Philosophy, physics, and the problems of spacetime emergence

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Abstract

According to theories of quantum gravity, spacetime may be non-fundamental. The implications of this observation are now widely debated in the philosophy of quantum gravity. In this paper we argue that what is often discussed under the umbrella term of "spacetime emergence" in the philosophy of quantum gravity literature in fact consists of a plethora of distinct and even highly different problems. We therefore advocate to cast such debates more specifically in terms of emergent spatiotemporal aspects as is already done in the physics literature. We first show how ambiguous the notion of spacetime is and offer five understandings of what *the* problem of spacetime emergence may still amount to. We then argue, however, that there are many philosophical problems relating to spacetime emergence and that none of the five understandings picks out a problem that is exceptional among these. Next, we observe that different spatiotemporal aspects are emergent in different quantum gravity approaches whereby speaking of quantum gravity collectively is problematic. Finally, we illustrate how inquiries about spacetime emergence are actually aided by conducting the investigation at the level of specific spatiotemporal aspects.

1 Introduction

In one of the seminal early papers on spacetime emergence, Nick Huggett and Chris Wüthrich find that "as far as many quantum theories of gravity are concerned, in various ways, familiar spacetime is not admitted at the fundamental level" (2013, 277). That spacetime may be a non-fundamental element of reality according to theories of quantum gravity and its consequences have since then been widely debated in the philosophy of quantum gravity. This paper, however, warns not to forget Huggett and Wüthrich's easily overlooked qualification "in various ways". More concretely, we defend the thesis that what is often discussed under the umbrella term of "spacetime emergence" in the

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philosophy of quantum gravity literature in fact consists of a plethora of distinct and even highly different problems.

At places, the philosophical literature can give the impression that there is one overarching philosophical problem associated with the emergence of spacetime in quantum gravity. Michael Esfeld, for instance, casts his investigation in terms of "the issue of spacetime in quantum gravity" (2019, 6). As Esfeld explains, "the issue is the emergence of spacetime from something that is fundamentally not spatiotemporal" (2019, 6). Referring to a similar issue, Baptiste Le Bihan likewise frames his discussions through "the problem of spacetime emergence in the philosophy of quantum gravity" (2019, 7). Apparently, we here have to do with a philosophical problem—*the* problem of spacetime emergence—that cuts across the different quantum gravity approaches and concerns the puzzling issue how spacetime can emerge if it is absent at the fundamental level of description.

Profound as this problem of spacetime emergence in quantum gravity may appear to be, this paper argues that the problem is ill-posed. In section 4, we argue that without a qualification of what is meant by spacetime, there is an immediate ambiguity concerning the exact circumstances under which this alleged problem of spacetime emergence occurs. What, we might ask, is characteristic of the theoretical frameworks where this problem is raised? Unpacking this ambiguity reveals five different types of ways to construe 'spacetime' in the '*the* problem of spacetime emergence' each coming with its own understanding of when the problem arises. Section 5 then considers each of these understandings more closely but argues that it is implausible that any exceptional problem should arise in any of these circumstances. This is not to say that there are no philosophical problems related to spacetime emergence. Rather, we argue that there are many, but that these are tied to the emergence of specific spatiotemporal aspects, which shall be used here to denote features that are associated with spacetime such as a metric, manifold, dimensionality, etc. The list of philosophical problems relating to the emergence of spatiotemporal aspects is, as such, long, but no arguments currently on offer show that any problem among these stands out. The issue with the available understandings of *the* problem of spacetime emergence is then that, even if they succeed with clearly picking out one of the problems on the list, none of these is an exceptional problem that warrants special attention. There are many problems of spacetime emergence, and each of them must be considered in its own specificity.

It is, however, not just those who cast their discussions as though there were a singular problem of spacetime emergence that must be more specific. As section 6 argues, our points are also relevant to those who explore the implications of spacetime emergence in quantum gravity for philosophical accounts of, for instance, mereology and composition or existing metaphysical frameworks like Humeanism. Framing such inquiries in the abstract as 'spacetime emergence in quantum gravity' is, again, simply too ambiguous for the inquiry to be meaningful. Indeed, the differences we identify between the typical issues posed by the emergence of the various spatiotemporal aspects imply that the question of whether, say, Humeanism is coherent with a quantum gravity approach—let alone spacetime emergence in quantum gravity as a whole—does very much depend

on exactly which spatiotemporal aspects are taken to be emergent. Furthermore, and this also applies to the alleged problem of spacetime in *quantum gravity*, the different approaches to quantum gravity differ rather significantly in what spatiotemporal aspects they take to be emergent. Different quantum gravity approaches will give different answers to our philosophical inquiries about spacetime emergence because the answers depend on and are specific to the spatiotemporal aspects.

On these grounds, it seems advisable to discontinue unqualified talk of spacetime emergence since this can give a misleading impression of unanimity. Instead we advocate to take the discussions at the level of spatiotemporal aspects. Casting the debates in these more specific terms serves two purposes. First, it makes it manifest that there are many interrelated, yet distinct, problems associated with "spacetime emergence." Second, it indicates that these problem*s* are to be resolved by detailed (philosophical) analysis of the particular emergent features and not through general or abstract discussions of how spacetime as such can emerge from the non-spatiotemporal.

Now, our call for specificity may be surprising given that spacetime emergence-talk is also widespread in the physics literature. One might counter our critique by arguing that the philosophy of quantum gravity, in fact, simply adopts an established practice in physics when the discussions are cast in more general terms. However, as discussed in section 3, the spacetime emergence-talk in physics rarely suffers from the ambiguity that is often found in the philosophical discussions. In the physics literature, it is usually sufficiently clear from context that the unqualified claims about spacetime emergence are meant to concern one or more specific spatiotemporal aspects. In addition, these emergence claims are typically made with respect to a specified quantum gravity approach. Thus, the proposal of this paper is, in a sense, precisely that the philosophical literature should adopt this practice of specificity from physics. Now, this may come across as a matter of linguistics. However, since the various spatiotemporal aspects inflict very different philosophical problems, insisting on specificity is not an exercise in pedantry but central to the resolution of key issues that have been raised about spacetime emergence in quantum gravity.

The paper proceeds as follows: Section 2 introduces the motivations for a theory of quantum gravity and their relationship to the emergence of spacetime. Section 3 documents the widespread spacetime emergence-talk in both the physics and philosophy literature on quantum gravity. Section 4 shows how ambiguous 'spacetime' is in the context of quantum gravity and offers five understandings of what *the* problem of spacetime emergence may amount to. Section 5 argues that there are many problems relating to spacetime emergence and that none of the five understandings of *the* problem designates a problem that is exceptional among these. Section 6 observes that different spatiotemporal aspects are emergent in different quantum gravity approaches whereby speaking of quantum gravity collectively is problematic. Finally, this section also illustrates how inquiries about spacetime emergence in quantum gravity are aided by conducting the investigation at the level of spatiotemporal aspects. After this, a conclusion follows.

