Explanations of and in Time

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Abstract: Various approaches to quantum gravity render spacetime an emergent phenomenon, with the existence and properties of spacetime depending in some way on a non-spatiotemporal underlying reality. This chapter investigates the mode of dependence that is involved. I explain and defend my recent proposal to classify different kinds of dependencies in terms of the principles mediating the dependency, and apply this proposal to the emergence of spacetime in quantum gravity. While philosophers have typically interpreted spacetime emergence as involving something like metaphysical grounding, I show how premises that are widely endorsed lead us to classify the emergence of spacetime in loop quantum gravity as causal in nature. I recommend spacetime functionalism as a resolution of this puzzle that vindicates the natural view of spacetime emergence as non-causal. I then explore a different approach to spacetime emergence in quantum gravity, the 'many-instant landscape' scenario described by Henrique Gomes, and show how it fits into the chapter's proposed framework for spacetime emergence.

1. Introduction

This volume explores conceptions of physical reality, suggested by theories of quantum gravity, in which spacetime as we know it is not fundamental. Theorists who wish to regard spacetime as real but non-fundamental typically speak of it as *emergent*. In this chapter I shall investigate how this emergence works.

The general notion of emergence is hugely contested, but we can extract two clear ingredients of the notion as it is applied within philosophy of science:

Dependence: Emergent phenomena depend on that from which they emerge.

Novelty: Emergent phenomena are novel relative to that from which they emerge.

Proponents of 'strong emergence' require some kind of ontological or metaphysical novelty in the emergent phenomena; proponents of 'weak emergence' require only novel epistemic or explanatory features. But how exactly to understand the Novelty ingredient need not detain us here; instead I want to focus on the Dependence ingredient. How exactly does the spatiotemporal depend on the non-spatiotemporal? Or to put it another way, how exactly does the non-spatiotemporal give rise to the spatiotemporal?

Contemporary metaphysics acknowledges a variety of different forms of dependence. The most familiar form is causal dependence. It may seem obvious that emergent spacetime is not caused to exist. I think that, in the end, this apparently obvious thought can be upheld. But as we shall see, it turns out to be surprisingly difficult to square with mainstream assumptions about how metaphysics and physics interact.

If spacetime emergence is not causal, what is it? A natural thought is that spacetime emergence is an instance of an inter-level relationship as conceived in the classical hierarchical image of science, where different sciences deal with different levels of phenomena of varying fundamentality.[1] We then have a spatiotemporal level that depends on a non-spatiotemporal level. Of course, there are many ways of understanding talk of levels, and many authors reject such talk altogether (see e.g. Thomasson 2014). The classical approach is that of Oppenheim and Putnam (Oppenheim and Putnam 1958), who characterise levels in mereological terms. A more general approach that is currently popular is to theorise about levels in terms of grounding (Fine 2012; Schaffer 2009); facts at the microphysical level are said to ground facts at the macrophysical level.[2] Reduction, whether this is then cashed out in terms of derivability or in some other way, provides a further set of theoretical tools to approach inter-level relations.

In what follows, I will work with the notion of grounding, although not much hangs on this and I hope my arguments will be intelligible to those who prefer other frameworks for understanding inter-level relations in science. Readers may regard my talk of grounding in this chapter as a placeholder for whatever non-causal relations connect levels of nature. For present purposes I am simply concerned to make conceptual space for the possibility that spacetime emerges non-causally.

We can now pose the question: is dependence of the spatiotemporal on the non-spatiotemporal an instance of causation or of grounding? Answering this question requires saying something general about how to distinguish instances of causation from instances of grounding, and on this point the literature is surprisingly thin. The distinction between grounding and causation is typically introduced by reference to paradigm cases and then presupposed without further explanation (Wilson 2018, forthcoming). There are

[1] In any realistic picture, these levels are likely to be vaguely characterized and only partially ordered.

