On Identifying Background-Structure in Classical Field Theories

Ryan Samaroo[†‡]

This article concerns the concept of background-structure in a classical field theory. I propose and evaluate three ways of fixing the extension of the concept, giving particular attention to the bearing of the Anderson-Friedman definition of an absolute object on that task. I attempt to show that, though that task cannot end with the Anderson-Friedman definition, that definition sharpens—and does not blur—the particular feature of general relativity that is the basis of nearly all attempts to fix the extension of the concept.

1. Introduction. This article concerns the origin and extension of the concept of background-structure. The extension of the concept, before more recent work, was easily circumscribed. The concept denoted precisely what is characteristic of the absolute space and time of Newtonian theory and of the absolute space-time of special relativity, the alleged conceptual monsters that were slain in the transition to the dynamical space-time of general relativity.

Newton thought of absolute space as implicit in his account of causal influence, an account in which absolute time is implicitly presupposed. The physical quantity *force* is not only caused but measured by the acceleration of mass, and Newton's laws define all three quantities simul-

†To contact the author, please write to: Department of Philosophy, University of Western Ontario, London, ON N6A 5B8, Canada; e-mail: rsamaroo@uwo.ca.

‡Anyone familiar with the work of Gordon Belot and Domenico Giulini will recognize my debt to them. I am grateful for discussions with audience members in Montreal and Bristol and for comments from Chris Smeenk, David Wallace, Steve Weinstein, and especially Bill Demopoulos, Robert DiSalle, and Wayne Myrvold. All errors are mine. This work was supported by the Social Sciences and Humanities Research Council of Canada.

Philosophy of Science, 78 (December 2011) pp. 1070–1081. 0031-8248/2011/7805-0029$10.00
Copyright 2011 by the Philosophy of Science Association. All rights reserved.

https://doi.org/10.1086/662275 Published online by Cambridge University Press

taneously.[1] The Newtonian dynamics expressed in the laws and in the corollaries to the laws implicitly defines the structure of classical space-time.

The structure of the space-time of Newtonian dynamics may be equally well discussed in terms of the theory's class of inertial systems. The laws of any theory formulated in the Newtonian framework or in the extension of that framework by the special theory determine an equivalence class of inertial reference frames. In Newtonian physics, those frames presuppose a global affine structure and separate metrical structures for space and time; in the special theory, they presuppose global affine and conformal structures and also the metrical structure of space-time. In both theories, those mathematical structures are fixed independently of dynamics, as part of the backdrop presupposed by dynamics, and, thus, do not evolve along with the classical fields.

Einstein's general theory of relativity comprises affine, conformal, and metrical structures. But, in contradistinction to Newtonian theory and special relativity where those structures are necessary presuppositions of the classes of inertial frames, they are determined by the distribution of mass-energy in the universe. In this way and others, general relativity revises what is characteristic about the absolute space and time of Newtonian theory and the absolute space-time of special relativity.

Some physicists and philosophers of physics, notably Rovelli (2001, 2004) and Smolin (2006), have elevated the dynamical character of general-relativistic geometry to the status of a general principle that they call 'background-independence'. Moreover, they take general relativity to contain a methodological lesson for those pursuing a quantum theory of gravity; namely, the kind and degree of background-independence exemplified in general relativity is an insight about nature that ought to be preserved in a future theory. Smolin, in particular, takes that lesson to suggest a research strategy that he summarizes in the following maxim: "Seek to make progress by identifying the background-structure in our theories and removing it, replacing it with relations which evolve subject to dynamical law" (2006, 204). My larger project is to evaluate the methodological status of this maxim, and, in that larger project, I make the case against background-independence.