2 Quantum Gravity

The majority of philosophical works on the subject take it that what goes by the label 'quantum gravity' is supposed to denote some future theory that consistently brings together what is often[1] considered the divided basis of modern physics: quantum theory and general relativity. Infamously, there are many different approaches to quantum gravity with physicists strongly disagreeing on which is the most promising. There is a sense in which this is largely due to researchers disagreeing on what exactly the question is in the first place.[2] Typically, such a theory is assumed to successfully apply 'the lessons from quantum theory' to general relativity and, hence, gravity or spacetime—very much depending on one's methodology and one's interpretation of general relativity. In particular, one may view general relativity as a theory of 'a thing called spacetime' or as, first and foremost, a theory of gravity. Accordingly, either the term 'quantisation of spacetime' or 'quantisation of gravity' is used synonymously for the research programme. Relatedly, since a quantisation of spacetime seems to suggest that (classical) spacetime 'emerges' (in a loose sense yet to be spelt out) from an underlying quantum structure, the notion 'emergence of spacetime'—or, conversely, 'disappearance of spacetime'—is ubiquitous in the debate.[3]

Since general relativity teaches us that there is a strong connection between spacetime and gravity, the competing takes on the research programme of quantum gravity—theories of quantum gravity as emergent spacetime theories or as quantised gravity theories—do exhibit overlap. It is important to note, however, that the views are not congruent. This is crucial for the project of this paper: based on explications of quantum gravity research as aimed at constructing theories without spacetime one could come to expect that there is a general problem of spacetime emergence. We find this sentiment, for example, in Joshua Norton's writing that "[o]ne of the primary tasks in building a quantum theory of gravity is discovering how to save spatiotemporal phenomena using a theory which, putatively, does not include spacetime" (Norton, 2021, 50).

However, or so we insist, 'spacetime emergence' is not a unifying trait of all approaches to quantum gravity: not all theories that seek to give a quantum description of gravity do also seek to give, or even obtain, a quantum description of key aspects of spacetime, but focus on issues like UV completion, for example.[4] The important issue here is that

[1] Cf. Salimkhani (2018)

[2] "No question about quantum gravity is more difficult than the question, 'What is the question?"' (Wheeler, 1984, 224).

[3] Generally, emergence is understood in a loose sense adopted from physics. It is merely supposed to indicate that some higher-level entity is sufficiently autonomous and novel with respect to its lower-level 'constituents'. Accordingly, emergence is supposed to be compatible with reduction (see Butterfield (2011) and Crowther (2016)). Moreover, emergence is usually understood in contrast to fundamentality. We abide by this. So, emergent stuff is non-fundamental (cf. Barnes (2012)). Note that whether some, say, entity is fundamental does not just ask whether some entity is on the list of what there is, but what its ontological status is—arguably, with regard to other entities. That which is fundamental is that which is ontologically privileged: it is ontologically independent of other entities and it is what other entities ontologically depend on (see Bennett (2017)).

[4] The fact that many quantum theories of gravity are divergent (and, hence, non-predictable) at high

such theory proposals *do not aim* for spacetime emergence at the outset. And even if the aims of quantum gravity research include a quantization of spacetime, this is different from claiming that the aims include "sav[ing] spatiotemporal phenomena using a theory which, putatively, does not include spacetime", as Norton writes.

To summarize, spacetime emergence is not what theories of quantum gravity generally aim at, but, *prima facie*, merely one of the programmatic views of what 'applying the lessons from quantum theory to the domain of general relativity' might mean. The truly general feature of all quantum gravity research is seeking a quantum theory of gravity—hence the name. Notably, of course, this work may then *result* in theories where certain spatiotemporal aspects are, in fact, absent. In so far as these spatiotemporal aspects feature in higher-level theories, this then suggests a sense in which they are emergent. Any philosophical problems relating to the spacetime emergence of quantum gravity as such arise after the fact. Spacetime emergence is not built into the research programme at the outset, and it therefore depends on the details of the theories whether there are any well-defined problems of spacetime emergence that arise from quantum gravity research; and what they are.

3 Spacetime Emergence-talk in Quantum Gravity

'Spacetime emergence'-talk is frequent both in the physics and philosophy literature on quantum gravity as this section documents. While this may give the impression that both fields are concerned with the emergence of spacetime in general, the contexts of the 'spacetime emergence'-talk in the physics literature reveal, as shown below, that it is typically just shorthand for claims about the emergence of specific spatiotemporal aspects. This specificity is less typical in the philosophical literature, although the philosophical claims made would require it, as this paper ultimately argues.

At the face of it, the 'spacetime emergence'-talk in physics and philosophy is quite similar (see table 1). The similarity is perhaps to be expected since the 'spacetime emergence'-talk in philosophy is purposefully inherited from the physics literature. This is exemplified by Le Bihan writing: "This essay aims at prompting a discussion between metaphysicians about how we should best understand philosophically what has been called by physicists working in quantum gravity 'space emergence'" (Le Bihan, 2018b, 74).[5] Accordingly, it seems that any criticism that such unqualified 'spacetime emergence'-talk is problematic is perhaps better directed at the physicists.

However, the superficial similarities in table 1 conceal the important difference that 'spacetime emergence' is only shorthand for more specific claims on the physics side whereas this type of specificity is often absent in the philosophical discussions. The

energies (the ultraviolet limit) is known as the problem of UV completion (see Crowther and Linnemann (2017)).

[5]We take it that nothing depends on using the notion of *space* emergence (instead of *spacetime* emergence) here.

Physics	**Philosophy**
Sindoni (2012, 8) discusses "situations where spacetime is emergent from a complicated underlying quantum gravity dynamics."	Le Bihan (2018a, 109) discusses some metaphysical issues in relation to "spacetime emergence as we find it in quantum gravity."
Faulkner et al. (2014, 2) states that "[a]ccording to the AdS/CFT correspondence, spacetime and gravitational physics in AdS emerge from the dynamics of certain strongly-coupled conformal field theories."	Muntean (2015, 279) speculates with explicit reference to AdS/CFT that "[d]ualities are a game changer here, as they may entail that spacetime is emergent."
Cao et al. (2017, 14) describe their work as a "model for emergent space."	Baron and Le Bihan (2021) "produce models in which spacetime has non-spatiotemporal parts."
Steinhaus and Thürigen (2018) titles their paper "Emergence of spacetime in a restricted spin-foam model"	Baron (2020) titles his paper "The curious case of spacetime emergence"

Table 1: Table with examples of 'spacetime emergence'-talk in physics and philosophy.

former is evident from the context of the quotes on the physics-side of table 1.[6] Sindoni (2012) is more particularly interested in how Lorentzian signature (as well as diffeomorphism and Lorentz invariance) can emerge in generic condensed matter systems. Faulkner et al. (2014) show how the linearized vacuum Einstein field equations are dual to a constraint on entanglement in a conformal field theory on Minkowski spacetime (denoted emergent dynamics below).[7] Cao et al. (2017) consider states in Hilbert space and explore how certain states can give rise to the emergence of first metric and then manifold. Steinhaus and Thürigen (2018) find a limit of the loop quantum gravity spin foam where the effective number of dimensions tends to zero.[8] We shall return to the details of some of these in section 5. The point here is merely that the 'spacetime emergence'-talk in physics is usually accompanied by further specifications in terms of *particular* spatiotemporal aspects like signature, symmetry, dynamics, metric, manifold, dimensionality, etc. In other words, 'spacetime emergence'-talk in physics is superfluous, abstract gloss—the actual work is done in the concrete.[9]

This specificity from context is not always found on the philosophy side. Le Bihan

[6]We are not thereby saying that the unqualified 'spacetime emergence'-talk is unproblematic in physics, but at least the context disambiguates it.

[7]Since this is a duality relation, it is questionable whether this is actually an instance of emergence as pointed out by Teh (2013), Dieks et al. (2015), Jaksland and Linnemann (2020), among others. This issue, however, is orthogonal to the present discussion.