[2] The grounding approach may subsume the mereological approach, if parts ground their wholes. (Cameron 2014). I will not address priority monist a (Schaffer 2010) which invert the relationship between levels.

clear cases of causation: collisions between billiard balls, initiations of chemical reactions, nutritional factors influencing disease. There are clear cases of grounding: the dependency of the pressure of a gas on the motion of its molecular constituents, the dependency of a set on its members, and the dependency of the permissibility of an action on the intentions of an agent. But is the dependency of spacetime on non-spatiotemporal reality more like the first kind of case or more like the second kind of case? The question is intractable as it stands; we need a general criterion for telling causation apart from grounding.

In the next section, I will criticise a temporal criterion for distinguishing grounding from causation and identify an alternative criterion – the *mediation criterion* – as better suited to understanding cases of dependent spacetime. In section 3 I argue that the application of the mediation criterion is liable to classify emergent spacetime in loop quantum gravity as caused rather than as grounded, but in section 4 I show how functionalism about spacetime provides a way of avoiding this unexpected, and potentially unwelcome, conclusion. Section 5 applies the framework of sections 2-4 to a case study of an emergent spacetime theory, the many-instant landscape view developed by Henrique Gomes. Section 6 is a conclusion.

2. Demarcation Criteria

In recent work I have explored a number of candidate criteria for distinguishing causation from grounding, arguing that the most obvious criteria fail (Wilson forthcoming). The most widespread (although usually implicit) of these criteria is what I call the *temporal criterion*. According to the temporal criterion, causation is diachronic – a cause and its effect occur at different times – while grounding is synchronic – a grounding fact and the fact that it grounds are facts about the same time.

The temporal criterion faces a number of difficulties. Elsewhere I have criticized it by appeal to apparent counterexamples in both directions – cases of simultaneous causation and of diachronic grounding[3] – but in the present context we face a problem even in applying the criterion. In a case of dependence of a spatiotemporal non-fundamental reality on a non-spatiotemporal fundamental reality, the

[3] Sample cases: Newtonian forces simultaneously cause instantaneous accelerations, and Obama *is* a former president because he *was* a president. See Wilson (forthcoming) for further discussion.

facts involved do not either occur at the same time *or* occur at different times. The non-spatiotemporal fundamental reality, as the label suggests, doesn't occur in time at all. The spatiotemporal non-fundamental reality doesn't occur in time either: if anything, time occurs in it. In cases of emergent spacetime it seems that the dependency involved in the emergence is neither diachronic nor synchronic, but rather timeless or *achronic*. The facts related by the dependency stand in no temporal relations at all to each other. For this reason, emergent spacetime hypotheses present a distinctive difficulty for the temporal criterion.

A potential response to this difficulty is to recast the temporal criterion into a *modified temporal criterion*: causation is diachronic while grounding is non-diachronic. Then both synchronic and achronic cases are classified together, and jointly contrasted with diachronic cases. While this avoids the immediate difficulty it may well seem suspiciously ad hoc. Nor does the response resolve all our problems: in recent work (Wilson forthcoming) I describe potential cases of synchronic causation (e.g. $F=ma$ in classical mechanics) and of diachronic grounding (e.g. cross-time consequences of externalist individuation criteria), and these cases cause trouble even for the modified temporal criterion. A further reason to worry about the modified criterion is that it rules out the conceptual possibility that the whole universe should be caused to exist, or that it should be intervened upon by an atemporal deity. Most importantly, in the present context the retreat to the modified temporal criterion is dialectically unsatisfying: it amounts to a bare stipulation that emergent spacetime and other forms of achronic dependence are grounding rather than causation. A principled basis for this classification is what we are after.

An alternative potential criterion that may occur to some readers is what I have called the distinctness criterion (Wilson forthcoming). According to the distinctness criterion, causation is a dependency relation between fully distinct events while grounding is a relation between not fully distinct events. This criterion is in effect used by Baron and Miller (2015) as at least a necessary condition[4] for causation in their discussion of causation in a universe with spatial but no temporal structure; they are drawing here on Lewis (1973). Baron and Miller argue that if two fully distinct events stand in a nomic dependency relation, then dependencies between them can count as causal even in the absence of any temporal relations. I have argued against the distinctness criterion elsewhere (Wilson forthcoming); for now, I note that that (as with the

