The Curious Case of Spacetime Emergence

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Abstract

Work in quantum gravity suggests that spacetime is not fundamental. Rather, spacetime emerges from an underlying, non-spatiotemporal reality. After clarifying the type of emergence at issue, I argue that standard conceptions of emergence available in metaphysics won't work for the emergence of spacetime. I go on to consider spacetime functionalism as a way to make sense of spacetime emergence. I argue that a functionalist approach to spacetime modelled on mental state functionalism is not a viable alternative to the standard conception of emergence in metaphysics. I go on to consider an alternative: 'partial' functionalism, whereby certain aspects of spacetime are functionalised, rather than spacetime as a whole.

1. Introduction

Recent work in fundamental physics suggests that spacetime does not exist.[1] The loss of spacetime arises with respect to theories of quantum gravity. These theories aim to reconcile our two most successful empirical theories—general relativity and quantum mechanics—to produce an account of gravity at small scales. Both loop quantum gravity and canonical quantum gravity appear to lack any spatiotemporal structure (see, for discussion, Rovelli (2004); Butterfield and Isham (1999); Kuchar (1992)). Some string theories also seem to lack spatiotemporal structure. This is evidenced by the presence of theory duals—mathematically equivalent formulations—in which there is no spacetime (Huggett and Wüthrich, 2013, pp. 280–281).[2] Indeed, it is not just spacetime that fails to exist in theories of quantum gravity. These theories seem to lack any spatial or temporal metric structure altogether.

As a result, theories of quantum gravity face a *prima facie* threat of empirical incoherence. A theory is empirically incoherent when the truth of that theory undermines its justification (Barrett, 1999, §4.5.2). The justification for a physical theory lies ultimately with observation. The theory must be confirmed or disconfirmed by the available observational evidence. In order for there to be observational evidence for a physical theory, we require at least three things: we need determinate spatial, temporal or spatiotemporal locations at which things can be observed, we need material entities at those locations, and

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[1] For discussion, see Anderson (2012); Bain (2013); Barbour (1999); Butterfield and Isham (1999); Kuchar (1992); Oriti (2014); Rovelli (2004)

[2] Wave-function realism interpretations of quantum mechanics also appear to lack spacetime. For discussion see Maudlin (2007); Ney (2015).

we require a relationship between located entities and located observers of the kind that can underwrite confirmation. In particular, we require a causal relationship whereby located entities can affect observers.

The trouble is that without any metric structure there are no spatiotemporal locations at which entities can be observed. The lack of a metric structure also seems to result in the loss of causation since, on the face of it, causation requires (at least) time to exist.[3] Thus, if a theory of quantum gravity is true, then the features needed for observation appear to be absent from reality. If, however, one manages to successfully confirm such a theory via observation, that can only be because there is enough metric structure in reality to support spatiotemporally located entities, observers and causation. And so any observation that might confirm the predictions of a theory of quantum gravity also ends up falsifying it.[4]

In response, a number of philosophers have denied that theories of quantum gravity imply the non-existence of spacetime. Rather, these theories imply only that spacetime is not fundamental. Spacetime is thus treated as an emergent phenomenon.[5] This gives us back the metric structure of spacetime at non-fundamental levels. We can then propagate matter fields over that structure in the usual way, which gives us back material entities. These entities can then form the basis of empirical observations, by affecting observers through standard causal pathways. Observation of these entities provides evidence for or against a theory of quantum gravity indirectly. Justification is mediated by inference to the best explanation, whereby facts about the underlying non-spatiotemporal reality are inferred via the role that those facts play in explaining the nature of observable entities.

The emergence of spacetime thus provides a promising way of avoiding the threat of empirical incoherence. As Wüthrich (forthcoming, p. 4) discusses, however, there are really two dimensions to the emergence of spacetime. First, there is the emergence of spacetime in the inter-theoretic sense. Emergence of this kind is compatible with reduction, and specifies the way in which the laws of one theory can be derived from the laws of another via bridge laws (see Butterfield and Isham (1999) and Crowther (2017, pp. 7–11)). This notion of emergence sits entirely at the level of theories, and involves relations of deducibility between quantum gravity and general relativity. Spacetime emerges in the sense that the laws of general relativity are deducible from a more fundamental theory.

Second, there is a conception of emergence as a metaphysical relation between entities (Lam and Esfeld (2013, p. 291) call this 'ontological emergence'). If spacetime emerges in this sense, then spacetime exists. Given that spacetime exists, and given that it does not exist fundamentally, it is important to provide an account of the metaphysical relationship between the more fundamental, non-spatiotemporal reality and spacetime. This metaphysical species of emergence is not an inter-theoretic relation, it is a relation 'in the world'.

The two notions of emergence are obviously related. The entities that must be linked by a metaphysical conception of emergence are the posits of the two theories that are linked

[3] Causation is usually thought to be a relation between events, which are individuated by their spatiotemporal locations. Baron and Miller (2014); Tallant (forthcoming) argue that causation without time is possible. However, the resulting notion of causation may not be sufficient for observation (see Braddon-Mitchell and Miller (forthcoming)).

[4] Braddon-Mitchell and Miller (forthcoming), Healey (2002), Huggett and Wüthrich (2013) and Maudlin (2007), all raise a version of this problem, though aimed at different theories in each case.

[5] See, for example, Bain (2013); Butterfield and Isham (1999); Crowther (2016, 2017); Huggett and Wüthrich (2013); Rovelli (2004); Wüthrich (forthcoming).

by the inter-theoretic notion of emergence. If all goes well, the inter-theoretic conception of emergence is the piece of theoretical structure that reflects or otherwise represents the metaphysical instance of emergence in the world.