[8]More precisely, they calculate the spectral dimensions.

[9]Note that we make no claim about the necessary and sufficient conditions for what counts as spacetime, nor for what qualifies as a spatiotemporal aspects. We merely point out that 'spacetime emergence'-talk in the physics literature is associated with the mentioned aspects.

(2018a), for instance, investigates the fate of priority monism—the view that reality as a whole is more fundamental than its parts (Schaffer, 2010)—"[i]f spacetime is not fundamental" (p. 104). The discussion, however, proceeds without specifying what particular spatiotemporal are at issue, in contrast with what is the practice in the physics literature.

It should be noted, though, that (parts of) the philosophical literature is arguably purposefully more abstract and general than the physics literature. Both Le Bihan (2018a, 108) and Baron (2020, 2209) variously differentiate between the particular problems that physics studies and a more general ontological or conceptual issue related to spacetime emergence. The latter is argued to involve an explanatory conceptual and ontological task that is not resolved even if a formal mathematical derivation is provided for how spacetime can be derived from an underlying non-spatiotemporal theory. In a shared piece, they write:

> It is far from clear, however, that the mathematical results alone are up to the explanatory task. This is because the explanatory question is not just the question of how we recover one theory or piece of mathematical structure from another. The question is really seeking an understandable physical picture of how it is that non-spatiotemporal entities and properties conspire to produce spatiotemporal ones. What we want is a minimal specification of the ontology that accompanies the mathematical results at issue, and that helps us to better grasp the dependent spacetime realist approach (Baron and Le Bihan, 2021).

We do not dispute that such explanatory work is needed. What we warn against, however, is to take this need for explanatory work as a reason to discuss spacetime emergence in the abstract rather than with reference to the specific spatiotemporal aspects and the philosophical issues that accompany their non-fundamentality. This is especially so if this discussion in the abstract gives the impression of being concerned with some allegedly exceptional *singular* problem of spacetime emergence, for instance how it is "that non-spatiotemporal entities and properties conspire to produce spatiotemporal ones," as Baron and Le Bihan writes. There is, as we shall argue, no such additional exceptional conceptual or ontological problem of 'spacetime emergence' over and above the sum of the philosophical problems relating to the emergence of the various specific spatiotemporal aspects. Neither is there a shared core in these specific problems that warrants speaking of "the problem of spacetime emergence in the philosophy of quantum gravity," as Le Bihan puts it above, and that would justify approaching them in the abstract.

4 What counts as Spacetime?

But let us approach the matter step by step. In this section, we propose what might be meant by someone inquiring about *the* problem of spacetime emergence. Recall that

this philosophical inquiry is prompted by the development of certain new theories (or theoretical frameworks) in physics. It is not a problem that is raised in all of physics. This rather trivial observation makes an, for our purposes, important point: The problem of spacetime emergence is raised by theories with certain characteristics. If the name of the problem is anything to go by, what these characteristics are will depend on what is meant by 'spacetime'. Thus, what is meant by 'spacetime' is crucial for deciding when this problem occurs and what it involves.

In almost all philosophical studies that investigate 'spacetime emergence' we do get at least some minimal qualification of 'spacetime'. For example, Le Bihan (2018a) seems to be interested specifically in the emergence of general-relativistic spacetime, when he qualifies that the candidates for (non-spatiotemporal) fundamental structure are assumed to be such that "neither our familiar macroscopic space and time nor the spacetime of general relativity can in general be easily mapped onto these structures" (p. 99). Similarly, Muntean (2015) seems to equate spacetime with the structure known from general relativity and so does Baron (2020) when he states that "[s]pacetime emerges in the sense that the laws of general relativity are deducible from a more fundamental theory" (Baron, 2020, 2209).[10]

However, what counts as spacetime is already disputed in the context of general relativity.[11] Traditionally, general-relativistic spacetime—in light of the hole argument—has been identified with the pair of manifold and metric structure $\langle M, g\rangle$ (call this the *geometric view*). More recently, Knox (2013, 2017) has proposed that spacetime is better understood as the role of providing an inertial background structure (call this *inertial spacetime functionalism*). According to this functionalist view, the pair $\langle M, g\rangle$, as a matter of fact, does not always realise the spacetime role—it is not always that which provides for inertial background structure. Knox (2013) gives the example of Poincaré gauge theory, where the general-relativistic constraint of a torsion-free connection is dropped such that the affine geometry and inertial structure of the theory generally come apart. As a result, the inertial spacetime functionalist will argue that spacetime is not in fact realised since there is nothing that realises inertial structure in Poincaré gauge theory—unless matter only couples to the symmetric, i.e., torsion-free part of the connection, in which case the theory is simply a reformulation of general relativity. Proponents of the geometric view will disagree. Since spacetime, on their view, is *always* realised by (or simply identical with) the pair $\langle M, g\rangle$, spacetime *does* feature in Poincaré gauge theory.

Already this debate on purely classical physics signifies that it is disputed what counts as spacetime. The issue, as exemplified above, is not only that functionalists identify spacetime with a functional role whereas proponents of the geometric view identify it with a pair of spatiotemporal aspects, i.e., manifold and metric. Rather, the crucial

[10]This seems overly restrictive. It would arguably be sufficient, if the laws of general relativity were recovered *approximately*.

[11]This is a semantic sub-question of the overall question 'what is spacetime?'. Notably, the latter also includes the famous sub-question for the ontological status of spacetime—including the substantivalist–relationalist debate—which will, however, not be of interest to us here.

difference, at least for present purposes, is that they disagree about whether spacetime actually features in a specific theory. If spacetime functionalists and proponents of the geometric view disagree whether spacetime is emergent in a given circumstance, they will arguably also disagree whether any problem of spacetime emergence occurs. According to spacetime functionalism, a manifold with metric is not sufficient for spacetime. Thus, in certain cases, a spacetime functionalist could consider spacetime as emergent, even if the underlying level of description features a manifold with metric. For the spacetime functionalist this might therefore qualify as an occasion to raise the problem of spacetime emergence whereas a proponent of the geometric view would reject this since spacetime, to them, is here still fundamental. Those like, for instance, Niels Linnemann (2020) who view an ordering structure with spacetime-split as essential to spacetime could similarly enter a disagreement with proponents of the geometric view whether *spacetime* is fundamental or not. A fundamental manifold with metric is not sufficient to secure, say, an ordering structure with a spacetime-split which additionally requires that the metric has Lorentzian signature. Conversely, to add a third example, a fundamental ordering structure with a spacetime-split is not sufficient for having a manifold with metric. This time, proponents of the geometric view would say that spacetime is non-fundamental whereas Linnemann would likely disagree. Thus, depending on what spatiotemporal aspects one regards as necessary for spacetime, different theoretical frameworks with different fundamental spatiotemporal aspects will be examples of emergent spacetime. These examples show that it is ambiguous when exactly spacetime is emergent and thus ambiguous when *the* problem of spacetime emergence occurs. This ambiguity cannot be remedied by explaining, as Le Bihan does above, that the concern is cases where "the spacetime of general relativity" cannot "be easily mapped onto [the underlying] structures." Whether such a mapping is possible will depend on what is regarded as necessary for spacetime and this is already disputed *within* general relativity.