[4] Baron and Miller do not directly address whether there can be grounding relations between distinct events, but the tenor of their discussion suggests they assume not; this would amount to full endorsement of the distinctness criterion.

temporal criterion) the emergent spacetime scenario presents a distinctive difficulty for the distinctness criterion. The distinctness criterion as employed by Baron and Miller and by Lewis explicitly concerns dependence between events. Baron and Miller undertake to argue that we can identify distinct events even in the timeless scenario. However, when we are dealing with emergence of spacetime from a wholly non-spatio-temporal fundamental level (as in loop quantum gravity) there may be no things identifiable as distinct events at the level of the fundamental physics at all; or at least, the basic physical elements of the theory will lack much of the structure we typically associate with events. So emergent spacetime hypotheses present special problems both for defenders of the temporal criterion and for defenders of the distinctness criterion as general accounts of the difference between grounding and causation.

It is time to turn to the approach that I favour for distinguishing between causation and grounding: the *mediation criterion*, which I have defended elsewhere (Wilson 2018, forthcoming). The mediation criterion makes use of the notion of a *mediating principle:* a general principle that mediates the connection between a particular dependent fact and the particular fact it depends on. The motivating picture here is that dependencies are not scattered piecemeal or at random about reality, but rather hold in a systematic way that is captured by a limited set of general principles. Whenever there is a dependency between two facts, there is some general principle in the vicinity linking facts like the former with facts like the latter. This does not amount to an endorsement of a general principle of sufficient reason: I am content to allow that many facts may have no explanation at all and that even dependency facts may only have partial explanations. The assumption we need is just that the holding of individual instances of dependency can always be at least partially accounted for in general terms, and I regard that as extremely plausible.

According to the mediation criterion, causal dependencies are dependencies that are mediated by some law of nature, while grounding dependencies are dependencies that are not mediated by any law of nature. Typically grounding dependencies are instead mediated by what I will call *constitutive principles*[5], principles that tell us what it is to be a particular thing or kind of thing. (In both cases there will also be a role for

[5] There is an interesting question here about whether logical and mathematical dependencies are mediated by constitutive principles, or by some other kind of principle. (They evidently are not mediated by any laws of nature, so they will not count as causal however we resolve their status.) One possible account of the difference between logical and metaphysical dependence would be that logical dependencies are mediated by inference rules whereas metaphysical dependencies are mediated by factual principles. I explore these matters elsewhere (Wilson MS).

background conditions of various kinds; set these aside for the time being.) The mediation demarcation criterion transforms questions about the nature of a dependency connection into questions about the nature of the general principles that mediate it. The idea behind it is that we can use the grasp we have on the notion of a law of nature to cast light on the distinction between causation and grounding.

Examples will help to illustrate the application of the mediation criterion. A paradigm particular case of causation would be a collision between two specific billiard-balls at some specific time, as described by classical mechanics. It is no coincidence that the resultant motion of ball B depends on the initial motion of ball A: energy and momentum are conserved in classical mechanics, and so the laws of classical mechanics determine that if the initial motion of ball A is varied then the resultant motion of ball B varies along with it. Here is a clear case of the dependency between two variables being explained by general principles: the dependency between the motions of the billiard-balls is being explained by the operation of the laws of classical mechanics. Thus the mediation criterion classifies this case as an instance of causal dependence. In contrast, a paradigm case of grounding is the dependence of the existence of the singleton set containing Socrates on the existence of Socrates himself. It is of course no mere coincidence that the existence of Socrates's singleton depends on the existence of Socrates: the principles of impure set theory dictate that all and only existing entities have a singleton set. Accordingly, if Socrates were to be somehow excised from reality then this singleton set would disappear along with him. Thus the principles of impure set theory explain why there's a connection between the philosopher and the set. No law of nature is involved in mediating the dependence, and so the mediation criterion counts this as a case of grounding.