My focus in this paper is exclusively on the second notion of emergence: emergence as a relation between entities. I will argue, first, that a common way of understanding emergence within metaphysics won't work for the case of spacetime emergence (§3). I will then turn to a more promising alternative: spacetime functionalism. My goal is to clarify the kind of functionalism that is needed. I will differentiate between two versions of spacetime functionalism: a version that is directly analogous to functionalism about the mind, and a weaker version that departs from functionalism about the mind in certain respects. In §4 will argue that the first form of functionalism comes up short, because it requires the same part-whole thinking embedded in the notion of emergence discussed in §3. I will close by elucidating the second version of functionalism in a bit more detail. I will begin in §2 by saying more about emergence in metaphysics.

2. Emergence

All types of emergence possess two common features. First, when some entity B emerges from some entity A, B is dependent on A. Second, despite the fact that B is dependent on A, B is autonomous from A in a certain respect. For instance, B might be a novel phenomenon. Or B might be robust with respect to changes to A, in this sense: there is some class of changes to A that don't result in changes to B.

There are at least two types of emergence: weak and strong. Strong emergence is generally taken to imply at least one of two things. First, when B is strongly emergent from A, there is a failure of *deducibility*, in this sense: a description of B cannot be derived from a description of A. Second, when B is strongly emergent from A, B cannot be explained in terms of A. There is an explanatory gap. In a case of weak emergence, by contrast, a description of B is still derivable from a description of A in principle, even if no-one knows how to carry out such a derivation. Similarly, B is still explicable in terms of A even if, again, no-one knows what the explanation looks like.

It is unclear whether there are any genuine cases of strong emergence. The most promising example is consciousness. For some, conscious mental states emerge from physical states despite the fact that mental states cannot be explained in terms of the physical states from which they emerge, and despite the fact that a description of the mental states cannot be derived from a description of the underlying physical states. For present purposes, however, I will assume that the case of spacetime emergence is an example of *weak* and not *strong* emergence. We have no reason yet to suppose that a description of spacetime cannot be derived from an underlying theory of quantum gravity, and nor do we have a reason to suppose that spacetime cannot be explained in terms of something more fundamental.

In the wider metaphysics literature, there is little agreement about how to formulate the two dimensions of emergence when it comes to the weak emergence of one entity from another. That being said, there appears to be a common thread running through most accounts. This common thread concerns the dependence dimension. Mereological composition is usually thought to be at least a necessary condition on dependence: the emergent entity is composed of the entities from which it emerges. To see the importance of composition to current definitions of weak emergence consider the following potted sample of such definitions. I have bolded the common element.

> *Emergence of higher-level properties:* All properties of higher level entities arise out of the **properties and relations that characterize their constituent parts**. (Kim, 1999, p. 21)
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> emergence1 ... refers to the idea that a higher order feature of a system can be understood by a **complete explication of the parts of a system and their interactions**. (Feinberg, 2001, p. 126)
>
> Modest Kind Emergence. **The whole has features that are *different in kind* from those of its parts (or alternatively that *could* be had by its parts).** ... a mouse might be alive even if none of its parts (or at least none of its subcellular parts) were alive. (Gulick, 2001, p. 17)
>
> **Emergence is about the properties of wholes compared to those of their parts, about systems having properties that their objects in isolation do not have.** (de Haan, 2006, p. 294)
>
> If P is a property of w, then P is emergent iff **P supervenes with nomological necessity, but not with logical necessity, on the properties of the parts of w.** (Van Cleve, 1990, p. 222)
>
> ... the 'emergence base' is not the reason the emergent property is instantiated—**it is the move from the i-level to the i+1-level by fusion that gives us emergence.** (Humphreys, 1997, p. 14)
>
> The criteria for emergent properties I take from the literature as more or less canonical are: (i) novelty of the properties in a system, (ii) that the properties result from **'essential interactions' of constituent parts of a system**, and (iii) that the laws governing properties be irreducible to laws about lower-level properties. (Reuger, 2000, p. 299)
>
> Accounts of emergence typically suppose that... systems, processes, particulars ... **depend on lower-level, ultimately physical entities at least in that the former are exhaustively composed of the latter...** The assumption of compositional dependence reflects the intended contrast with dualist accounts. (Wilson, 2016, p. 364)

Note that composition is not typically thought to be both necessary and sufficient for weak emergence (Humphreys (1997) above is the exception). Rather, composition must be supplemented with something else. Usually, with causation or interaction of some kind. In the context of emergent spacetime, the causal dimension of weak emergence is a problem. As already noted, time appears to be necessary for causation. If fundamental reality lacks spatial, temporal or spatiotemporal properties, then it is unclear how there can be causal interaction between the components that fuse together to form spacetime.

For some, worries about causation alone might sink any hope of understanding the emergence of spacetime via the conception of emergence embodied in the definitions above. Arguably, however, causal interaction is not necessary for emergence. It does not appear in all such definitions. Moreover, there may be non-causal notions of interaction that can underwrite emergence. For instance, gravitational interactions and geometric interactions may provide a non-causal alternative to causal structure.[6]

At any rate, my focus is on the mereological element of emergence. As we shall see, the necessity of composition poses a problem for the application of standard notions of weak emergence to the emergence of spacetime. The problem is a purely conceptual one. The concept of parthood breaks down when it is applied beyond its usual application within a spatiotemporal context, and so a new notion of emergence is needed.

First, however, I will briefly explain why a mereological conception of emergence is tempting. After all, while many accounts of emergence seem to presuppose a notion of composition, this is not universal.[7] It is, however, no accident that a mereological conception of weak emergence has become popular in metaphysics (if not canonical, as Reuger suggests above). Many cases of weak emergence are ones in which the emergent phenomenon appears to be composed of something at a more fundamental level.

