-parameter affecting the behavior of an ordinary object will typically decrease as the size of the ordinary object increases. So a larger ordinary object, like a school bus, might be thought of as weakly emergent *to a greater degree* than a smaller ordinary object, like a coffee mug, since the probability of a micro-parameter (e.g. the exact position and momenta of the individual particles) is less likely to affect the behavior of the school bus than the behavior of the coffee mug.

6. What Is Cotemporal Material Dependence?

All of the above discussion has focused on Wilson's understanding of autonomy. Let's turn now to think a bit more about her understanding of dependence. According to Wilson, the type of dependence involved in metaphysical emergence is *cotemporal material dependence*. As noted above, the central examples of emergence (e.g. the special science cases) are cases in which the base entities compose the emergent entities. One would be forgiven, then for thinking that cotemporal material dependence just is composition.

This is relatively straightforward, but it does raise some concerns, in particular about whether and to what extent Wilson's account of emergence can extend to contemporary debates in physics, where it isn't straightforward to understand the base entities as composing the emergent entities. Insofar as one thing helps compose another thing, both entities are standardly assumed to occupy the same physical space. But that assumption breaks down in the examples from philosophy of physics that I introduced at the beginning. If the based entity is a field in a high-dimensional space how can that field composed entities in ordinary 3-dimensional space? And in interpretations of quantum gravity on which spacetime itself is the emergent entity, it similarly isn't obvious in what sense the base entities would compose the emergent entities.

Comments in the conclusion of the book show that Wilson is aware of this, and is leaving it to future work. That's fair enough, but it's worth pushing a little here, if only to try to get a sense of how this future work is likely to develop.

For instance, in some places in the book, Wilson says that cotemporal material dependence can be "understood as involving both (physical) substance monism and the minimal nomological supervenience of emergent feature types on base feature types" (ibid.: 73). One might take this as an indication that maybe physical substance monism in combination with minimal nomological supervenience is a sufficient condition for cotemporal material dependence.

This is likely to help with the extension of the account to at least some of the contemporary cases in physics. But it does raise some other questions. In particular, it seems like in some cases, composition as an indicator of cotemporal material dependence and minimal nomological supervenience as an indicator of cotemporal material dependence might be in tension. For instance, consider again the cases of quantum entanglement that I suggested in section 2 were potential cases of DOF-based strong emergence. Are these actually cases in which the emergent entity (the entangled system) in fact cotemporally materially depends on the base entities (the individual particles)? It isn't entirely clear.

On the one hand, the entangled system is plausibly composed by the individual particles. But also, the behavior of the entangled system does not nomologically supervene on the behavior of the individual particles—indeed it is the other way around. That's why the case seems like one that would give rise to DOF-based strong emergence.

In fact, if (substance monism plus) minimal nomological supervenience is a sufficient condition for cotemporal material dependence, then maybe cases of entanglement are better understood as cases where the individual particles are *weakly* emergent from the entangled system. After all, on this understanding, the individual particles cotemporally material dependent on the entangled system and you need *fewer* degrees of freedom in order to describe the behavior of those particles.

At any rate, all of this suggests that in order to understand the implications of Wilson's account—and in particular the DOF-based implementation of the account—in philosophy of physics, one will need to not only delve into the complexities of degrees of freedom as indicators of autonomy, but also into cotemporal material dependence as well.

7. Conclusion

The above discussion shows just how rich Wilson's account of metaphysical emergence is by exploring the ways in which just one implementation of her account (the degrees of freedom-based implementation) can be applied to debates within philosophy of physics. The questions raised above are, I think, quite difficult ones. But that just shows how interesting the concept of metaphysical emergence is and the great potential for important further work on this topic within the philosophy of physics.[5]

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