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BOOK REVIEW

Review of James Read's *Background Independence in Classical and Quantum Gravity*

General relativity is often viewed as providing a radical theory of space and time compared to those theories that came before. Einstein, at least initially, thought that the crucial distinguishing feature of general relativity was that it satisfied the principle of general covariance: the equations of motion retain their form under smooth but otherwise arbitrary coordinate transformation. However, Kretschmann (1917) famously showed that any theory can be given a generally covariant formulation, so general covariance cannot be the mark of general relativity. There have since been several proposals for the characteristic feature of general relativity that distinguish it from previous theories, and these proposals have been used as motivation for formulating novel theories of quantum gravity. A prominent proposal is that general relativity is distinguished from its predecessors in virtue of being "background-independent": roughly, it has no non-dynamical fields. However, there are many different definitions of background independence in the literature. James Read's *Background Independence in Classical and Quantum Gravity* undertakes the task of analyzing the content of these definitions, their relationship to one another, and the verdicts they give for a variety of theories. In doing so, it arguably provides the most comprehensive classification of definitions of background independence and their application to different theories in the philosophical literature.

The book would be of interest to philosophers of physics with interests in the foundations of spacetime theories and quantum gravity. It would also be useful as a complementary book to a graduate class on the philosophy of space and time, and as a resource for reviewing classical and quantum theories of spacetime. While it could provide an introduction to the concept of background independence, the book has reasonably high technical prerequisites, and therefore I wouldn't recommend it to someone unfamiliar with literature on the philosophy of spacetime theories. However, whenever knowledge of other debates is presupposed, the book provides detailed footnotes with references to the relevant literature.

There are several central points that the book makes. First, background independence is really an assortment of loosely related notions where no notion is apt for all applications. Second, assessing whether a theory is background-independent depends not only on what definition one uses, but also on how one interprets the theory: it depends upon which fields are considered "physical" or "geometrical," which models are taken to be physically equivalent, and how we split dynamics from kinematics. Third, the background independence of general relativity is not unique relative to all definitions and formulations of theories before it. Therefore, background independence is not the distinguishing mark of general relativity that some might have hoped for.

In more detail, Chapter 2 provides the framework for spacetime theories used in the book. First, it introduces the distinction widely used in the philosophy of physics literature between "kinematically possible models" (KPMs) and "dynamically possible models" (DPMs), where the latter are those KPMs that satisfy the equations of motion. The distinction between KPMs and DPMs is important for Read's classification of definitions of background independence since requiring some object to be fixed in all KPMs is stronger than requiring it to be fixed in all DPMs.[1] Second, this chapter introduces the notion of "gauge redundancy" in a theory, which Read defines as the thesis that distinct KPMs are taken to represent equivalent physical situations. It is important for later arguments in the book concerning the ambiguity of some accounts of background independence that one cannot settle whether a theory exhibits gauge redundancy on purely formal considerations; rather, gauge redundancy is treated as an interpretational thesis.

Chapter 3 analyzes and refines several definitions of background independence from the physics and philosophy literature. To evaluate these definitions, one needs to have some prior understanding of what concept they are trying to capture. The way that Read captures the prior notion of background independence is through three theories whose background (in)dependence is taken to be intuitive:[2]

SR1 has KPMs (M, η_{ab}, φ), where η_{ab} is the (fixed) Minkowski metric, and DPMs are determined by the massless Klein–Gordon equations $\eta^{ab}\varphi_{;ab} = 0$.
GR1 has KPMs (M, g_{ab}, φ), where g_{ab} is the (not fixed) Lorentzian metric, and DPMs are determined by the Einstein equation and $g^{ab}\varphi_{;ab} = 0$.
SR2 has KPMs (M, g_{ab}, φ), and DPMs are determined by $g^{ab}\varphi_{;ab} = 0$ and $R^{a}_{bcd} = 0$. In this theory, the Lorentzian metric g_{ab} is fixed in all DPMs of the theory.

The intuition that Read adopts is that **SR1** and **SR2** are background-dependent theories since they have a fixed metric (and so a non-dynamical field), while **GR1** is background-independent.

These toy theories immediately show that background dependence cannot be merely about whether some object is fixed in all *KPMs* of a theory, since this goes against the intuition of **SR2**. One can therefore see the definitions in this chapter as providing alternatives that do capture the intuition that **SR2** is background-dependent along with **SR1**.

