Spacetime is as spacetime does

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The main research programs in quantum gravity tend to show that standard relativistic spacetime is not fundamental. The precise and different ways in which it is not fundamental depend on the particular quantum theory of gravity, but they all seem to suggest a radical picture according to which spacetime itself is not part of the fundamental physical ontology. This perspective raises gnawing worries about the very characterization of this non-spatio-temporal physical ontology, about the emergence of the usual spatio-temporal quantities that constitute our everyday macroscopic experience, and about the very possibility of empirical evidence, including the experimental confirmation of these theories themselves. This latter point is especially problematic: if space and time are necessary preconditions of theory confirmation in empirical science, then a theory denying the fundamental existence of spacetime undermines the very possibility of its own empirical justification. Consequently, such a theory would seem empirically incoherent. This threat of empirical incoherence has also been voiced in the context of the interpretation of quantum mechanics, in particular as an argument in favor of Bell's notion of 'local beables', which are the fundamental elements of the physical ontology that are localized in a bounded region of spacetime. According to this argument, no contact between theory and empirical evidence is possible without local beables. The worry, then, is that no contact with empirical evidence is possible without fundamental spacetime quantities.

In most of the physics literature on quantum gravity, this challenge of empirical incoherence amounts to the usual constraint of consistency with the superseded theories: in particular, any theory of quantum gravity should recover in some appropriate regime the smooth relativistic spacetime picture of the theory of general relativity. This consistency constraint is a central concern in all quantum gravity programs and may typically involve approximation and limiting procedures. In this context, the issue is a technical one. However, from a conceptual point of view, the worry is that the consistency constraint is a necessary but not sufficient condition for the challenge of empirical incoherence to be met. To many, it remains unclear in what precise sense spacetime quantities, including local beables, can emerge from a fundamental non-spatio-temporal ontology.

This contribution aims to show how the tools of functionalism can help to avoid the threat of empirical incoherence. Our central claim is that spacetime need not be fully recovered in some strong ontological sense in order to provide a ground for empirical evidence and everyday experience, but only its functionally relevant features. Just as mental states can be functionally defined by their roles executed by the underlying ontology of neural states, spacetime can be functionally understood in terms of its roles in physical theories and these functions may be executed not by relativistic spacetime, but rather by an underlying ontology of non-spatio-temporal structures described by quantum gravity.

The first step of this strategy is the functional characterization of the relevant spacetime features, such as the metrical and inertial structure. This latter should in particular allow the functional characterization of the crucial notion of spatio-temporal localization,

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which is at the heart of the argument for local beables to avoid empirical incoherence. The second step involves showing that the non-spatio-temporal structures under consideration can play the right sort of functional role. The details of the functional instantiation of relevant spacetime features (in particular spatio-temporal localization) by non-spatio-temporal entities need to be worked out in concrete cases. We will focus here on two important research programs in quantum gravity: loop quantum gravity and causal set theory. We will show in these two cases how the required approximation and limiting procedures can be functionally understood such that the right sort of functional roles are instantiated. Beside the fact that the general relativistic limit involves many unsolved technical issues in both loop quantum gravity and causal set theory, we argue that the functional perspective developed here averts the conceptual issues related to the emergence of spacetime from fundamental non-spatio-temporal entities, here causal sets or spin networks (or spin foams in the covariant approach to loop quantum gravity). To the extent that these latter can be understood in the appropriate regime as being functionally related as standard spacetime quantities such as dimensionality, topology, timelike and spacelike distances, spacetime volumes, or the like, they just are (functionally) spacetime quantities in this limit. There is no further question about the emergence of these spacetime quantities and therefore no threat of empirical incoherence on this basis.

We will focus in particular on how causal sets and spin networks can functionally reproduce spacetime localization, which grounds the notion of local beables and the very contact between theory and empirical evidence. In loop quantum gravity, we will discuss the functional (and approximate) implementation of a standard spacetime lattice picture familiar to quantum field theory, which allows for localization, and from there how smooth relevant features can be functionally reproduced in the appropriate limit, such as the connection and the associated parallel transport. In causal set theory, quantities can be recovered from the fundamental causal set that approximate the dimension, topology, and distances of the approximating spacetime.

What makes the non-spatio-temporal entities described by quantum gravity concrete physical entities, rather than merely abstract mathematical ones? The standard criterion for distinguishing the concrete from the abstract relies on spacetime itself: concrete entities are in spacetime, abstract ones are not. Clearly, such a spacetime criterion is just not available for characterizing a physical ontology of non-spatio-temporal entities. An alternative characterization of concrete entities involves some notion of causal efficacy: concrete physical entities as opposed to abstract mathematical ones can be considered as causally efficacious in some sense. Whereas it does not seem obvious how to make explicit a precise notion of non-spatio-temporal causation, we argue that some weaker functional counterpart of causal efficacy could do the job here. The non-spatio-temporal structures are concrete physical structures in virtue of the (approximate) spacetime functions they instantiate. If the physically salient emergence of spacetime has been established, the status of the non-spatio-temporal entities as concreta is secured.