In this short article, however, I take up the prerequisite task of identifying and taxonomizing the kinds of mathematical structures that might constitute background. I have two goals: (i) I begin by clarifying the sense in which general relativity can be said to be background-independent. I

1. It is significant, however, that absolute space represents a superfluous level of structure—the assumption of a privileged rest frame—that is not required for Newton's account of causal influence.

https://doi.org/10.1086/662275 Published online by Cambridge University Press

review the relativity of motion characteristic of the general theory that commits us to the requirement of general covariance—diffeomorphism invariance, on a more modern presentation—and I show that that concept is a much narrower one than background-independence. (ii) I consider the Anderson-Friedman definition of an absolute object that gives rise to another important conception of background-independence. This is the focal point of the article, and I make both the positive and the negative cases for taking that definition as a means of identifying and taxonomizing background-structure. And, though I set aside my case against background-independence for another article, there are a number of points in this project of identification and taxonomy at which the concept of background-independence appears altogether chimerical, and so I do not withhold from making some skeptical remarks that nonetheless strengthen that case.

2. Background-Independence and General Covariance. There is a sense in which the earliest discussion of background-structure in a classical field theory is found in Newton's criticism of Cartesian physics in *De grav*. However, let us begin by getting clear on the kind and degree of background-independence exemplified in general relativity.

Einstein took the first steps toward the relativity of motion characteristic of the general theory in his 1905 paper. In that paper, he presented a new relativity principle in order to address the incompatibility of electromagnetism with the Galilei-Newton relativity principle. This achievement became one of the two basic postulates of the special theory. Yet, no sooner was the special theory formulated than he began his search for a new theory of gravitation.

In 1907, he realized that inertial mass and gravitational mass are not merely proportional or indistinguishable but identical. That identity is established by the *equivalence principle*, according to which it is impossible to distinguish locally between a uniform gravitational field and a uniformly accelerated frame, and that identity formed the basis for Einstein's insight that the laws governing nongravitational interactions take the same form in a freely falling frame in a gravitational field that they would take in an inertial frame. In this way was the unique status of the classical inertial frame fatally compromised, and the fundamental distinction between inertial and noninertial frames collapsed. The relevant distinction became one between systems in free fall and non-free-fall motion, and the Lorentz-invariance of the equations of motion had to be understood as only a subset of some larger invariance group. Einstein sought, therefore, to generalize the equivalence of inertial frames in special relativity

https://doi.org/10.1086/662275 Published online by Cambridge University Press

to include frames in arbitrary states of motion.[2] He referred to that generalization as the *principle of general relativity*, and he realized that, if that principle is satisfied, there is no way of smoothly laying down a global coordinate system. To satisfy the principle of general relativity, the laws of his gravitation theory required a coordinate-general expression. He referred to that requirement as the *principle of general covariance*.

With the equivalence principle and the requirement of general covariance to which it commits us, no longer was there an equivalence class of preferred coordinate systems determined by the laws, and no longer were there the global affine, conformal, and metrical structures. Though Einstein did not use the locution 'background-independence', he certainly appealed to the notion in his own characterizations of the general theory. I will call that notion proposal 1.

> **Proposal 1.** A theory is background-independent if it satisfies the requirement of general covariance.

But no sooner do we have this proposal than we must respond to an objection: general covariance was trivialized nearly as soon as it was presented. In the 1916 paper, Einstein gave an argument for general covariance that, following Stachel, we now know as the 'point-coincidence argument'. The locution 'point-coincidence' refers to the view that all physical observations consist in the determination of purely topological relations (coincidences) between objects of spatiotemporal perception. The argument runs as follows: all evidence for or against a physical theory rests on immediately verifiable facts; immediately verifiable facts are exhausted by point-coincidences; thus, physical observations are reducible to point-coincidences. On this argument, any mapping that preserves point-coincidences preserves a theory's physical content, and, thus, no coordinate system is privileged.