So far, so good. Of course, once we move beyond paradigm cases matters are not so clear-cut. In particular, moving to unfamiliar physical contexts tests our grasp of the distinction between laws and non-laws. The best way to find out whether our grasp of this distinction is adequate to its assigned role is to investigate its application in some concrete cases. In the next section I turn to the application of the mediation criterion to the emergence of spacetime in the specific context of the loop quantum gravity family of quantum theories of gravity. Further applications with which to contrast this case would certainly be valuable – the case of renormalization group explanations is a particularly interesting application to consider – but these will have to await further work. This paper focuses on emergent spacetime, and it relies on whatever grasp of the law/constitutive principle distinction we can muster in that context.

3. The Mediation Criterion in Loop Quantum Gravity

A major consideration that favours the approach to classifying dependencies that is built around the mediation criterion is that the criterion extends seamlessly to atemporal forms of dependency: unlike the temporal criterion, it does not presuppose a background temporal structure in order to classify dependencies as causal or as grounding. There is room, therefore, to apply the mediation criterion to the emergence of spacetime in quantum gravity. I will consider in particular the application of the mediation criterion to the emergence of spacetime in loop quantum gravity (LQG). The reason for this choice is that I take LQG to be the most well-developed approach in which spacetime is fully emergent: on typical interpretations, LQG assumes less fundamental spatiotemporal structure than its main rival, string theory.[6] LQG accordingly presents the most radical conceptual break with the classical conception of spacetime as fundamental constituents of reality. In section 5 I will turn to a different approach to quantum gravity, Henrique Gomes' 'many-instant landscape' in which time is emergent but space is not, so that the different applications of the mediation criterion may be contrasted.

As I understand LQG[7], the aim is to describe a fundamental non-spatiotemporal reality, the physical behaviour of which gives rise to 'effective' spatiotemporal structure at a non-fundamental level. Accordingly, what is posited is the dependence of the spatiotemporal aspects of the world on some non-spatiotemporal aspects of the world. Applying the mediation criterion, we ask what principles mediate the connection between the non-spatiotemporal facts and the spatiotemporal facts. Such principles would explain why, given the non-spatiotemporal facts, we obtain the spatiotemporal facts. A first-pass schematic answer extractable from LQG is the following:

***LQGP*:** If there is a suitable superposition of spin foams, then spacetime exists and can be approximately represented by a model of General Relativity.

[6] This question is complicated by the interpretation of dualities in string theory; considerations of duality have suggested to some that spacetime is (in my sense) fully emergent in string theory also. See Huggett (2017) and Le Bihan and Read (forthcoming) for discussion.

[7] I will not need to get into any technical details of LQG. The version of the theory with which I am most familiar is that of Rovelli (2000) but I think that the aspects of the theory that I will discuss are common to most approaches.

It is up to the proponents of LQG to fill out the details of this schema. Wüthrich (2017) describes one way in which these details may be spelled out, drawing on work by Butterfield and Isham (1999, 2001) and by Ashtekar, Rovelli and Smolin (1992). For LQG to be viable, its proponents will need to be able to specify in general terms what features are required for a superposition of spin foams to give rise to familiar four-dimensional spacetime as approximated by particular models of General Relativity – as well, of course, as being able to show that such features are present in well-behaved and well-understood models of LQG. Assuming LQG proponents succeed in identifying such features of superpositions of spin foams, they will have identified some candidate physical principles connecting the fundamental reality of spin foams with the emergent reality of spacetime.

What, then, is the nature according to LQG of the principles schematized by LQGP? – are they laws of nature, or are they constitutive principles? It would be wrong to assume that because these principles are posited as part of a candidate physical theory they must be laws of nature. Theories that have historically been central to physics, such as the atomic theory of matter and the wave theory of light, involve constitutive principles as well as laws of nature. The principles concerning the interactions of atoms are laws of nature and mediate causal connections, but the principles concerning the dependency of bulk properties of macroscopic matter on the collective behavior of the matter's atomic constituents are constitutive principles and mediate grounding connections. The principles concerning the propagation of waves are laws of nature and mediate causal connections, but the principles concerning the dependency of light colour on wavelength are constitutive principles and mediate grounding connections.