Perhaps the most compelling example of this is the weak emergence of macro-level phenomena from micro-level phenomena. It is very natural to characterise this emergence in compositional terms. Doing so helps us to understand the relationship between the macro-level entity and the micro-level entity in a straightforward manner. A macro-level phenomenon such as water is composed of lower-level entities, namely H_2O molecules, and it is because water is composed of H_2O molecules with certain properties that water has properties like wetness and viscosity.

Composition also seems useful for characterising the weak emergence of micro-phenomena from lower-level entities. Molecules are composed of atoms, which are composed of sub-atomic particles, which are, in turn, identified with excitations in fields. Indeed, when it comes to understanding the inter-level relationships between entities quite generally, it is very natural to think in compositional terms. It is for this reason that some metaphysicians, like Paul (2012), believe that composition plays a privileged role in constructing the world as we know it.

In the case of emergent spacetime, the kind of emergence that we are dealing with is broadly of apiece with these other cases of weak emergence. We have an entity at one level—spacetime—and we must try to account for the existence of that entity in terms of something at a lower level. Moreover, the level distinction appears to be of broadly the same kind as other cases of weak emergence: it is a matter of scale (in this case: energy scale). Since many of our most successful accounts of this kind of inter-level emergence make use of composition, we have at least some reason to apply it to the case of quantum gravity as well.[8]

[6]A number of philosophers suggest that there is a non-causal, mathematical style of explanation that plays a substantive role in scientific explanation. Gravitational explanations and geometric explanations are often cited as examples, see Colyvan (2001, pp. 50–52).

[7]It may be false for strong emergence, see Barnes (2012).

[8]One might argue that some approaches cannot be understood in compositional terms, such as Hu's (1999) account of emergent gravity, and so we shouldn't try to capture quantum gravity inside this framework. However, note that Hu appears to characterise his own emergent gravity program in compositional terms (of course we would need to look at the details):

> Something assumed to be 'elementary' at a lower energy or with a coarser resolution at one time will later be found to be a composite at a higher energy or under a finer resolution... Constructing the macroscopic structure and dynamics from known microscopic constituents is often easier, such as getting hydrodynamics from molecular dynamics. Going the other

3. Parthood and Emergence

I am not the first to worry about the use of composition as the basis for spacetime emergence.[9] However, the point has not been made as forcefully as it can be. To demonstrate the problem, I will start with a certain picture of spacetime. According to this picture, spacetime is mereologically composed of spacetime regions. Spacetime regions are, in turn, composed of non-spatiotemporal entities, which are the elementary entities posited by a fundamental theory of quantum gravity.

The trouble comes this way. There is an intimate relationship between location and parthood. Intuitively, the location of an object is a function of the location of its parts. Sider (2007, p. 25) describes this intimacy in terms of the following inheritance principle:

> **Inheritance of Location:** If x is part of y, then y is located wherever x is located.

The inheritance of location is, according to Sider, one of the conceptually significant aspects of parthood. As he puts the point:

> The locations of a thing's parts are automatically reflected in the thing's location ... Parthood is alone in this respect; my location is not tied to the locations of my relatives, things I own, things I am near, and so on ... our actual usage of 'located' reflects the peculiar intimacy of parthood; we choose a meaning that matches my boundaries with my parts' locations. (Sider, 2007, p. 25)

The inheritance of location poses a problem for the composition of spacetime regions from non-spatiotemporal entities. To see this, consider some spacetime region R. R is located within spacetime more generally: it has a determinate spatiotemporal location within the manifold. Now, suppose that for every part of R, $x_1 ... x_n$, each of the x_n lacks a spatiotemporal location. Then it is not true that R is located wherever its parts are. That's because R has a spatiotemporal location, but none of its parts do. So, if the inheritance of location is true, then R cannot be composed of parts that lack a spatiotemporal location. But the inheritance of location *is* true. So, spacetime regions cannot be composed of non-spatiotemporal entities. Call this: the argument from intimacy.

I anticipate four responses to the argument from intimacy. First, consider a person's body. A body is composed of various parts: knees, shoulders, hands, toes and so on. Nonetheless, one might argue, the body is not located where, say, the hand is. There is, however, no resulting puzzle concerning how bodies can be composed partly of hands. And so, by analogy, there is no puzzle in the case of spacetime either. Regions of spacetime, like a person's body, are composed of parts without being located anywhere that the parts are located.[10]

> way, i.e., deducing molecular features from hydrodynamics, is more difficult. For spacetime structures, the former is the task of emergent gravity, the latter is the goal of quantum gravity. (Hu, 2009, p. 3)

Moreover, even if the compositional approach is a non-starter for Hu's view, the causal sets approach and loop quantum gravity appear to posit physical entities at high energy scales that could potentially compose entities at low energies.

[9] Wüthrich (forthcoming); Lam and Wüthrich (2018) and Ney (2015) object to mereology as a basis for spacetime emergence.

[10] I am grateful to an anonymous referee for raising this issue.

This response can be addressed by distinguishing two notions of location: exact location and weak location. Gilmore (2018) provides the following informal gloss on exact location:

> x is exactly located at a region y if and only if x has (or has-at-y) exactly the same shape and size as y and stands (or stands-at-y) in all the same spatial or spatiotemporal relations to other entities as does y.

And Parsons (2007, p. 203) explains weak location as follows:

> x is weakly located at a region y if and only if y is 'not completely free of' x

So, for instance, suppose that Sara is standing outside the lounge room with her arm through the doorway into the hall. In this situation, she is exactly located in a region that partially overlaps the lounge room and that partially overlaps the hall. This region has the same size and shape as Sara and stands in all of the same spatiotemporal relations as she does. Sara is also weakly located in both the lounge room and the hall (despite the fact that Sara is not exactly located in either room) because neither the lounge room nor the hall is 'completely free' of Sara.