The moral of the above is that to inquire about the emergence of spacetime one needs to fill in the details regarding the used notion of spacetime. Trying to preserve the sense of the phrase '*the* problem', there are, in our view, four different ways to do so, and, on top, a fifth option that rejects that any further specification is needed, warranted, or advisable (see table 2).[12]

When 'spacetime' in 'the problem of spacetime emergence' is qualified as the spacetime of general relativity, as is often done, the perhaps most immediate understanding would be that 'spacetime' should be conceived according to one of its interpretations in the general relativity literature. Thus, what is meant by 'the problem of spacetime emergence' can be made clear by giving the *specific* necessary and sufficient spatiotemporal aspects that must be there for spacetime to be realised (call this the *specific* construal of spacetime). The absence of these spatiotemporal aspects at some underlying level then gives rise to the problem of spacetime emergence. If several spatiotemporal aspects are specified as necessary, further specification is needed regarding whether the philosophically interesting problem is meant to occur when none or just one of the necessary

[12]There is a sense in which all these notions are compatible with what Le Bihan and Baron say about general-relativistic spacetime—so the following is also an attempt of explicating what they might mean.

Name	**Understanding of 'spacetime'**	**Entailed understanding of *the* spacetime emergence problem**
Specific	Specific spatiotemporal aspects are necessary and sufficient for spacetime.	The problem arises when these specific spatiotemporal aspects (or a subset of them) are emergent.
Thick	All spatiotemporal aspects are necessary for spacetime.	The problem permeates all cases where any spatiotemporal aspect is emergent.
Thin	Any spatiotemporal aspect is sufficient for spacetime.	The Problem occurs when all spatiotemporal aspects are emergent.
Cluster	No spatiotemporal aspect is necessary but certain clusters of them are sufficient for spacetime.	The problem permeates all cases where no sufficiency condition for spacetime is satisfied.
Pre-theoretic	Spacetime is not analysable in terms of spatiotemporal aspects.	The problem concerns the emergence of spacetime as we experience it, independently of more precise formal notions.

Table 2: An exhaustive list of possible conceptions of spacetime and corresponding attitudes towards an overarching problem of spacetime emergence depending on the conception of the constituent 'spacetime.' None of them are viable, as we argue.

conditions are not satisfied fundamentally, i.e., whether all or just one necessary spatiotemporal aspect is emergent. For instance, concerning the geometric view, it would have to be specified whether the problem of spacetime emergence occurs when both metric and manifold are emergent, or just one.

Following the suggestion from section 3 that the philosophical problem of interest is of a more general character, one might, however, be reluctant to say that the problem of spacetime emergence occurs only when specific spatiotemporal aspects are emergent. Rather, it might seem to be a more general problem that arises whenever *some* spatiotemporal aspect is emergent. In one reading, this suggests that 'spacetime' in 'the problem of spacetime emergence' is understood rather restrictively as referring to something that is only realised in theories where none of the spatiotemporal aspects present in general relativity are emergent, but all are fundamental. Accordingly, we can speak of the emergence of spacetime as soon as just one aspect of spacetime is emergent. This signifies a rather *thick* conception of spacetime (call it the *thick* or restrictive construal). This thick understanding of 'spacetime' furthermore appears to abide by the proposal that the philosophy literature is merely continuing the linguistic practice surrounding 'spacetime emergence' in physics. There, spacetime emergence is also routinely invoked even when only one spatiotemporal aspect is emergent.

Another possibility is to adopt a rather liberal or *thin* understanding of the notion 'spacetime' (call it the *thin* construal). Here, all necessary conditions are dropped and any spatiotemporal aspect on its own is sufficient for spacetime. As soon as a theory includes at least one spatiotemporal aspect, it features spacetime. Adopting this thin construal of 'spacetime', the problem of spacetime emergence must then be understood to occur when *all* spatiotemporal aspects are emergent, i.e., in theories where no spatiotemporal aspect remains fundamental. On this construal, there is no problem of spacetime emergence, if just one spatiotemporal aspect remains fundamental, the key idea being that the problem occurs when the fundamental level is entirely free of anything spatiotemporal.[13] This might be what Baron and Le Bihan (2021) identify as the problem of explaining "how it is that non-spatiotemporal entities and properties conspire to produce spatiotemporal ones".

An intermediate alternative to the thin and thick construal of spacetime is to adopt Baker's (2020) view of spacetime as a cluster concept (call it the *cluster* construal). According to Baker, there are no necessary conditions for what counts as spacetime, but instead several distinct sufficient conditions. So, similar to the thin construal, it remains ambiguous what features are at the coarse-grained level where spacetime is said to emerge. When no spatiotemporal aspect is necessary but certain clusters of them are sufficient for spacetime, the problem of spacetime emergence can, in turn, be understood as permeating all cases where no sufficiency condition for spacetime is satisfied at an underlying level of description. As such, we might regard this as saying that *the* problem of spacetime emergence only arises when sufficiently many spatiotemporal aspects are

[13]What is our interpretation of Baron and Le Bihan (2021), was first explicitly defended by Niels Linnemann as the *ontological problem of minimal spacetime*.

absent at the fundamental level (and not in all cases as the thick construal would have it). Which exactly these are, however, is not fixed in the cluster conception.

Lastly, there remains the option to reject our reconstruction in terms of spatiotemporal aspects by opting for a *pre-theoretic* conception of spacetime (or perhaps even space and time), e.g., as we experience it. Such a construal wants to take spacetime as unanalysable in terms of spatiotemporal aspects. In our view, this position places itself in the peculiar position of not being able to make transparent *when* the alleged problem occurs and, upon further specification, will transform into one of the lines of argument discussed above. Here is why. If the issue is not straightforwardly intended to address why we experience things as we do (see Ismael (2021) for a preliminary discussion), which is arguably a problem in cognitive science, the pre-theoretic spacetime must be specified in terms of some formal structure to be comparable to the structures at an underlying level of description. If this was not done, it would be impossible to tell whether the pre-theoretic spacetime is in fact absent, i.e., they would be unable to tell whether a theory raises problems related to spacetime emergence or not. In other words, the pre-theoretic construal needs to connect in some way to the physical theories. However, this arguably requires an analysis in terms of spatiotemporal aspects—at least all our theories employ spatiotemporal aspects. Thus, this position is, in our view, unstable and will decay into one of the four other options considered here.

5 The Many Problems of Spacetime Emergence

The previous section gave four proposals for what might be meant by 'spacetime' and how this determines what one takes *the* problem of spacetime emergence to be. One construal gave specific necessary and sufficient conditions for 'spacetime', thus specifying what spatiotemporal aspects are tied to this problem. On the thick construal of 'spacetime', the problem occurs for theoretical frameworks where at least one spatiotemporal aspect is absent (i.e., non-fundamental, i.e., emergent). In contrast, a thin construal of 'spacetime' made the problem one that occurs when all spatiotemporal aspects are absent. Finally, in-between, it followed from the cluster construal that the problem occurs when none of the sufficiency conditions for spacetime are satisfied.

Now, this section argues that none of these explications of 'spacetime' and 'the problem of spacetime emergence' vindicate the existence of any exceptional problem of spacetime emergence as such. Instead, there are many different interesting philosophical questions raised by and tied to the emergence of the various specific spatiotemporal aspects; the examples of emergent dimensionality, Lorentz signature, and metric are to justify this in the following. Although one might want to group these problems under one label, we end this section by warning against doing so.