It is a natural thought that the emergence of spacetime is a form of grounding, not causation. The mediation criterion accordingly predicts that it should be a natural thought that the principles concerning the emergence of spacetime should be constitutive principles, and not laws of nature. And this prediction is borne out; it is a natural thought that instances of the LQGP schema are principles about the underlying nature of spacetime. Detailed interpretive work on LQG, of the sort referenced above, is then conceived as telling us about how spacetime is made up or constituted according to LQG. This initially-plausible-seeming picture, however, is immediately threatened by a clash with the conjunction of two widely-held assumptions within metaphysics and philosophy of physics respectively: that constitutive principles are metaphysically non-contingent and that Newtonian spacetime is metaphysically possible.

The problem, in short, is that the following four claims cannot all be true together:

1. Spacetime is constituted by a superposition of spin foams.
2. Constitution of spacetime is metaphysically non-contingent.
3. Newtonian spacetime is metaphysically possible.
4. Newtonian spacetime is not constituted by a superposition of spin foams.

If the constitution of things is in general non-contingent (as metaphysicians almost uniformly suppose it is) then there is only one possible way in which spacetime can be constituted, and so either emergent spacetime as in LQG or fundamental spacetime as in Newtonian mechanics must be impossible[8].

There are routes out of this puzzle which involve giving up widely-endorsed metaphysical assumptions. In particular, we might give up 2 and reject the Kripkean principle of the necessity of constitution. Or, we might give up 3 and reject the inference from conceivability to possibility[9]. These moves may seem tempting, and especially so to those with no sympathy for contemporary metaphysics. So, would either move be justifiable as naturalistic metaphysics? I think not. In the present dialectical context, such moves would be out of proportion; whether there is or is not good reason to reject 2 or 3, such reason is unlikely to turn on anything specific to spacetime. After all, LQG is a theory about spacetime, not a theory about constitution or about modality. Without some independent argument against 2 or 3 and without some explanation of why they have seemed plausible despite being false, the moves just look ad hoc.

Assuming, then, that we retain 2 and 3, we can break the argument down as follows:

1. Spacetime emergence is mediated by LQGP.
2. Constitution of spacetime is metaphysically non-contingent.
3. Newtonian spacetime is metaphysically possible.
4. If spacetime were Newtonian, LQGP would be false.

[8] Note that even if we regard Newtonian mechanics as inconceivable on the grounds (for example) that it does not allow for stable matter, the present problem remains unresolved since it concerns fundamental spacetime rather than any particular theory in such spacetime. For theoretical pathologies to resolve the present problem, there would need to be something irredeemably wrong with every theory that posits a fundamental spacetime; this seems improbable.

[9] I should note that I have argued that 3 is false on completely independent grounds (Wilson 2013). The present chapter adopts more orthodox assumptions about modality for the sake of the argument.

5. LQGP is not a constitutive principle.
6. If LQGP is not a constitutive principle, it is a law of nature.
7. Spacetime emergence in LQG is causation, not grounding.

Could we live with this conclusion? Perhaps; but it would at least be somewhat surprising, and so it is worth exploring potential ways of avoiding the result.

4. Spacetime Functionalism

The best way of avoiding the conclusion that spacetime emergence is causal, without being forced into ad hoc metaphysics, seems to me to be to adopt functionalism about spacetime. If to be spacetime is to occupy a certain functional role within physical reality, and if that functional role can be occupied by entities of varying underlying constitution – that is, if spacetime can be multiply realized – then our conclusion 7 can be avoided and spacetime emergence can once more be regarded as grounding rather than as causation.

Functionalism about X is the view that to be X is to have a certain characteristic behaviour or function. Functionalists distinguish between *roles* and *realizers*: the role is the function itself, and the realizer is the thing that functions. Functionalism about spacetime, then, is the view that to be spacetime is to have characteristic spatiotemporal behaviour.