The difference between weak and exact location helps to illuminate the difference between the body case and the spacetime case. It is true that the body is not exactly located at the region occupied by any one of its parts alone. For that to be the case, the entire body would need to be where, say, the hand is. But the region occupied by the hand does not have the right size or shape for the body to be located there. Thus, a version of Sider's inheritance principle along the lines of 'if x is part of y, then y is *exactly* located wherever x is *exactly* located' is false. The intended principle, however, is a mixture of weak and exact location, namely: 'if x is part of y, then y is weakly located wherever x is exactly located.' This principle is true in the body case and seems to capture an important relationship between parts and wholes.

For example, suppose that Sara is sitting by the pool, dangling one leg over the edge. Sara is clearly in the water in at least a weak sense, despite the fact that her whole body isn't in the water. The pool is not completely free of Sara because her leg is in there. More generally, any location that houses one of Sara's parts is not completely free of Sara. If Sider's principle were false and Sara were not weakly located wherever her parts are exactly located, then she wouldn't be in the pool in any sense despite the pool not being completely free of her.

The spacetime case falsifies Sider's inheritance principle so understood. Unlike bodies, spacetime regions are not even weakly located where there parts are exactly located, because none of the parts are located in spacetime whereas the region is. This is like saying that Sara is in the lounge room despite the fact that no part of Sara is in the lounge room: not her hand, not her foot, not her head, not her heart: nothing.

This brings us to the second response to the argument from intimacy. One might deny that spacetime regions are located within spacetime. Because spacetime regions are not located, the resulting picture leaves room for those regions to be composed of non-spatiotemporal parts without falsifying the inheritance of location. But the picture is unsatisfactory, for two reasons. First, it is difficult to understand how it is that spacetime regions fail to be located within spacetime. If regions are not located in spacetime, then they should not have any spatiotemporal properties. But they clearly do: regions are metrically related within the four-dimensional geometry that characterises general relativity.

Second, and relatedly, if spacetime regions are not located within spacetime, then any object that is located at a spacetime region would not, itself, be located in spacetime. For instance, Sydney is located at a certain spatiotemporal region R. Despite this, Sydney would not be located within spacetime because while it is located at R, that region itself is not located anywhere in spacetime. Denying this implication and maintaining that something is located in spacetime by being located in regions that are not located in spacetime is a bit like saying that Sara is located in France because she is in Nice despite the fact that Nice is not in France. Regions need to be located within spacetime in order to make sense of generic, object location within spacetime.

The third response to the argument from intimacy is to deny that the emergence of spacetime should be routed through spacetime regions, mereologically speaking. Thus, we should relax the assumptions that I used to frame the problem. Once we have relaxed these assumptions, we can say that spacetime emerges in virtue of being directly composed from a range of non-spatiotemporally located objects. Spacetime regions are then located within spacetime. Presumably, spacetime regions are still parts of spacetime. The thought is just that spacetime is composed of non-spatiotemporal parts as well.

This option faces a dilemma. Either spacetime is spatiotemporally located or it is not. If spacetime is spatiotemporally located then it is not true that spacetime is located wherever its parts are located. That's because spacetime is composed of at least some parts that are not spatiotemporally located. So, the inheritance of location fails again. If, on the other hand, spacetime is not spatiotemporally located, then neither are spacetime regions. That's because if spacetime is not spatiotemporally located, while the spacetime regions (which are parts of spacetime) are, then it is not true that spacetime is weakly located wherever its parts are located and so the inheritance of location still fails. If, however, spacetime regions are not spatiotemporally located then, as before, it is difficult to make sense of the location of objects within spacetime.

The only way to avoid the dilemma is to maintain that spacetime regions are not parts of spacetime, and thus that spacetime is wholly composed of entities that lack a spatiotemporal location. This frees one up to maintain that spacetime is not spatiotemporally located without violating the inheritance of location, since none of its parts are spatiotemporally located (because it has no spacetime regions as parts which are located). The trouble is that the resulting picture is bizarre. Spacetime does not have any regions as parts. Given this, it is difficult to make sense of the claim that an object is located in spacetime, since spacetime has no regions as parts at which the object can be located. It is therefore not even clear in what sense we are still talking about spacetime, given that it cannot do the work that is usually associated with it: namely, locating objects.

The fourth response to the argument from intimacy—and the one that I suspect will tempt most people—is to deny the inheritance of location for parthood. It is just not true that if x is part of y, then y is weakly located wherever x is exactly located. Precisely what consideration of the spacetime case teaches us is that parthood is not intimate, *pace* Sider's suggestion. On its own, this might not seem like much of a cost. At best, we have a strong intuition that the inheritance of location is true. We can, then, just deny the intuition and press on.

However, to frame the cost as merely the denial of an intuition is to understate the problem. For once we see how the problem goes for the inheritance of location, it is possible to raise similar problems for a range of other plausible claims about parthood. Here are three such claims (I'm sure there are others). First, consider Markosian's (2014, p. 5) Subregion Theory of Parthood (STP):

> **STP:** For any x and for any y, x is a part of y iff the region occupied by x is a subregion of the region occupied by y.

STP is highly intuitive. As Markosian puts the point:

> I would say that of all the main answers to all the various questions concerning the mereology of physical objects, STP is probably the most intuitive. Only a complete mereological radical would deny that occupying a subregion of the region occupied by an object is a *necessary* condition for being a part of that object. (Markosian, 2014, p. 5)

A similar point is made by Braddon-Mitchell and Miller (2006, pp. 223–224), who write that:

> It is at least *necessary* that a proper spatial part is an object that occupies a region of space that is a sub-region occupied by the whole. This minimal necessary condition presupposes very little.