In 1917, Erich Kretschmann brought to light an important physical implication of the point-coincidence argument that he took to trivialize general covariance. He thought that, if indeed a theory's physical content is exhausted by point-coincidences, the equations of any theory can be made generally covariant without a modification of that content. Kretschmann's challenge was taken seriously in the 1960s by Trautman, Anderson, Wheeler, Fock, and others, who learned to distinguish the requirement of general covariance from the symmetries that Einstein's equations admit. Henceforth, we will be discussing those symmetries and not the requirement of general covariance as understood by Einstein.

2. There is more to say about the tenability of the principle of general relativity and the alleged equivalence of frames, but I will not address that here. See DiSalle (2006).

https://doi.org/10.1086/662275 Published online by Cambridge University Press

3. The Anderson-Friedman Program. James Anderson challenged the view that general covariance is the characteristic feature of general relativity, pointing out, as did Kretschmann, that any theory can be given a generally covariant formulation. He claimed that the characteristic feature of general relativity is the representation of its metric affine geometry by what he called a 'dynamical object'. To state his claim properly, I will give an abstract characterization of a classical field theory. I do so only in meanest outline and in a familiar notation. See Pitts (2006) for a more technically and historically careful treatment of the Anderson-Friedman program and the differences between Anderson's and Friedman's definitions.

Let me represent the *space-time* of a classical field theory T as an ordered n-tuple of the form $(M, O_1, \ldots, O_n)$, where M is a smooth manifold and $O_1, \ldots, O_n$ are *geometric objects* on M. Defining "geometric objects" is a nontrivial task, but, in general, the objects in question here will be tensors and tensor fields but also tensor-like objects, such as the Christoffel symbol, which is required for the definition of the covariant derivative. The *dynamical laws* of T will be built up out of these geometric objects. These laws have the form $f(O_1, \ldots, O_n) = 0$.

Let me now turn to the concept of an automorphic *mapping* of geometric objects on the manifold. If such a mapping is infinitely differentiable, one-to-one, onto, and has an infinitely differentiable inverse, then that mapping, denoted d, is called a *diffeomorphism*, and M and M' are said to be diffeomorphic; that is, they have identical manifold structures. The arbitrary diffeomorphisms d form a group, often denoted *diff*(M) as a reminder that they are automorphisms of M. Elements of *diff*(M) act on the geometric objects of the theory in question.

With this framework in hand, let me return to Anderson's (1967, 83–84) proposal for characterizing general relativity and other classical field theories in terms of two kinds of geometric objects. (The following definitions are Michael Friedman's [1983, 57–60] reformulation of Anderson's original definitions.) A geometric object φ_i is an *absolute object* of T just in case, given two models (M, φ_i) and (M, θ_i) for T, φ_i and θ_i are invariant under *diff*(M). Anderson called a geometric object that does not satisfy this definition a *dynamical object*.

Anderson's distinction between absolute and dynamical objects is the basis of his definition of a theory's *symmetry group*, namely, the largest subgroup of *diff*(M) that leaves invariant the theory's absolute objects. It is noteworthy that, though Anderson defines a theory's symmetry group in terms of that theory's antecedently defined absolute objects, on an alternative understanding, the lack of absolute objects would be expressed by the lack of nontrivial symmetries.

That definition is significant in that in confronts Kretschmann's chal-

https://doi.org/10.1086/662275 Published online by Cambridge University Press

lenge head-on: theories may be rewritten so that their geometric objects are invariant under the actions of subgroups of *diff*(*M*) like the Poincaré group or so that they are invariant under *diff*(*M*) itself, even though, in their standard formulation, they would be invariant only under more limited mapping groups. It is precisely the further requirement expressed in the above definition that is supposed to distinguish a theory's symmetry group from its mapping or covariance group. That requirement, on Anderson's account, distinguishes general relativity, whose metric affine geometry is characterized by a dynamical object, from previous theories.[3]

We now have the basic concepts with which to consider the next candidate for background-independence. Before moving on, however, I want to note that in this framework the requirement of general covariance is satisfied to the extent that all of a theory's geometric objects are invariant under *diff*(*M*); thus, I will refer henceforth to general covariance as diffeomorphism-invariance. At this point, I also note that both Rovelli (2001, 2004) and Sorkin (2002) identify background-independence with diffeomorphism-invariance, albeit with some qualification in Rovelli's case.