Functionalism about spacetime blocks the argument for spacetime emergence as causal. Recall the first two premises:

1. Spacetime emergence is mediated by LQGP.
2. Constitution of spacetime is metaphysically non-contingent.

In the functionalist picture, 1 and 2 cannot be true together on a uniform reading of 'spacetime'. If we focus on the realizer of the spacetime role, then 1 is true (since the emergence of that actual realizer is mediated by LQGP) but 2 is false: it is contingent which realizer plays the spacetime role. If we focus on the spacetime role itself, then 2 is true (since the nature of the spacetime role is non-contingent) but 1 is false: the connection between the physical facts and the existence of spacetime is now mediated by a *functional* *constitutive principle*, and this functional principle (unlike LQGP) does not make reference to any specific realizer.

What is a functional constitutive principle? In my usage, it is a principle that specifies the functional role in question by connecting the performance of that function with the existence of the functionally constituted phenomenon. In computational functionalism about the mind, the relevant principle might be that to think is to perform certain computations. In functionalism about life, the principle might be that to be alive is to maintain homeostasis, to metabolize, etc. In a functionalism about seats, perhaps the relevant principle might be that to be a seat is to be something that can be sat upon. In each case, the functional constitutive principle in question says that what it is for some functionally-constituted fact to obtain is for some particular role to be realized.

It has been suggested to me by Carl Hoefer and by Eddy Keming Chen that instead of functional constitutive principles we might appeal at this point to a determinable/determinate structure: *being a spacetime* would be a determinable property and *being a Newtonian spacetime* would be a determinate of the spacetime determinable, with *being an emergent spacetime in LQG* a distinct determinate of the same determinable. My reasons for preferring to take the functionalist route are not specific to the emergent spacetime context; I take it to be a general scientific methodological principle that where possible it is desirable to account for determinable/determinate structures in terms of functional resemblance across the different determinates. Here I would echo Dennett (2001): "Functionalism in this broadest sense is so ubiquitous in science that it is tantamount to a reigning presumption of all of science". However, I don't take this to be decisive; while it may be unfamiliar to regard *being a spacetime* as a determinable property, doing so remains a live option.

In the spacetime functionalism context, the million-dollar question is: what is the functional role of spacetime? The most influential proposal in the present literature is that of Eleanor Knox:[10]

> "a structure will play the spacetime role in our theories just in case it describes the structure of the inertial frames, and the coordinate systems associated with these." (Knox MS)

[10] Knox is here building on ideas of Harvey Brown (2005). See also Lam and Wüthrich (2018), who offer an alternative characterization of the spacetime role which they argue to be more general than Knox's.

Knox is in effect proposing that to be spacetime is to be whatever element of reality it is that determines inertial motion of matter. It is easy to see how this would be a different element of reality depending on whether Newtonian mechanics or LQG were correct. In LQG (let us assume for the sake of argument) certain non-fundamental structural features of superpositions of spin foams determine the inertial motions of matter. In Newtonian mechanics, fundamental absolute space determines the inertial motions of matter. Hence spacetime is differently realized according to the two different theories, yet retains a single functional constitution across both cases.

In my view the ability to seamlessly handle a variety of hypotheses about spacetime, including theories that make spacetime fundamental and theories that make it emergent, is the most powerful consideration in favour of spacetime functionalism. Functionalism provides the best way to make clear sense of the idea that theories with such radically different conceptions of the underlying nature of spacetime are nevertheless theories about one and the same thing. This consideration was already forceful enough when comparing different theories of non-quantum spacetime, but the radical variety of live theoretical possibilities within the quantum gravity literature makes spacetime functionalism seem close to inevitable if we are to compare the various different approaches.[11]

Spacetime functionalism provides one clear way to regard spacetime as grounded rather than caused. There are other ways: for example, the hypothesis of a determinable-determinate structure of possible spacetimes, or a more-or-less-ad-hoc rejection of premises 2 and 3. But to adopt any such approach is still merely to indicate the shape of an answer to the question of how spacetime emerges in quantum gravity. Once we have found a way to regard spacetime as grounded, we still need to understand the details of what it is grounded in and of which functional constitutive principles mediate the grounding dependency.