This minimal necessary condition is difficult to reconcile with the claim that spacetime regions have entirely non-spatiotemporal parts. For any such region R, every proper part of R, $x_1 ... x_n$ fails to occupy a spatiotemporal region. Because R is spatiotemporal however, R does occupy a spatiotemporal region (the region that wholly overlaps just that region). Given that R occupies a spatiotemporal region, each of its proper parts must occupy some sub-region of the region that R occupies. If, however, each of the x_n fails to occupy *any* spatiotemporal region, then they fail to occupy a sub-region of R. So, the necessary condition embedded in STP—like the inheritance of location—is false for spacetime regions.

Another claim that is falsified by the composition of spacetime regions by non-spatiotemporal entities is this: for any y that is spatiotemporally located, every proper part of y is smaller than y itself. As before, consider some spacetime region R. Suppose that R is composed entirely of parts $x_1 ... x_n$ that are not spatiotemporally located. Then it is false that every proper part of R is smaller than R itself. That's because one of the x_n is smaller than R only if it is coherent to assign one of the x_n a size in the same sense of size that applies to R. But the x_n are not spatiotemporally located and so *a fortiori* the x_n do not have a size in the relevant sense.

Third, consider the following intuition. Each part of a spatiotemporal located entity contributes something to the extent of that entity, with the composition relation summing the extents of each part. We can formulate this intuitive idea as follows:

> **The Compositionality of Extension:** For any y that is spatiotemporally located and for any $x_1 ... x_n$, if $x_1 ... x_n$ compose y, then the spatiotemporal extent of y is a function of the spatiotemporal extensions of $x_1 ... x_n$ and the spatiotemporal relations between $x_1 ... x_n$.

A spacetime region R that is composed entirely of non-spatiotemporal parts $x_1 ... x_n$ violates the compositionality of extension. If the x_n have no spatiotemporal properties, then they lack any extension whatsoever in a particularly strong sense: the concept of 'extension' is misapplied to these entities. No matter what the function f is, and thus no matter how we compose the x_n, we cannot get the extent of R from entities to which the concept of 'extension' is misapplied.

Taken together, the four claims above (including the inheritance of location) provide us with a conceptual grip on the notion of 'parthood'. In order for spacetime regions to be mereologically composed of entities that are not spatiotemporally located, all four claims must be denied. However, it is very difficult to see what is left of the parthood concept once these claims are denied. Of course, one can always define a new notion: parthood* and stipulate that this new notion satisfies the formal axioms of mereology. The point, however, is that in so far as we understand parthood over and above its formal properties, that understanding is not available to us as a basis for comprehending parthood*. So, while spacetime regions might be composed* of entities that are not spatiotemporally located, it is rather unclear what this means. Granted, we have the purely formal properties of parthood* to guide us, but these formal properties are possessed by a great many relations, and so they do little to shed light on a notion of composition*. In short, in the absence of a substantive theory of parthood*, parthood* cannot be used as a basis for the emergence of spacetime without rendering the associated notion of emergence conceptually mysterious.[11]

What should we conclude from this? We should certainly not conclude that spacetime isn't emergent. Whether spacetime is emergent is an empirical matter that must be settled by our best science. Rather, we should conclude that the standard metaphysical conception of emergence won't do for spacetime emergence, at least not if the goal is to render the relevant variety of emergence understandable. Lam and Wüthrich (2018) demur:

> ... the framework of QG may well use mereological tools without relying on spacetime, and may well appeal to general, non-spatiotemporal composition relations.

They do not expand on this remark, and so it is difficult to know what to make of their suggestion. One option, however, might be to take the notion of qualitative parthood (a.k.a. logical parthood) advocated by Paul (2002) and offer that up as a candidate for parthood*.[12] Indeed, Paul's notion of qualitative parthood allows for the fusion of properties, which may not be located anywhere in physical reality. And so, her view does, in principle, allow for the fusion of entities that are not spatiotemporally located. That being said, there is little reason to suppose that Paul's notion of qualitative parthood falsifies the inheritance of location in the manner described here. While qualitative parthood can be used to fuse entities that lack a spatiotemporal location, Paul never shows how to use qualitative parthood to fuse entities that lack a spatiotemporal location to produce entities that possess one. If qualitative parthood does not falsify the inheritance of location, however, then it is not a good candidate to be parthood*, which violates inheritance necessarily.

Moreover, as Paul (2012) makes clear elsewhere, the notion of qualitative parthood yields an account of spacetime only when it is situated within a broader bundle theory of objects, in which properties are fused with primitive spatiotemporal relations to produce a

[11] Braddon-Mitchell and Miller (2006, pp. 224–225) also argue that the concept of a part breaks down when STP is falsified.

[12] Le Bihan (forthcoming) makes this suggestion.

spatiotemporal manifold. On this picture, the properties that compose a spatiotemporally located object are located wherever the object is located and the object itself is located wherever the spatiotemporal properties it has as parts locate it. Again, the inheritance of location is preserved. What is needed to make sense of parthood* is a clear example of a viable parthood concept that violates inheritance. Paul's account is not much use in this respect.

There are thus two options before us. First, we can try to develop a new conception of parthood by filling out parthood*. This can then be used to develop a mereological conception of spacetime emergence.[13] Second, we can work out how to proceed without mereology and thus attempt to reimagine spacetime emergence. As Wüthrich (forthcoming, p. 10), in a different mood, puts the point:

> ... the widespread and intuitive 'constitutionalism', i.e., the view according to which our experienced world is ultimately constituted by, or built up from, elementary building blocks or atoms of spatiotemporal 'beables', may not offer an adequate understanding of the truly puzzling situations we presently face in fundamental physics.