4. Background-Structure Encoded in Geometric Objects and Beyond. I have presented the definition of an absolute object not only to move beyond the trivialization of general covariance but because Anderson took the presence of absolute objects in a theory to imply that theory's commitment to a certain form of background-structure, though he himself did not use that expression. Thus, the Anderson-Friedman definition provides us with another strategy for identifying background-independence, which I will call proposal 2.

> **Proposal 2.** A theory is background-independent just in case it has no absolute objects.

Note that I have not written "a theory is background-independent just in case it contains no absolute objects under *diff*(*M*)." It matters little whether the group is *diff*(*M*) or some other more physically restrictive group—what is dynamical under one group or equivalence relation may be absolute under another. What matters is that the relevant concept of background is entirely encoded in the geometric objects on the manifold.

But no sooner do we have this proposal in hand than we must respond to several objections. I will consider two here. The first objection holds that the Anderson-Friedman distinction between absolute and dynamical objects cannot capture the intended and essentially physical distinction. Robert Geroch (reported in Friedman 1983, 59 n. 9) pointed out that even in general relativity, with a metric affine geometry characterized by

3. I will not address the debate over whether general relativity has an absolute object.

https://doi.org/10.1086/662275 Published online by Cambridge University Press

a dynamical object, one might draw up a scenario in which geometric objects like nowhere-vanishing vector fields and symplectic forms count as absolute objects. He made his point with the following example. Suppose we have a cosmological model in which there is omnipresent dust, all the particles of which are at rest in some Lorentz frame. The density of the dust particles n is defined as the number of particles per unit volume in the unique inertial frame in which the particles are at rest. The motion of the dust is expressed in terms of its flux across a surface defined by $\boldsymbol{N} = n\boldsymbol{U}$, where $\boldsymbol{N}$ is the number-flux 4-vector and $\boldsymbol{U}$ is the 4-velocity of the particles. In such a universe, the velocity field $\boldsymbol{U}$ would be nowhere-vanishing and would count as an absolute object on Friedman's definition; that is, there would be a background reference frame in the imaginary model, the rest frame of the dust. Roberto Torretti (1984) gave another counterexample to the Anderson-Friedman distinction. He formulated a theory of modified Newtonian mechanics that admits models of constant nonpositive curvature. He pointed out that such curvature is undeniably a kind of background-structure yet escapes the Anderson-Friedman definition of absoluteness. Pitts (2006) presents and discusses still other counterexamples.

Depending on one's sensibilities, this line of objection may be reason enough for giving up proposal 2. But let me set this aside here. I think the bearing of these sorts of counterexamples on the viability of the Anderson-Friedman program is a separate issue, and one that exceeds the scope of this article.

Let me take up another line of objection. This objection strikes at proposal 2 in a different way. Proposal 2 commits us to the view that background-(in)dependence is an all-or-nothing affair. However, Gordon Belot (2011) has recently pointed out that the concept admits of degrees. He considers the vacuum solutions to Einstein's field equations that give rise to de Sitter, anti–de Sitter, and Minkowski space-times. These particular solutions have boundary conditions such that the resulting space-times have the global asymptotic behavior of one of the spaces of constant curvature.

In slightly more detail, take some theory formulated in the framework of general relativity. In that framework, there are no geometric objects that encode a background. Now, suppose we build into the kinematically possible configurations of the dynamical objects not only the requirement of smoothness and global hyperbolicity, from which we obtain determinism, but also the requirement that space approximates Minkowskian geometry as one approaches spatial infinity. Such a theory admits $diff(M)$ only locally, not generally; only a subgroup of $diff(M)$ preserves the asymptotic boundary conditions. The theory lies between paradigmatically background-dependent theories in which geometric objects propagate in Minkowski space-time and paradigmatically background-independent

https://doi.org/10.1086/662275 Published online by Cambridge University Press

theories such as spatially compact general relativity. So, even though the theory has no geometric objects that encode background-structure, the boundary conditions ensure that any solution has the structure of a Minkowskian background at spatial infinity.