In section 3, we illustrated how spacetime emergence in the physics literature is, for instance, associated with emergent gravitational dynamics, locality, metric, dimensionality, Lorentzian signature, Lorentz invariance, and diffeomorphism invariance (this list is arguably not exhaustive). Emergent dimensionality was exemplified with the work

of Steinhaus and Thürigen (2018), who, in the context of loop quantum gravity, investigates the spectral dimension changes with length scale under the title "Emergence of spacetime in a restricted spin-foam model." The number of dimensions is typically treated as a fixed external parameter associated with topology: a surface is topologically two-dimensional because it can be divided by a line which can, in turn, be divided by a point.[14]. However, as Carlip (2017) observes, we have no direct access to the topological dimension. Rather, we ascertain the number of dimensions based, for instance, on how the volume of a sphere scales with its radius (internal scaling dimension) or by looking at how quickly something diffuses (say, milk in coffee; the rigorous definition is in terms of a free scalar field). "More dimensions mean [...] slower diffusion—there are more 'nearby' points," as (Carlip, 2017, 5) points out. The latter is the spectral dimension investigated by Steinhaus and Thürigen (2018). It is, as they explain, "an effective dimension as seen by a free scalar field" (Steinhaus and Thürigen, 2018, 1). In general-relativistic backgrounds, the spectral dimension agrees with the topological dimension, but the findings of Steinhaus and Thürigen (2018) suggest that in loop quantum gravity, even though the underlying spin network is topologically four-dimensional, the spectral dimension will approach zero at small length scales,[15] taking fractional values on the way. Thus, "as seen by a free scalar field," the number of (spectral) dimensions is scale dependent and may even take on non-integer values.

These findings raise several conceptual and metaphysical questions. Clearly, it opens a discussion about the meaning of 'dimension'. This includes how to tackle circumstances where the different formal definitions of dimension disagree. Transposing this to metaphysics, a question might be which of these capture the *true* dimensionality and which are merely (sometimes misleading) *indicators* of the number of dimensions. There is also a task in building a metaphysics that supports non-integer, scale-dependent dimensions, and perhaps a further question of whether the zero (spectral) dimensions of the smallest length scales should be regarded as a special case of dimensionality or as the absence of dimensionality. There are, in other words, interesting philosophical questions associated specifically with the emergence of dimensionality.

Another example is emergent Lorentzian signature which, as mentioned above, Sindoni (2012, 8) discusses as a situation where "spacetime is emergent." 'Signature' refers to the sign of the eigenvalues of a metric tensor $g_{\mu\nu}$ when represented as a matrix. It can be expressed by three values that number how many eigenvalues are negative, positive, and vanishing. In general relativity the metric has Lorentzian signature: in four dimensions it has three eigenvalues with equal sign and one eigenvalue with opposite sign; $(-,+,+,+)$ according to the standard convention. The difference in sign is responsible for the fact that two events, a^μ and b^ν, with spatiotemporal distance $ds^2 = a^\mu b^\nu g_{\mu\nu}$ can be either *spacelike* separated (for $ds^2 > 0$), *timelike* separated (for $ds^2 < 0$), or *lightlike* separated (for $ds^2 = 0$). Loosely speaking, the difference in sign captures the difference between space and time. One scenario with emergent Lorentzian signature

[14]See Carlip (2017) for a more rigorous definition of topological dimension

[15]Small length scale here denotes length scales close to the characteristic length scale of the spin network in question.

considered by Sindoni (2012, section 9) plays out in a Riemannian background with positive-definite metric. Here, all eigenvalues have equal sign. So there is no difference between, in particular, spacelike and timelike separation. The separation between all events is the same, conventionally assumed to be spacelike whereby this background is timeless. However, if the scalar fields on this background have non-quadratic kinetic terms, the effective metric can have Lorentzian signature at the level of the equations of motion (see Girelli et al. (2009) for further details). In other words, Lorenzian signature *results* from dynamical symmetry breaking.[16] In this scenario, the split between space and time—as captured by the signature—is not fundamental but emergent.

Philosophically, it is intriguing to consider that time, or at least a distinction between spacelike and timelike separation, can emerge from a background where none of these are fundamental. Relatedly, whether the emergence of time is indeed implied by the emergence of Lorentzian signature or whether emergent signature only entails an emergent space-time split is another interesting venue of investigation. Linnemann (2020) raises the question of how to construct a metaphysics that supports the emergence of "a local split between something time(like) and something space(like)" (p. 14) and answers in the negative that the spacetime functionalism advocated by Lam and Wüthrich (2020) is no answer to this question. Thus, another metaphysical framework is needed. Devising this seems to be an important task for philosophers in light of emergent split implied by emergent Lorentzian signature. As part of these considerations, we might also inquire how to understand any alleged transition from a Riemannian phase (without symmetry breaking) to a Lorentzian phase (with symmetry breaking), if there is no time (see Huggett and Wüthrich (2018, 1201-1202) for a preliminary discussion).

As a final example of philosophical problems raised by a specific spatiotemporal aspect, consider metric emergence. This is, for instance, explored by Cao et al. (2017) who show how a metric might be obtained from entanglement structures in certain states in Hilbert spaces. They begin with a quantum state ψ in a factorisable Hilbert space $\mathcal{H}$ that is decomposed into factors $\mathcal{H} = \otimes_p^N \mathcal{H}_p$. So, loosely speaking, they assume that the quantum system can be decomposed into (a large number of) subsystems. The reduced states of the factors can be entangled and this entanglement can be quantified through the mutual information.[17] Since mutual information is symmetric, we can define a graph by associating each factor with a vertex and the edge weights with the mutual information between the reduced states of each pair of factors. Cao et al. (2017) then show that this graph (or all its connected sub-graphs) can be equipped with a metric where the distance between two vertices is given as the smallest sum of a function of the mutual information weights connecting the vertices. They then argue that this distance can be interpreted as *spatial* distance.

[16] We are not making a judgement about the viability of approaches with emergence Lorentzian signature. As Sindoni (2012, 34-35) emphasises, they face rather significant challenges. It might be interesting to add that signature change is now considered in the more worked out context of loop quantum cosmology (see Brahma (2020)).

[17] The mutual information between the state of two factors, A and B, is given as $I(A, B) = S(A) + S(B) - S(AB)$ where $S(A)$ is the entanglement entropy.

Several philosophical questions are raised if this approach bears out, most immediately, whether this is in fact an instance of emergence or whether it merely involves re-representation.[18] If the approach shows distance relations to be non-fundamental, then it challenges, for example, the usual setup of Lewis' (1994) Humean supervenience thesis and his modal realism where elements are world-mates if and only if they are spatially distanced (Lewis, 1986). Relatedly, an emergent metric poses problems for what Schaffer (2001) calls the "spatiotemporal individuation principle" (p. 249) whereby entities are individuated by being at a distance from each other.[19]

There are, as indicated, interesting and highly relevant philosophical problems to raise with respect to the emergence of each of these spatiotemporal aspects. We expect that few will doubt that this is the case. This, however, signifies the challenge faced by those who want to argue that there is something like *the* problem of spacetime emergence. For this to be more than an arbitrary label for one of the many philosophical problems related to spacetime emergence—or the emergence of spatiotemporal aspects, as we prefer to say—*the* problem of spacetime emergence would have to stand out among them. What is not made explicit, but thought to be exceptional about *the* problem of spacetime emergence is precisely what the different construals discussed in section 4 give an answer to.