Lam and Wüthrich (2018) have recently suggested one alternative to the 'building blocks' picture described above: spacetime functionalism. In what remains I will attempt to clarify the broad spacetime functionalist picture. I will argue, first, that the standard version of functionalism that we find in the philosophy of mind is not appropriate for the case of spacetime functionalism.[14] After that, I will use the broad functionalist approach to offer an alternative. Note that I don't take what I say in the next section to be an objection against Lam and Wüthrich's project, since it is not clear that their view is supposed to be the spacetime analogue of mental state functionalism. Instead, I take it to be a necessary point of clarification, one that helps to illuminate the kind of functionalism that is needed in the case of spacetime.

4. Spacetime Functionalism

Functionalism about mental states aims to fully reduce mental states to functional kinds. So, for instance, consider a particular mental state: a pain. A functionalist about pain maintains that pain can be completely characterised, without loss, in terms of a particular functional role. It is then both necessary and sufficient for pains to exist that something occupies the relevant functional role. Standard functionalism about mental states is thus not an eliminativist doctrine. Mental states genuinely exist, and they exist in virtue of a complete reduction of mental states to functional role specifications. According to a version of spacetime functionalism that is modelled on standard functionalism about the mind, then, a complete characterisation of spacetime is given in terms of a functional role

[13]One option that has been suggested to me by a referee for this journal is to look more carefully at Causal Set Theory. Like LQG, Causal Set Theory, lacks fundamental spacetime (see Huggett and Wüthrich (2013)). Nonetheless, the basic elements of Causal Set Theory do seem to be isomorphic to a part-whole structure of some kind. I lack the space to consider this option here, but I agree broadly that causal set theory provides a more natural basis for developing a notion of parthood* and a mereological conception of spacetime emergence.

[14]Ney (2015) briefly argues against the use of spacetime functionalism as the basis for emergence. The argument I will present goes beyond the cursory remarks that Ney makes, but is broadly similar in spirit.

specification. Spacetime, like pain, exists so long as something is playing the relevant functional role.

Spacetime functionalism of this kind proceeds in two broad stages. First, one must specify the functional role for spacetime. This functional role characterises spacetime completely, and without loss. Functional roles in the philosophy of mind are specified in terms of a network of causal inputs, causal interactions and causal outputs. An alternative functional characterisation must be provided in the case of spacetime, since, as noted, causation is a temporal notion, and so it is unclear how a non-spatiotemporal ontology could play a functional role that is causally specified. The most conceptually straightforward way to provide a complete characterisation of spacetime in terms of a single functional role is to find the Ramsay sentence for spacetime that captures the theoretical role that spacetime plays in physics (I say 'conceptually straightforward' because it is technically very challenging). The relevant Ramsay sentence will specify those general features that something must possess in order to play the spacetime role. Exactly what these features might be is up for debate. Knox (forthcoming) suggests that it is sufficient for something to play the spacetime role if it describes the structure of inertial frames in coordinate terms. Lam and Wüthrich (2018) suggest that localisation, spatial distance, temporal duration and the topological aspect of spacetime might all be open to functional specification. For present purposes, it doesn't really matter what the spacetime role is. All that matters is that the spacetime role is not specified causally.

Second, one must provide an account of what, if anything, plays the relevant functional role. The entities that play the spacetime role are alleged to be the fundamental, non-spatiotemporal entities posited by a theory of quantum gravity. Because of this it is difficult to know exactly how viable the second stage of the functionalist project is without a completed theory of quantum gravity in hand. Still, through a careful consideration of two important approaches to quantum gravity—loop quantum gravity and the causal sets approach—Lam and Wüthrich (2018) provide a proof of concept for how the second stage in a functional characterisation of spacetime might be completed. They show, in both cases, that something can play (at least) the localising role that they attribute to spacetime.

Unfortunately, a functionalist approach to spacetime emergence of this kind won't do because it requires a notion of composition. In order to see the problem, it is important to differentiate between two broad varieties of functionalism: role functionalism and realiser functionalism. The difference is clear in the case of mental states, like pain. According to functionalists about pain, there is a particular functional role associated with the concept of pain, characterised by causal inputs (hot pokers, pinches, punches and the like), causal interactions with other mental states (such as forming beliefs like 'I am in pain') and causal outputs (such as yelling "stop pinching me!"). According to *realiser* functionalism, pain just is whatever plays the pain role. So, for instance, if C-fibres firing is what plays the pain role in humans, then pain just *is* C-fibres firing. According to *role* functionalism, by contrast, 'being in pain' is the higher-order property of being in some state or other that realises the pain role. So, for instance, a human might be in pain because they have the property of being in a state that realises the pain role, namely: the state of having their C-fibres fire. However, an alien with a completely different physiology can also be in pain and that's because they have the property of being in a state that realises the pain role as well, even though this state is not the state of C-fibres firing.

The same distinction needs to be drawn in the case of spacetime functionalism. According to realiser spacetime functionalism, spacetime just is whatever plays the spacetime role. Thus, just as pain is identified with C-fibres firing, spacetime just is whatever has the structure of inertial frames (say), or whatever possesses the right combination of spatial distance, temporal duration and topology. According to role spacetime functionalism, by contrast, 'being spatiotemporal' is the higher-order property of a physical system being in a state that realises the spacetime role.

Consider, first, realiser spacetime functionalism. As noted, this view identifies spacetime with whatever plays the spacetime role. Now, either the entity, E, that plays the spacetime role is an elementary posit from a theory of quantum gravity, or E is not a posit of such a theory. Suppose, first, that E is such a posit. Then it follows, from spacetime functionalism, that E just is spacetime. Since the elementary posits of such a theory are not supposed to be spatiotemporal but, rather, are supposed to be different in kind, and lacking in spatial, temporal and spatiotemporal properties, the entity that plays the spacetime role cannot be an elementary posit of a theory of quantum gravity.