To make precise various degrees of background-(in)dependence, Belot introduces a distinction between a theory's geometrical and physical degrees of freedom. The *geometrical degrees of freedom* are represented by the geometric objects, figuring in the dynamical laws of a theory, that parameterize the equivalence classes of space-time geometries. The *physical degrees of freedom* are represented by the geometric objects that parameterize the quotient space obtained by identifying gauge-equivalent solutions. A theory is then said to be *fully background-dependent* just in case it has no geometrical degrees of freedom and *fully background-independent* just in case its geometrical and physical degrees of freedom match. Of greater moment, however, is the possibility of characterizing theories of ambiguous background-structure. A theory is said to be *nearly background-dependent* if it has only finitely many geometrical degrees of freedom and *nearly background-independent* if it has a finite number of nongeometrical degrees of freedom. In this way, proposal 2 is both recovered and situated in a wider spectrum of possibilities in which its uniqueness is undermined.

Belot's distinctions help clarify the idea that there are various degrees of background-(in)dependence; in the same measure, they sharpen the ambiguity of the concept of background-structure. But, setting aside Belot's approach, there is a more general sense in which the concept is ambiguous. Provided that a theory has no absolute objects, does background-independence require (i) that a theory *presuppose* nothing about global structure or (ii) that a theory *preclude* the possibility of such structure? For general relativity could be said to satisfy neither points i nor ii, since the theory holds that geometry is everywhere locally Lorentzian, making Belot's point trivially true; or, general relativity could be said to satisfy only point i in that geometry is dependent on matter distribution. Though I leave aside the case against background-independence for the sequel to this article, this particular ambiguity already suggests a reason to avoid taking background-independence as a philosophical requirement.

Belot's point also provides an opportunity to comment on the distinction between local and global structure in general relativity. The general theory departs from Newtonian theory and special relativity in that it places no a priori restrictions on global structure; to put the point in Carnapian terms, global geometry is relegated to the *P*-rules of the framework. But that departure, though radical, does not stem from any philosophical motivation to construct a theory with that characteristic but

https://doi.org/10.1086/662275 Published online by Cambridge University Press

from the fact that the equivalence principle motivates a purely local definition of a geodesic.[4]

With Belot's point, we have moved well beyond Anderson's technical expectations for his definition. But, whether or not Anderson foresaw such objections to his absolute-dynamical distinction himself, we must bear in mind that he sought to address Kretschmann's challenge, proposing a means of distinguishing a theory's covariance group from its symmetry group. Thus, in reply to the question whether we are being unfair to Anderson, I believe we must situate his distinction in that context. More generally, Anderson seems to have been motivated by the task of characterizing what is conceptually distinctive about general relativity without appealing to philosophical oversimplifications.

5. Further beyond Geometric Objects. To this point, I have only considered some of the strongest mathematical structures that may be imposed on a manifold, namely, metrics and other geometric objects both absolute and dynamical. I have also considered the imposition of asymptotic boundary conditions from which background-structure may arise. In contrast, Smolin (2006) points out that one may count dimension, topological and differential structure, and even the metric signature as background-structure, though he leaves as an open question whether lower levels of background-structure are essential or may be eliminated in a future theory. Though I take Smolin's suggestion seriously, it reinforces the idea that there is something chimerical about background-independence: no sooner have we cut off one head than two more spring up to take its place; no sooner do we seem to be getting a hold of the concept than it slips away again. In any case, it is noteworthy that general relativity presupposes these lower-level features yet allows for solutions in which they are violated by (for example) singularities.