Theories of quantum gravity that incorporate emergent spacetime posit a non-spatiotemporal fundamental reality that underlies spatiotemporal reality. The non-spatiotemporal reality is intended to be fully physical in nature, even though it lacks spatiotemporal properties; so it is plausible to think it continues to be governed by physical laws of nature relating its different elements, whatever exactly those elements may be. According to the mediation criterion, any dependencies mediated by laws of nature are causal

[11] This point is emphasized by Lam and Wüthrich (2018).

dependencies. This line of thought suggests that non-trivial physical theories that describe a non-spatiotemporal fundamental reality will typically still involve extensive causal dependencies between different elements of that reality. In such a scenario, then we would have a general answer to our question about the grounds of spacetime: spacetime is grounded in causal processes at the fundamental level.

It is frequently assumed that there can be no causation without space and time[12]. However, it seems to me that this assumption stems from the mistaken assimilations of causation with diachronic dependence and of grounding with synchronic dependence. Once we recognise the potential for the causation/grounding distinction to come apart from the diachronic/synchronic (or diachronic/non-diachronic) distinction, we see that there is the potential to draw a principled line between non-diachronic dependencies that are cases of causation and non-diachronic dependencies that are cases of grounding. Non-diachronic causal dependencies will be mediated by laws of nature whose essential role is not that of evolving a physical system in time, but rather of determining (timelessly) the values of certain 'output' physical variables in terms of 'input' physical variables. Such generalized laws may be unfamiliar, but I see nothing impossible in them[13].

An argument could even be made at this point that a fundamental physical theory *must* posit at least some causal dependencies between distinct physical variables: perhaps a theory which consists only of constitutive principles, without including any laws of nature, would not count as a physical theory at all but rather a metaphysical theory. While I think this argument has some merit, I will not explore it further here. What I want to focus on instead is a specific way of implementing the general thought that spacetime is grounded in non-spatiotemporal physics. One illustrative proposal concerning the functional grounds of spacetime in quantum gravity, which features in recent work by Henrique Gomes, is considered in the next section. In Gomes' proposal (Gomes 2017), space is fundamental but time is not, and temporal orderings are reconstructed by appeal to dynamical properties of particular subsystems that are capable of functioning

[12] Baron and Miller (2014, 2015), who have argued for the possibility of causation in a timeless setting, are a notable exception within the metaphysics literature. Their arguments are complementary to my arguments in this section, although they are working with the distinctness criterion rather than with the mediation criterion. In the quantum gravity literature, causal set theory (e.g. Dowker 2013) may be seen as an alternative implementation of the idea that causal relations are more fundamental than spatiotemporal relations and may exist in the absence of the latter.

[13] Nor do Baron and Miller (2015).

as (relational) clocks. The proposal fits neatly into the general model for understanding functional emergence of spacetime that I have been defending in this chapter.

5. Grounding the Spatiotemporal in the Many-Instant Landscape

Gomes (2017) models possible quantum histories in a 'timeless' state space of *spatial field configurations*. He calls this the 'many-instant landscape'. To calculate transition probabilities, Gomes uses path integrals along paths from an 'initial' boundary condition, through a 'record' state, to a 'resultant' state. These paths cannot in general be interpreted as temporal histories. Some segments of these paths allow for stable clock behaviour, giving rise to an emergent temporal domain, but not all path segments do. States in the 'deep quantum' domain do not stand in any temporal relations to any other states.

Gomes himself takes causality to be conceptually linked closely to time, and in particular to the relativistic notion of timelike intervals, and accordingly he restricts the term 'causal' to apply only within the emergent temporal domain. For reasons explained earlier in the chapter, I prefer to use 'causal' more broadly; in my preferred usage from sections 1-4, all of the physically permitted[14] histories in Gomes' picture are causal histories, since there are law-of-nature-mediated explanatory connections between the states along these histories, even though only some of the histories count as temporal histories. However, to avoid confusion in the remainder of this section I shall adopt a terminology that does not clash with Gomes' own usage and contrast temporal histories with *dynamical histories*[15]. In these new terms, what the many-instant landscape picture aims to do is to account for the temporal ordering of states in terms of a more fundamental underlying dynamical ordering that makes essential appeal to a distinctive boundary condition.