According to the thick construal, *the* problem permeates all cases where any spatiotemporal aspect is emergent. It thus stands by being a problem over and above the many many problems associated with the emergence of particular spatiotemporal aspects. This, furthermore, might warrant seeking its solution in the abstract rather than in the details of each case. Analogously, the the cluster construal proposes that *the* problem permeates all cases where none of the sufficiency conditions for spacetime are satisfied, and one version of the specific construal similarly proposes that *the* problem occurs when any one of the necessary conditions for spacetime are not satisfied. In other words, all argue that *the* problem of spacetime emergence is exceptional because it permeates *multiple* cases where *different* spatiotemporal aspects are emergent. In making this claim, however, these proposals are faced with the task of identifying some commonality between these cases that this alleged problem could subsume

The issue is that the philosophical problems raised by the different emergent spatiotemporal aspects are not immediately related. For instance, neither emergent dimensionality nor emergent Lorentzian signature challenge the metaphysical frameworks—Humeanism, modal realism, and spatiotemporal individuation—that are challenged by emergent metric. Any solution to these challenges, or any other question relating to emergent metric, seems to have little bearing for what dimensionality is when physics shows that the number of dimensions can change dynamically. Moreover, such dimensional reduction can, as Carlip (2017, 6) shows, occur in both Riemannian and Lorentzian backgrounds.[20] The question how a transition from Riemannian to Lorentzian signature

[18]This question has already been raised in the similar context where gravitational dynamics is alleged to emerge from entanglement dynamics (Jaksland and Linnemann, 2020; Ney, 2021).

[19]See Jaksland (2020) for a discussion of how mutual information might individuate entities instead).

[20]Though the difference between Riemannian and Lorentzian signature only exists in two and higher

is metaphysically possible already assumes a metric whereby issues relating to metric emergence do not come into play. Hence, the philosophical problems associated with the emergence of specific spatiotemporal aspects appear to be (sufficiently) independent of each other. Knowing the answer to one is of little help when seeking the answer to one of the other.

These differences between the specific problems, and even more so their apparent independence, pose a severe challenge to the claim that there is an exceptional problem—*the* problem of spacetime emergence—that permeates more cases where different spatiotemporal aspects are emergent. Given the apparent differences exemplified by the cases of emergent dimensionality, signature, and metric, little indicates that there is such a commonality between the problems they raise.[21] This, of course, is no argument that there is no such shared commonality, but we do think that it places the burden of proof on those who proclaim its existence.

Those in the literature who allude to the existence of a singular problem of spacetime emergence in quantum gravity, however, do not provide such an argument. Le Bihan (2019, 3), for instance, develops his "hard problem of spacetime emergence" in purely general terms, describing how "[t]he hard problem of spacetime is to account for the apparent explanatory gap, or conceptual discrepancy, between the primitive notions of the spatio-temporal and the non-spatio-temporal theories" Le Bihan (2019, 8). In using the plural "notions" and "theories," we might get the impression that this is a problem that arises in multiple cases, for instance when different spatiotemporal aspects are emergent, but Le Bihan only gives the adjacency–locality problem in loop quantum gravity as a concrete example. While this indicates that there is such an "apparent explanatory gap," within some quantum gravity approach—presumably due to metric emergence—it does little to answer our concern that there is, in fact, no unifying trait between the cases where *different* spatiotemporal aspects are emergent as the thick construal would have it. Most likely, this is therefore not Le Bihan's aim. Rather, we might get the suspicion that "the hard problem of spacetime emergence" is not a problem in its own right but rather a *type* of problem. It is not itself asking a philosophical question but it instead *denotes* a group of different philosophical questions relating to the emergence of spatiotemporal aspects where an apparent explanatory gap occurs. This interpretation is further supported when Le Bihan adds that "the specifics of the explanatory gap will vary from one approach to quantum gravity to another" 2019, 8. Should this be so, however, it only corroborates our claim here that there are many problems of spacetime emergence, and it emphasises that also these alleged hard problems should be approached at the level of the specific emergent spatiotemporal aspects rather than in the abstract.

Any proposal that there is a common core to these many explanatory gap problems that allows for, and indeed calls for, an abstract approach would simply raise the issue

dimensions, 'dimension' here refers to topological dimension which dimensional reduction leaves unchanged.

[21] One might reply that all of these cases concern emergence, and the overarching problem might therefore be related to what emergence is. This question, however, is neither peculiar to spacetime or to quantum gravity as the alleged overarching question suggests.

#	Non-fundamental spatiotemporal aspect(s)			
0	None			
1	Space-time split	Metric	Dimension	...
2	Split + Metric	Metric + Dimension	Dimension + Split	...
n	...	...	...	...
N	Split + Metric + Dimension + ...			

Table 3: Table of hypothetical theoretical frameworks corresponding to each cell with differing non-fundamental spatiotemporal aspects. The single cell in row 0 corresponds to general relativity and that in row N to the case where all N spatiotemporal aspects are non-fundamental. For the sake of simplicity only three spatiotemporal aspects are included explicitly.

anew of what this core might be. Whether framed like this or as the proposal that some exceptional problem of spacetime emergence is shared many instances where different spatiotemporal aspects are emergent, we contend that the burden of proof lies with those making these proposals. However, neither Le Bihan's nor anyone else in the literature provides such an argument for the existence of such commonalities between the emergence of *different* spatiotemporal aspects.

Table 3 provides another way of parsing these challenge. It depicts various hypothetical theories with varying spatiotemporal aspects being emergent. The numbers organise the hypothetical theories in a hierarchy by the number of spatiotemporal aspect that they take to be emergent. Each cell in the table can thus be interpreted as standing for a possible world with the same manifest spatiotemporal aspects as in the actual world but where different (combinations) of them are emergent. The single cell in row 0 corresponds to a world where all spatiotemporal aspects are fundamental. A world according to general relativity falls in this cell in row 0, assuming that the spatiotemporal aspects comprise those that are manifest in general relativity (see Le Bihan and Linnemann (2019) for a discussion). The next row is numbered by 1 since it contains hypothetical theories where exactly one spatiotemporal aspect is emergent. Row N again only contains one cell since this is the case where all N spatiotemporal aspects are emergent. Importantly, the numbers should not be associated with levels of description/reality within one world.

According to the thick construal, *the* problem of spacetime emergence arises in all rows except row 0. Above, this proposal was questioned by observing that the philosophical problems raised in each of the cells in row 1 are rather different. It would thus at least be highly non-trivial—and therefore in need of an argument—that any problem should be shared between all these cells. With the table, we can, however, add a further complication. Consider the difference between the problems raised by the cell in row 0 and the emergent metric cell in row 1. Compare that to the difference between the problem raised by the emergent dimensionality cell in row 1 and the emergent dimensionality and metric cell in row 2. In both cases, a difference is that the philosophical issues relating the emergent metric, like those discussed above, are added. However, in the first case,

the thick construal will have it that *the* problem of spacetime emergence is added on top. The reasoning is that there is a qualitative difference between row 0 and 1 which does not exist between row 1 and 2. A rather immediate candidate for such a qualitative difference is, of course, that only row 0 does not raise any problems relating to spacetime—or spatiotemporal aspects, as we prefer to say. This qualitative difference, however, does not seem to amount to a problem in itself but merely to a description of the problems raised in the rows 1-N. Thus, our question stands: When adding, say, metric among the emergent spatiotemporal aspects, what is the alleged qualitative difference between therefore moving from row 0 to 1 as compared to moving from 1 to 2? An analogous issue can be raised about the cluster construal but here we are concerned instead with the alleged qualitative difference in moving from a cell where some sufficiency condition for spacetime is satisfied to a cell where none of them is satisfied. Finally this issue also applies to the variant of the special construal where *the* problem of spacetime emergence occurs when just one of the necessary conditions for spacetime are not satisfied.