Let me return to the problem of taxonomy. At this point, one might want to set aside the lower levels of background-structure identified by Smolin in order to frame a proposal that encompasses Belot's point alone. One might try to formulate something like a proposal 2a: A theory is background-independent just in case it contains no absolute objects and does not have background-structures arising from boundary conditions imposed on the theory. But this seems gerrymandered in the extreme, and, in any case, it is subject to the same ambiguities I raised above. So, how are we to fix the extension of background-independence so as to include those kinds of background-structures that are not defined in terms of geometric objects on a manifold? I shall draw on Smolin (2006), Giulini

4. I am grateful to Robert DiSalle for conversations and corrections on these points.

https://doi.org/10.1086/662275 Published online by Cambridge University Press

(2007), and Belot (2011), and, though I do not do full justice to their views, I think something like the following underpins them:

> **Proposal 3.** A theory is background-independent just in case it has no framework that shapes the evolution of the fields without itself being shaped by them.

This proposal is very nearly the so-called action-reaction principle: for something to be physical, it cannot act without being acted upon. That principle, Einstein claimed, was part of the basis that motivated him to look beyond Newtonian physics and special relativity for a successor theory. And the idea certainly lies behind Anderson's definition of an absolute object. I will not criticize here Einstein's view that space-time should not act without being acted upon (see DiSalle 2002). Nor will I address the bearing of the action-reaction principle on discussions of background-independence. I will note only that the action-reaction principle seems to loom behind nearly all proposals for fixing the extension of background-independence.

A metaphor by Novalis—"Theories are nets: only he who casts will catch"—is particularly apt for the evaluation of proposal 3. The main objection to proposal 3 is that it is a step too far; it is a catchall for nearly any kind of mathematics used in the formulation of a theory. Proposals 1 and 2 are subsumed, but room is left for other conceptions of background-structure. It may be that a finer-grained classification is possible, one that offers intermediate proposals between 2 and 3, but I will not attempt that here; I will err on the side of greater generality rather than greater specificity. I will note only that, by catching everything, proposal 3 blurs even the line between the *language* required for saying anything at all and *properly theoretical claims* within that language. Where that line is drawn will vary from theory to theory, and, if it can ever be drawn sharply, it will not be drawn a priori or by some philosophical requirement like background-independence. As ever, it will be an empirical phenomenon—some physical criterion—like the light postulate or the equivalence principle that governs the application of some or another corpus of mathematical theory. For instance, one needs an empirical reason to impose asymptotic boundary conditions in general relativity, and, in view of that, one might not want to formulate the theory or a philosophical requirement on the theory so that such an imposition is precluded a priori. At the very least, an important strength of proposal 2 over proposal 3—or any proposal underpinned by the action-reaction principle—is that it does not dissolve the important differentiation of background-structures into a "night in which all cows are black."

If proposal 3 is a step too far, what, if anything, remains to be said about proposal 2? I have presented the negative case for proposal 2: I

https://doi.org/10.1086/662275 Published online by Cambridge University Press

have charged it with failing to account for kinds of background-structures that are not encoded in the geometric objects on a manifold. Though that particular criticism is certainly bound up with the Anderson-Friedman program, I would like to distance the failure of proposal 2 from the viability of that program. The net cast by Anderson was a good one, so good that we learn a great deal by considering what slips through. It is a virtue of the Anderson-Friedman program that it highlights the global nature of the background-structures presupposed by the classes of inertial frames in Newtonian theory and special relativity, and it highlights the way in which the equivalence principle forces us to revise our understanding of those structures—no longer presuppositions of the dynamics but evolving along with the classical fields. That one can formulate counterexamples to the effect that general relativity has such and such an absolute object does not diminish the Anderson-Friedman program's basic characterization of the difference between theories formulated in a Newtonian or special-relativistic framework, on the one hand, and those formulated in a general-relativistic framework, on the other. In this way, that program sharpens—and does not blur—the dynamical character of general-relativistic geometry that is the basis for nearly all proposals for background-independence.