Suppose, then, that E is not an elementary posit of a fundamental theory of quantum gravity. In this situation, the emergence question is left wide-open. For now a further explanation is needed of how E, which is spatiotemporal, emerges from the non-spatiotemporal ontology of a theory of quantum gravity. Identifying the entity that plays the spacetime role with something that is not an elementary posit of a theory of quantum gravity merely shifts the bump in the carpet.

Similar considerations apply to role spacetime functionalism. As noted, role spacetime functionalism is the view that 'being spatiotemporal' is the higher-order property of being in a state that plays the spacetime role. Either the entity that is in this state is an elementary posit of a theory of quantum gravity, or it is not. If it is, then that entity possesses the property of 'being spatiotemporal'. And so, the entity posited by a theory of quantum gravity turns out to be spatiotemporal after all. But it is not supposed to be spatiotemporal. Let us suppose, then, that there is some further entity that is not an elementary posit of a theory of quantum gravity and that this entity is in a state that plays the spacetime role. This further entity unproblematically possesses the property of being spatiotemporal. But, once again, the question of emergence is left open. For what we want to know now is how this spatiotemporal entity emerges from the elementary entities posited by a theory of quantum gravity.

Now, there is an obvious response to the two problems just outlined. Consider the following analogous argument.[15] Suppose that a group of quarks functionally realises a blue shoe. Suppose we then ask: what is the blue shoe? According to realiser functionalism, we identify the blue shoe with whatever plays the blue shoe role. Thus, the group of quarks just is a blue shoe. But that's madness! No quark is a blue shoe. Similarly, according to role functionalism we identify the blue shoe with the higher-order property of being in a state that plays the blue shoe role. The group of quarks in question has this property, because they are in the relevant state. But then it follows that the group of quarks just is a blue shoe, because it possesses the relevant property. But again, no quark is a blue shoe.

It should be evident where the argument goes wrong in the quark case. Both role functionalism and realiser functionalism require that a group of quarks is a blue shoe in some sense, because those quarks manage to play the blue-shoe role or because they are in a state that plays the relevant role. But it simply does not follow from this that the individual quarks that make up the collective are blue or shoe-like. To think otherwise is to mistake

[15] I am grateful to two anonymous referees for pressing me on this issue.

the properties of the quarks taken together with the properties of each individual quark.

The same can thus be said in the case of spacetime functionalism. While it is true that the elementary posits of a theory of quantum gravity are spacetime or have the property of being spatiotemporal as a collective, because the collective plays the spacetime role, it does not follow from this that the individual members of that collective—entities like causal sets, quantum loops and the like—have any spatiotemporal properties. The elementary posits of a theory of quantum gravity are no more spatiotemporal than the individual quarks that realise the shoe are blue.

This is clearly the right response to the worry in the quark case. The response only makes sense, however, because it invokes part-whole thinking. In the quark case, we can resist the claim that individual quarks are blue or shoe-like but only by treating the quarks as parts of a larger entity that plays the blue shoe role. For it is only once we have conceptualised the case in this way that we can help ourselves to a general principle about parthood, namely that a property of the whole is not, necessarily, possessed by any of its parts. This principle can then be used to prevent the downward transmission of properties from a collection of quarks to the individual quarks in that collective.

In order for the response to work in the spacetime case, we must follow a similar line of thought. As with the quark case, we need to say that there is a larger entity that is composed of the elementary posits of a theory of quantum gravity and it is this larger entity that realises spacetime and is thus spatiotemporal. For it is only then that we can appeal to the plausible notion that the parts do not in general inherit the propertes of the whole and thus maintain that the elementary posits of a theory of quantum gravity are not also spatiotemporal. If we can't rely on the part-whole distinction in this way, then it is not clear how to resist the transmission of spatiotemporal properties onto the relevant entities. Without composition, the objection raised above for role and realiser spacetime functionalism seems to succeed in a way that it doesn't for the quark analogue.

As we have seen, it is difficult to make sense of the notion that spacetime is composed of non-spatiotemporal parts. But even if we could somehow make sense of this idea and thus treat the spacetime case like the quark case, a problem remains. The trouble is that including this mereological aspect in the broad functionalist approach demotivates spacetime functionalism to a certain extent. Spacetime functionalism is supposed to be an alternative to a 'bulding blocks' picture of emergence. If some such picture is embedded in the broad functionalist framework, however, then it is no-longer a viable alternative.

5. Partial Functionalism

So far I have argued for two claims. First, that the standard conception of emergence is not applicable to the emergence of spacetime, because it requires mereological relations between emergent spacetime and an underlying non-spatiotemporal reality. Second, that the emergence of spacetime cannot be reformulated in the same terms as functionalism about the mind without presupposing mereological notions.

In this section, I will outline an alternative interpretation of the broad spacetime functionalist picture that avoids these difficulties. The view described in the previous section seeks to fully characterise spacetime in terms of some functional role. We can contrast this 'complete' functionalism with a 'partial' functionalism about spacetime. Partial spacetime functionalism has two features. First, spacetime is not given a complete specification in terms of a functional role and so spacetime is not treated as a functional kind. Instead, we focus on particular functions that spacetime can perform and seek to analyse those in functional terms. We then find entities that are capable of realising those functions, without realising full-blown spacetime. Second, and as a direct result, partial spacetime functionalism is not committed to the existence of spacetime. Spacetime, on this picture, does not emerge. What does emerge, however, are certain functional aspects of spacetime that make the world look spatiotemporal at certain scales even though, strictly speaking, it isn't.