Table 3, however, is particularly useful for illustrating a challenge to the proposal—associated with the thin construal—that *the* problem of spacetime emergence only occurs when all spatiotemporal aspects are non-fundamental. On this understanding, the problem of spacetime emergence is one that arises when moving from the next to last to the last row of table 3. Since there is only one cell in this row, the thin construal avoids the issue of arguing that the same problem occurs in many different cells as, for instance, the thick construal argues. Instead, however, the thin construal has to argue that there is a philosophical problem raised by formal frameworks falling in the cell in row N that is exceptional as compared to the many problems occurring in the cells in the other rows. Otherwise, this cell just raises more problems related to spatiotemporal aspects without singling out any one of them, i.e., more problems of the same kind. Suppose for the sake of argument that we have resolved all philosophical issues relating to the non-fundamentality of dimensionality and metric, respectively. This is arguably no guarantee against additional problems arising in the cell in row 2 where both are non-fundamental at the same time. This ordinary proliferation of problems resulting from complexity takes place whenever we move down the rows in table 3. Observing that there are problems that only arise when all spatiotemporal aspects are non-fundamental is therefore not sufficient to single this case out. Rather, for *the* problem of spacetime emergence to be exceptional in any way, proponents of the thin construal would have to argue that the case where all spatiotemporal aspects are non-fundamental generates a problem that is qualitatively different from those arising from complexity when moving from, for instance, row 1 to row 2 in table 3. They would have to show that, say, adding emergent split to the case where all spatiotemporal aspects but split are already emergent is generating a qualitatively different problem as compared to the problems arising when adding emergent split to, say, emergent metric. Furthermore, this extra problem must be the same irrespective of which cell in row N-1 that one compares to, i.e., the same problem must arise irrespective of whether metric, split, etc. is added as the "last" emergent spatiotemporal aspect.

On these grounds, we find it questionable that such a problem should exist and any

claim to the contrary would, in our view, be in need of a good argument. Without such an argument, we find it warranted to assume that the philosophical problems raised when all spatiotemporal aspects are non-fundamental are just more of the same kind of problems that arise when one or more spatiotemporal aspects are non-fundamental, i.e, of the same kind as those philosophical problems that arise in all the other cells of table 3. Furthermore, the proposal that an exceptional problem arises when all spatiotemporal aspects are non-fundamental also entails a rather peculiar dependence on what exactly we include among the spatiotemporal aspects. Overlooking one of these aspects or adding one that should not be included will easily make us mistaken when this problem arises.

Finally, these issues are also faced by the variant of the specific construal where *the* problem of spacetime emergence occurs when none of the necessary conditions for spacetime is satisfied. On this construal, the problem is also tied to a specific cell in table 3, though which one will depend on the specific conditions. For purposes of argument, let split and metric be necessary and sufficient for spacetime. Again, the issue is to argue that the problem arising in this cell (in this example in row 2 of the table), is qualitatively different from those philosophical issues that are raised elsewhere; especially those arising in the emergent split and emergent metric cells, respectively.

In conclusion, neither the specific, the thick, the thin, nor the cluster construal can single out a problem among the many problems related to the emergence of spatiotemporal aspects. Any claim would the contrary would require a substantial argument and no such argument is currenctly offered in the literature. None of them succeeds at identifying an exceptional problem that can qualify as *the* problem of spacetime emergence. Rather, the discussion indicates that none of the many philosophical problems associated with the emergence of spatiotemporal aspects is exceptional. Each cell of table 3 raises interesting but different philosophical issues. While none of these philosophical problems is as such singled out, it is arguably still a matter of linguistic convention whether to denote one or a grouping of them by 'problem of spacetime emergence'. Proponents of the specific construal—and perhaps to a lesser degree the other construals—might indeed argue that *what spacetime really is* is captured by their necessary and sufficient conditions, such as metric and manifold, and thus insist that the problem of *spacetime* emergence strictly concerns that cell specifically. Even so, however, there are clearly more philosophical issues related to the emergence of spatiotemporal aspects. In our view, this proliferation is a reason why it is in general ill-advised to speak in terms of 'problem of spacetime emergence'. Doing so, we think, risks (1) obscuring the centrality of the specific spatiotemporal aspect, and (2) impeding the investigation of other interesting spacetime-related problems that do not involve the emergence of the spatiotemporal aspect(s) of choice.

(1) If a problem arises in the context of metric emergence, it is hardly helpful if it is formulated in a way that could also associate it with, for instance, emergent dimensionality or an emergent space-time split. As such, formulating such specific problems in general terms obscures the centrality of the spatiotemporal aspect in

the set-up—and thus presumably also for solving—the problem.

(2) If the connection to, say, the metric is emphasised, but the problem of interest is nevertheless cast as a problem of spacetime emergence, then this might furthermore convey the impression that said problem is the only or at least the most important issue relating to spacetime emergence; an effect that is only amplified if this is cast as *the* problem of spacetime emergence. However, as indicated above there are arguably many interesting philosophical issues associated with the emergence of many spatiotemporal aspects. All of these deserve philosophical scrutiny, but this may be overlooked if the label 'problem of spacetime emergence' is used only for very few of them.

Related issues arise if one proposes to use 'problem of spacetime emergence' about any problem relating to the emergence of spatiotemporal aspects despite the fact that these problems are very different. While this is, in a sense, in line with the established practice in physics, doing so will again be prone to move the debate away from the level of detail—particular to each spatiotemporal aspect—required for a proper discussion of such problems. It is, of course, admissible to say some problem is *a* problem of spacetime emergence but following the practice of the physics literature, it is then important to also specify what is at issue in further detail including the spatiotemporal aspect under consideration.

One might object that casting the problem in terms of spacetime rather than, for instance, metric emergence can lift it away from the mathematical formalism and thereby towards more conceptual modes of inquiry. This could be a valuable point, *if* it were not the case that these problems relating to emergence—and thus their solution—precisely depend on the details of the spatiotemporal aspects in question, as we shall argue in the next section. There, we will also make the point that this prominence of the specific spatiotemporal aspects entails that few, or perhaps none, of the associated philosophical issues permeate all the currently competing quantum gravity approaches.

6 "In various ways"

In accordance with the sentiment that there is an exceptional problem of spacetime emergence in quantum gravity, the philosophical literature can at places give the impression that the different approaches to quantum gravity feature the same kind of spacetime emergence and thus the same problem. Le Bihan, for instance, describes how "many approaches to quantum gravity such as loop quantum gravity or string theory are often interpreted as denying the *fundamental reality of spacetime*" (Le Bihan, 2018a, 97, emphasis in original).[22] Likewise, Baron explains that in quantum gravity "there is an

[22]Note that we take 'fundamental' as the relevant claim here, ignoring the additional existence-talk. It is not at issue whether spacetime is real only if it is fundamental or can be real although it is emergent. What is at issue is whether something dubbed 'spacetime' is fundamental or emergent (following, for example, **?**). For this, it is irrelevant which criteria for existence one adopts. Hence, we suppress the

expectation that spacetime will be an emergent phenomenon in whatever the correct account turns out to be" (Baron, 2021, 387). The problem—or problem*s*—relating to spacetime emergence might hence be taken to be *shared* between all these "many approaches" where spacetime is not fundamental.[23] In this section, however, we shall argue that the respective character of spacetime emergence in the competing quantum gravity approaches is *currently* rather different, loop quantum gravity and string theory being good examples of this. This point is echoing Huggett and Wüthrich's (2013, 277) remark that spacetime emerges "in various ways". Notably, however, we argue that this shows the importance of specifying not only the spatiotemporal aspect in question, as argued above, but also the quantum gravity approach of interest. There are many problems of spacetime emergence and they each concern the specific quantum gravity approaches rather than all of them. We therefore warn against remarks that could give an impression to the contrary.