6. Conclusion. So what are the taxa? With each of my three proposals, I have tried to identify a genuine candidate for background-independence. There is a sense in which the requirement of general covariance is a candidate for background-independence. But, as we know, Kretschmann's point was that theories that are not generally covariant in their standard formulation may be reformulated, a point that the Anderson-Friedman program masterfully addressed. There is also a sense in which a theory that is free of absolute objects is a candidate for background-independence. Indeed, I have treated general covariance and a theory's freedom from absolute objects as separate proposals. However, I think the fundamental taxonomical grouping is between those kinds of background-structures that are encoded in geometric objects and all those that are not. Proposals 1 and 2 are, therefore, two species of the same genus. Proposal 3 is something of a catchall, but, there too, one might distinguish between different species, namely, background-structure arising from the imposition of boundary conditions on a theory and lower levels of background-structure. It may be that a still-finer-grained classification is possible, but, even considering only the case of general relativity, the ambiguity of what taking background-independence as a philosophical requirement might mean casts doubt on the fruitfulness of the task.

Let me summarize what I take from the foregoing: (i) It is sometimes said that diffeomorphism invariance and background-independence are

https://doi.org/10.1086/662275 Published online by Cambridge University Press

synonymous. One goal of this article has been to pry these concepts apart. (ii) There is an important difference between those forms of background-structure that are encoded in the geometric objects on a manifold and those that are not. Identifying background-(in)dependence with the presence or absence of absolute objects fails to account for forms of background-structure that are not encoded in the geometric objects on a manifold. (iii) There is something peculiar about the situation of Einstein's geometrization of gravity. Although that geometrization was an empirically well-motivated move in his construction of general relativity, there is not an equally clear motivation to formulate the particular dynamical character of that theory as a much more general kind of metaphysical or methodological principle.

REFERENCES

Anderson, James L. 1967. *Principles of Relativity Physics*. New York: Academic Press.

Belot, Gordon. 2011. "Background-Independence." *General Relativity and Gravitation* 43: 2865–84.

DiSalle, Robert. 2002. "Reconsidering Ernst Mach on Space, Time, and Motion." In *Reading Natural Philosophy*, ed. David Malament, 167–91. Chicago: Open Court.

———. 2006. *Understanding Space-Time*. Cambridge: Cambridge University Press.

Friedman, Michael. 1983. *Foundations of Space-Time Theories*. Princeton, NJ: Princeton University Press.

Giulini, Domenico. 2007. "Some Remarks on the Notions of General Covariance and Background-Independence." In *Approaches to Fundamental Physics: An Assessment of Current Theoretical Ideas*, ed. Erhard Seiler and Ion-Olimpiu Stamatescu, 105–20. Berlin: Springer.

Pitts, Brian. 2006. "Absolute Objects and Counterexamples." *Studies in History and Philosophy of Modern Physics* 37:347–71.

Rovelli, Carlo. 2001. "Quantum Spacetime: What Do We Know?" In *Physics Meets Philosophy at the Planck Scale*, ed. Craig Callender and Nick Huggett, 101–22. Cambridge: Cambridge University Press.

———. 2004. *Quantum Gravity*. Cambridge: Cambridge University Press.

Smolin, Lee. 2006. "The Case for Background Independence." In *The Structural Foundations of Quantum Gravity*, ed. Dean Rickles, Steven French, and Juha Saatsi, 196–239. Oxford: Oxford University Press.

Sorkin, Rafael. 2002. "An Example Relevant to the Kretschmann-Einstein Debate." *Modern Physics Letters* A 17:695–700.

Torretti, Roberto. 1984. "Review: Space-Time Physics and the Philosophy of Science." *British Journal for the Philosophy of Science* 35:280–92.

https://doi.org/10.1086/662275 Published online by Cambridge University Press