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[14] Gomes' framework also allows us to characterize generic histories, subject to no equation-of-motion constraints; such histories do not in general display any law-like behaviour and I would not be inclined to regard them as physically possible histories, although different approaches to the metaphysics of these histories are no doubt possible.

[15] The word 'dynamical' has unfortunate connotations of change, and correspondingly of temporal succession. The intended use of the term here is opposed to 'kinematical'; it aims to indicate substantive constraints imposed by physics on the world, without having any implications for time or change.

Gomes takes inspiration from Boltzmannian approaches to the thermodynamic temporal asymmetry. In Boltzmannian approaches, a very special low-entropy boundary condition is allied with dynamical laws and a probability measure over states to provide an explanation of the observed temporal asymmetry of entropy. The hypothesis of this special boundary condition is known as the *Past Hypothesis:*[16]

Past Hypothesis: A low-entropy boundary condition obtains at one temporal end of the universe.

We label the low-entropy end of the universe the 'initial state'; however, as Price (1994) emphasizes, we do not have any grip on which end of the universe is initial and which is final that is independent of our physical description of the universe. Hence, in using the term 'initial state' we should be careful not to attribute any intrinsic direction to time. We have an asymmetry *in* time not an asymmetry *of* time.

Gomes retains the general shape of the Boltzmannian account of temporal asymmetry, but extends it beyond domains where temporal orderings are well-defined, replacing the Past Hypothesis with a boundary condition at the most homogeneous point of the underlying configuration space:

Dynamical Past Hypothesis: A maximally homogeneous spatial field configuration φ^* obtains, and all dynamically permitted histories pass through it.

We now think in terms of a dynamically initial state instead of a temporally initial state, but as previously this should not be taken to imply any independent grip on the dynamical orientation of the universe. We have an asymmetry *in* the dynamical order rather than an asymmetry *of* the dynamical order.

There are clear affinities between the Past Hypothesis and the Dynamical Past Hypothesis. Each of them picks out a particular state as physically privileged, and as having a foundational role with respect to the calculation of transition probabilities between states that makes it indispensable for our physical understanding of the macroscopic asymmetry of time and causation. The key conceptual point, for present purposes, is that the Dynamical Past Hypothesis generalizes the Past Hypothesis by dropping the presupposition of a fundamental temporal ordering of states.

[16] David Albert's *Time and Chance* (Albert 2000) is the source of this term, and the *locus classicus* of recent discussions.

The resulting picture is one in which the temporal ordering of states is emergent rather than fundamental. What is fundamental is the dynamical ordering of states, and the associated transition probabilities. These fundamental physical elements then ground the existence of spacetime according to an appropriate functional constitutive principle, the details of which Gomes leaves open but describes in general terms as follows:

> "space-times do not exist a priori, but require a relational construction of duration—or definitions of clocks—on classical solutions. i.e. in general one must define clocks and an experienced duration through the classical evolution of relational observables…" – Gomes (2017) p.5.

Where emergent time is well-defined, the temporal ordering will align with the dynamical ordering. But the dynamical ordering is defined even in the deep quantum epoch, dynamically prior to the emergence of time. There need not be (and plausibly will not be) any sharp differences between these temporal and non-temporal domains; whether emergent time is well-defined over a given sequence of instances may be a vague and messy business. No worries: all of the vagueness is restricted to the derivative level. The dynamical ordering remains well-defined, and the fundamental level remains precise.

6. Conclusions

I have argued that emergent spacetime raises a distinctive challenge to standard views of how grounding and causation differ. Approaches that presuppose that space and time are fundamental aspects of reality need to be made more flexible in order to make coherent sense of theories of quantum gravity that posit a nonspatiotemporal fundamental reality.

The mediation criterion is one suitable generalized criterion for distinguishing grounding from causation. The criterion permits us to count spacetime emergence as grounding either by appeal to functionalism about spacetime or by appeal to a revisionary view of the nature of spacetime as non-contingent. The criterion also allows for fundamental physical reality to have pervasive causal structure even in the absence of pervasive temporal structure. Loop quantum gravity and Gomes' many-instant landscape provide two very different potential implementations of emergent spacetime, but each can be understood through application of the mediation criterion.[17]

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