Huggett and Wüthrich discussed different approaches to quantum gravity and "observed that the seriousness of these challenges depends a great deal on what they [the different approaches; our remark] postulate instead of spacetime" (Huggett and Wüthrich, 2013, p. 277). In particular, Huggett and Wüthrich argue that "[d]ifferent theories leave more or less of the standard structure of spacetime intact" (Huggett and Wüthrich, 2013, p. 277), hence one should "pose the challenge of empirical incoherence [which is their object of investigation; our remark] to them separately" (Huggett and Wüthrich, 2013, p. 277). For example, causal set theory arguably does away with the metric, but keeps fundamental causal relations from which the familiar general-relativistic spacetime is then understood to emerge. Similarly, the metric is absent in the formalism of loop quantum gravity, and hence arguably best interpreted as emergent. In string theory, however, we do find a fundamental metric structure as central to the formalism. On the other hand, string theory needs dimensional reduction which is not the case in loop quantum gravity. So, at least *prima facie*, spacetime emergence is very different in string theory and loop quantum gravity or causal set theory. All three approaches might be said to feature spacetime emergence, but they do so "in various ways" indeed.

This stresses that the consideration of the specific spatiotemporal aspects *does* matter given the current landscape of quantum gravity research. The differences between causal set theory, loop quantum gravity, and string theory exemplify the challenge of treating them collectively in discussions about spacetime emergence. This is only further complicated since these differences cannot be captured as differences in degree—unlike what Huggett and Wüthrich's 'more or less' and similar remarks in their paper seem to suggest.[24] But if the differences are not simply differences in degree, then it is not

existence issue here.

[23]Following Le Bihan's suggestion of a "hard problem of spacetime emergence" discussed in section 5, his remark should perhaps rather be interpreted as suggesting that the same conceptual issue arises and not be considered as the claim that the spacetime emergence is of the same kind in the different quantum gravity approaches. If this is so, however, it is not very clear from the context.

[24]Reading Huggett and Wüthrich (2013) more closely does reveal a more nuanced view, though. While they write, on the one hand, that "[q]uantum gravity's denial of the 'spacetimehood' of the fundamental structure thus comes in degrees" and "[w]e thus find a spectrum of theories with increasingly iconoclastic

adequate either to say that one's spacetime emergence problem of interest is 'general' in the sense that it occurs in all approaches with a sufficient degree of emergent spacetime. This does, of course, permit the view that any philosophical problem relating to the emergence of a particular spatiotemporal aspect is relevant in all current or future approaches where this aspect is emergent. Still, the discussion should take place at this level of specificity and not as unspecified discussions of spacetime emergence in quantum gravity.

This is also relevant to those who explore the implications of spacetime emergence in quantum gravity for general philosophical issues, for instance, existing metaphysical frameworks like Humeanism. We are now turning to this issue and explain why specificity is needed in these debates as well. So, here is why specificity is key in philosophical debates. We have already mentioned that, for instance, Le Bihan (2018a) argues—in the abstract—that "priority monism is in tension with many research programs in quantum gravity" on the basis that "promising approaches to quantum gravity such as loop quantum gravity or string theory deny the fundamental reality of spacetime" (p. 95). Notably, however, there is no indication why Schaffer should be committed to, say, a fundamental metric. All Schaffer's view seems to require is some unifying structure that allows for the derivative parts being contiguous. While a priority monist would arguably not mind learning that the metric (i.e., distance relations) is emergent, emergent contiguity (due to emergent adjacency relations, for example) is likely to pose a severe threat to the position. Accordingly, the assessment of Schaffer's proposal depends on the specific details of what it is that is emergent.

Similarly, also the fate of Lewis-inspired metaphysics, typically dubbed Humeanism, depends on the details of what it is that is emergent in the various approaches. However, again, these details are often not discussed in the literature. For instance, Daniel Dohrn only very generally comments that he has "doubts as to whether fundamental physics can be reconciled with Humean metaphysics", since "according to our best theories of quantum gravity, the world is not fundamentally spatio-temporal" (Dohrn, 2020, 19). Now, arguably (and contrary to the Schaffer case), traditional Humeanism would be bothered by an emergent distance structure, since it is distance relations that are the world-making relations for the Humean (see Jaksland (2021)).[25] But it is unclear why Humeanism should be bothered by, say, an emergent spacetime-split or emergent

re-conceptions of 'spacetime"' (Huggett and Wüthrich, 2013, p. 277), they also point out the following:

> there really is no single 'spectrum' of cases, linearly ordered by some single factor encapsulating the 'spacetiminess' of the structures in question. Instead, one should picture the situation as more akin to an at best partially ordered field of theories in a space with multiple dimensions corresponding to ways in which these structures depart from relativistic spacetimes. In particular, the way one might rank theories conceptually, according to how much of the concept of spacetime they maintain, does not always align with the ranking according to the ease with which putative local beables or their surrogates can be found. [...] We now proceed to describe six types of departures from relativistic spacetimes, loosely ordered in decreasing similarity to relativistic spacetimes. (Huggett and Wüthrich, 2013, p. 277)

[25]We may understand this version of Humeanism as being mainly concerned with the question of how

dimensionality. Thus, when investigating potential issues for metaphysical programmes like Humeanism sufficient specificity is required.

This task is actually nicely met by Lam and Wüthrich (2021) who study the impact of specific theories of quantum gravity like loop quantum gravity and causal set theory on metaphysical conceptions of laws of nature like Humeanism, primitivism, and dispositionalism. In particular, they concretely analyse which spatiotemporal aspects pose a threat to certain forms of Humeanism.

7 Conclusion

Modern physics is discussed to raise the issue of the non-fundamentality of spacetime, usually dubbed the problem of spacetime emergence. We first noticed that the related discussions in physics are typically concerned with the status of specific spatiotemporal aspects, while the philosophical debate often lacks this specificity.

We then argued that it is ambiguous what 'spacetime' is supposed to refer to and offered an exhaustive list of five construals of spacetime and the resulting alleged problem of spacetime emergence. Furthermore, the different theories of quantum gravity do not hint at any shared problem of spacetime emergence, and, in particular, they do not hint at any exceptional problem. Instead, we argued that there are many different specific problems, all of which are important and must be approached in their own specificity. Referring to these problems in the abstract as 'the problem of spacetime emergence' might preclude precisely this. This is not a step backwards for the philosophical investigation of spacetime in quantum gravity but a step forward since specificity is what is required to resolve many of the outstanding issues as section 6 exemplified.

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the facts of the mosaic are ensured to be facts about the *same* world. There might be other versions of Humeanism that, with respect to the type of issue at hand, focus on the very need of some mosaic-enabling structure as such. In this case, the issue is adjacency rather than distance: what is needed is some structure that 'spreads out' the facts.

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