Something like partial functionalism is suggested by Lam and Wüthrich when they write that:

> Spacetime need not be fully recovered in some strong ontological sense .... in order to provide the grounds for empirical evidence and everyday experience, but only certain functionally relevant features. (Lam and Wüthrich, 2018, p. 40)

Denying the existence of spacetime might seem rather extreme, but I don't think it has to be, for two reasons. First, we can be a bit more liberal about the ontology of partial functionalism, and maintain that spacetime at least approximately exists, where it is sufficient for spacetime to approximately exist that the partial functionalist program be a success. To be clear, I am not positing an entity 'approximate spacetime' and saying that this new entity exists. The idea, rather, is that while spacetime as we normally conceive of it does not exist, the relevant functions of spacetime are performed by the ontology of a theory of quantum gravity, and they are performed in such a way that we can speak loosely of spacetime's existence, even though such talk is strictly speaking false.

Second, if we consider, once again, what motivates the claim that spacetime exists in the first place, then—to a certain extent—those motivations can be satisifed by the approximate existence of spacetime (though perhaps not entirely, see below). As we saw, the chief motivation for taking spacetime to be an emergent phenomenon is the threat of empirical incoherence facing theories of quantum gravity. If spacetime exists and is emergent, then the solution to this problem is straightforward. The epistemology of quantum gravity is no different to the epistemology of science more generally. What matters for addressing the threat of empirical incoherence, however, is not so much that spacetime exists, but rather that those features of spacetime that support observation can be recovered. In principle, then, we don't need to recover the existence of spacetime in order to enjoy some of its benefits, if the relevant features can be recovered in some other way.

Of course, it may be that theories of quantum gravity do not posit anything that can perform the necessary functions of spacetime. We can, however, lean on some of the work that has already been completed by spacetime functionalists in order to resolve this kind of worry. As already noted, spacetime functionalists have shown that at least some of the functions of spacetime can be performed by the fundamental ontology of loop quantum gravity and causal set theory. In particular, Lam and Wüthrich (2018) have shown that a particular function of spacetime—that of providing locations for entities—can be performed by something that is not, itself, spatiotemporal.

If we proceed in this way, then we don't need to explain how spacetime emerges, because it doesn't, at least not in a metaphysical sense. This enables the partial functionalist to avoid the problems outlined above. Because spacetime does not exist, there is never any threat of attributing spatiotemporal properties to the elementary entities posited by a theory of quantum gravity. Moreover, there is no reason that I can see why a mereological conception of emergence is needed in the case of partial functionalism. All we need is for the elementary posits of the theory to play the role of locating entities. We don't need some group of those entities to play the functional role of being spacetime, and so we don't need to say that the fundamental entities come together to form some more complex entity that does this work. Instead, the fundamental entities themselves can just play the role of being locations, in the way that spacetime regions do.

Moreover, even if some kind of mereological picture is needed, it is not clear that the arguments raised in §3 will apply. Consider, for instance, the argument from intimacy. This argument gets going because we are trying to build spacetime from entities that do not have any spatiotemporal locations. The argument itself relies on the whole having a spatiotemporal location that the parts lack. Partial functionalism denies that anything has a spatiotemporal location and so we are not going to get the same mismatch between the location of the whole and the location of the parts. Instead, we can say that the parts and the whole share the same location, it is just not a spatiotemporal location.

For Lam and Wüthrich, partial functionalism about spacetime constitutes a complete solution to the problem of empirical incoherence. As they put the point:

> From a functionalist point of view, nothing remains beyond showing how the fundamental degrees of freedom can collectively behave such that they appear spatiotemporal at macroscopic scales in all relevant and empirically testable ways. (Lam and Wüthrich, 2018, p. 45)

As noted in §1, in order to fully address the problem of empirical incoherence we need at least three things: we need the locations that observable entities can occupy; we need the material entities that occupy those locations (including observers) and we need a causal relationship between observers and the material entities in question that is of the right kind to scaffold observation. To date the focus has been on showing how partial functionalism about spacetime can deliver location, and how it may be able to deliver causation, depending on what we take causation to be. But, and this is perhaps not something that Lam and Wüthrich make clear, their partial functionalism should also include a functionalist treatment of spatiotemporally located matter. For without matter, there are no observables, even if there is—in principle—a way for observables to be located.

One way to do this, and the approach that I favour, is to functionalise the basic building blocks of matter—the fields and particles of the standard model of particle physics. Note that a complete functionalism in the Quantum Field Theory (QFT) case would likely face the same troubles as a complete functionalism about spacetime, since in both cases the functional realisers will not be spatiotemporally located (assuming that they are the posits of a theory of QG), while the entities being functionalised will be. So the relevant functionalisation should, again, be partial. The idea then is that, in addition to finding something in the ontology of a theory of QG that can perform the functions of spacetime, we also try to find something that can perform the functions of QFT entities. Namely, those functions that are ultimately important for empirical observation.

I lack the space to develop the material dimension of partial functionalism here. I will note, however, that for at least some approaches to quantum gravity, there has been progress on developing models of particles that make use of a non-spatiotemporal ontology.[16] These models stop short of a full-blown derivation of QFT. Instead,

[16] For example, Bilson-Thompson's (2005) braid model of particles, which has been combined with LQG and spin-foam theories (see Bilson-Thompson et al. (2012, 2009, 2007)).

what they provide is a demonstration that certain features of how particles behave, such as the strong and weak interactions, can be derived using an ontology that is not spatiotemporal in nature. These models are still in their infancy, but they present a promising basis for developing a partial functionalism about matter, as well as spacetime.

Acknowledgements I am grateful to two anonymous referees for their immensely helpful feedback on the paper. Earlier versions of this paper were presented at the CPT/FraMEPhys Workshop on Time and Explanation held at the University of Milan and the First International Workshop on Time held at Osaka City University. I am grateful to audiences at both workshops for their feedback on the paper, and am especially grateful to Alastair Wilson for hosting the Milan workshop and Takeshi Sakon for hosting the Osaka workshop. Work on this paper was funded by an Australian Research Council Discovery Early Career Researcher Award DE180100414 and a Discovery Project DP180100105.

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