One might, in response, bite the bullet and say that **SR2** is background-independent. However, we are supposed to think that **SR1** and **SR2** are two formulations of the same theory. This raises the question: Can two formulations of a single theory disagree about the background independence of the theory? This

[1] Read also introduces a novel third category—"boundary possible models" (BPMs)—that form a different subset of the KPMs: those that satisfy certain boundary conditions. However, we won't consider the role of these models in this review.

[2] These example theories are taken from Pooley (2016), although Read expands upon the discussion of these theories in several ways.

question arises throughout the book, but as a way to circumvent the issue, Read adopts a methodology of assessing the background independence of theories "on their own terms" without reference to theories that one takes to be equivalent to them.

Chapter 4 examines whether various classical theories satisfy the definitions of background independence. The theories considered include Newtonian gravitation formulated on Galilean spacetime, Newton–Cartan theory, and general relativity, but also an action formulation of Newton–Cartan theory, teleparallel gravity, Kaluza–Klein theory, scale-invariant particle dynamics, and shape dynamics. Read finds that in several cases the definitions give different verdicts, and in some cases, the verdict a definition gives depends on how one interprets the theory in question. A surprising case is that of the action formulation of Newton–Cartan theory, which differs from Newton–Cartan theory in the verdict under several definitions, and therefore highlights that intuitively equivalent theories might be regarded as differing in their background independence. It is also interesting, as Read notes, that scale-invariant particle dynamics—a supposedly "relationalist" theory—is rendered background-dependent on most definitions.

Chapter 5 considers whether various quantum theories of gravity satisfy the different definitions of background independence. It first characterizes the KPMs and DPMs of a general quantum theory of gravity. The theories then considered include perturbative string theory (in different forms), the AdS/CFT correspondence, and loop quantum gravity. Again, the conclusion is that different definitions of background independence can give different verdicts to varying degrees of ambiguity.

Chapter 6 concludes with a discussion of the role of background independence in light of the arguments in the book. There are two important remarks that Read makes here. First, we gain deeper insight into the content and classification of spacetime theories by exploring whether they satisfy the different definitions of background independence since it provides a way to distinguish the role played by different parts of the models of the theory. Second, rather than taking background independence to be a necessary part of future theories, the different definitions may be regarded as "guiding principles" for the construction of future theories. In other words, it might be fruitful to search for background-independent theories but we should not rule out a theory because it fails to satisfy some definition of background independence.

The book is extremely careful and insightful in its analysis of background independence, and I think it provides a convincing pluralistic stance. However, there are parts of the book that could benefit from further analysis. First, I think there is more to be said about the methodology of evaluating the background independence of a theory "on its own terms." It seems that a strong part of the intuition regarding whether the verdict that a definition of background independence gives is the *right* one relies on claims about what different formulations of a theory might look like (such as in the case of **SR1** and **SR2**). But even when it comes to determining *whether* a theory is background-independent according to some definition, this methodology depends upon what a theory's "own terms" are, i.e., what an individual theory is in the first place. And any way of spelling this out seems to commit one to a certain view about the different ways one can write down the "same" theory. Indeed, at several points, I wondered whether what was being characterized as an interpretational ambiguity could instead be characterized as a disagreement about what constitutes the theory. In the end, I felt that the issues that Read wanted to circumvent via this methodology were the ones that needed more thorough discussion.

Second, although I was convinced that we gain deeper insight into spacetime theories by considering their background independence, I think there is more to be said about what it means to take background independence to be a "guiding principle." As a descriptive thesis, it seems true: notably, proponents of loop quantum gravity take background independence to guide the formulation of the theory. Moreover, I take it to be unobjectionable that starting with background independence is *one* way to motivate the construction of novel theories. But how should background independence be weighed up with other principles? And how should one weigh up the different definitions of background independence in some context? Indeed, one might take the plurality of definitions (and the fact that even different formulations of a single theory can differ regarding their background independence) to suggest that there is no single thing one can point to about background independence to say why it is *desirable*. How can one therefore motivate background independence as a criterion for future theories?

Finally, a natural question that the book raises is: If background independence is not a special feature of general relativity compared to previous theories, then what is, if anything? I take part of the role of the book to be that it highlights that this remains a live question and that analysis of the kind provided in the book is necessary for gaining a deeper understanding of the road map of spacetime theories and their relationship to one another. It definitely inspired me to think more about these questions.

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