How Could Relativity be Anything Other Than Physical?

Wayne C. Myrvold
Department of Philosophy
The University of Western Ontario
wmyrvold@uwo.ca

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Abstract

Harvey Brown's *Physical Relativity* defends a view, the dynamical perspective, on the nature of spacetime that goes beyond the familiar dichotomy of substantivalist/relationist views. A full defense of this view requires attention to the way that our use of spacetime concepts connect with the physical world. Reflection on such matters, I argue, reveals that the dynamical perspective affords the only possible view about the ontological status of spacetime, in that putative rivals fail to express anything, either true or false. I conclude with remarks aimed at clarifying what is and isn't in dispute with regards to the explanatory priority of spacetime and dynamics, at countering an objection raised by John Norton to views of this sort, and at clarifying the relation between background and effective spacetime structure.

1. Introduction

Harvey Brown's *Physical Relativity* is a delightful book, rich in historical details, whose main thrust is to an advance a view of the nature of spacetime structure, which he calls the *dynamical perspective*, that goes beyond the familiar dichotomy of substantivalism and relationism. The view holds that spacetime structure and dynamics are intrinsically conceptually intertwined and that talk of spacetime symmetries and asymmetries is nothing else than talk of the symmetries and asymmetries of dynamical laws. Brown has precursors in this; I count, for example, Howard Stein (1967) and Robert DiSalle (1995) among them. And he has successors; a number of contemporary writers have adopted views along the same lines; among these are to be counted Eleanor Knox's *spacetime functionalism* (Knox, this volume).

The full import of the dynamical perspective has not been appreciated by all commentators on the book, and, indeed, there are passages that suggest that it was not fully appreciated by Brown himself, as we shall see. I claim that a full appreciation of the view has the capacity to transform the way that debates about the ontology of spacetime take place.

I will argue that a full-blown defense of the view requires considerations of a sort that are very much out of fashion in the contemporary philosophical landscape. These involve considerations of the way that our concepts—in this case, spacetime concepts—gain purchase on the physical world. Though there can be no thought of a return to a discredited operationalism or verificationism, we nevertheless would do well to pay attention to the role that spacetime concepts play in the network of concepts we employ in our talk and thought about the physical world. Reflection on this, I claim, shows that a view along the lines advocated in *Physical Relativity* is the only possible one. Dynamical and spacetime concepts are inextricably intertwined to an extent that putative rivals fail to make sense; they do not succeed in expressing anything at all, either true or false.

2. Shifts in spacetime theories

To see this, it is useful to take as an example the radical shift in our spacetime notions associated with the shift from an Aristotelian, noninertial physics, to an inertial physics.

An Aristotelian universe is finite, bounded within the celestial sphere. The center of the sphere is dynamically distinguished, in that it is the point towards which heavy objects, those containing a preponderance of the element Earth, naturally tend, as these, unless forced to do otherwise, will tend to a state of rest as close to the centre as they can get.

That the dynamical laws for terrestrial objects invoke a state of rest means that there must be a matter of fact about whether an object within the Aristotelian universe is in motion or not. Clearly, if an object is moving towards or away from the center, it is in motion. But the laws require there to be a matter of fact about whether an object that remains at a constant distance from the center is rotating about the center or not. That is, there is a standard of rotation about the center. This is not to be identified with rotation with respect to the stars fixed in the celestial sphere, as the distinguished state of nonrotation does not coincide with nonrotation with respect to the fixed stars; on the contrary, the sphere of fixed stars is in rotation with respect to the standard of nonrotation relevant to terrestrial dynamics.

The spacetime structure appropriate to Aristotelian dynamics is much less symmetric than Galilean or Minkowski spacetime. Being spatially finite, it cannot be invariant under rigid spatial translations. Furthermore, since it has a dynamically privileged point, namely, the center of the cosmos, the spacetime structure is not invariant under transformations that move points around inside the sphere unless they keep that point fixed. However, the dynamics of terrestrial objects *is* symmetric with respect to rotations of the cosmos about its center.[1]

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[1] To avoid complications of interpretation, we confine our talk of dynamics, in the Aristotelian context, to the dynamics of terrestrial objects. According to Aristotle, it is in the nature of celestial objects to continually move in a circle. This accurately describes the behaviour of the celestial sphere, but why the motion of the wandering stars should be, not circular motion, but rather, compounded of circular motions, is a bit mysterious. There was a longstanding tradition among ancient astronomers (referred to as the *compromise of Geminus*) that *physics*, which deals with the causes of motion, is to be restricted to terrestrial phenomena, and that astronomers should confine their efforts to saving the

At every point in the Aristotelian cosmos other than the center, there is a dynamically distinguished direction: towards the center, and there is a distinguished standard of rotation about the center. We are justified in calling this *spacetime structure* because it is on the basis of this structure that we can express the notions of rest and motion required to formulation the dynamical laws. There is a difference between a certain point and certain directions being *dynamically* distinguished and merely being distinguished by relations with other objects. In an Aristotelian universe, every point can be distinguished from every other, in that every point within the universe has a unique distance from the center, and angular coordinates can be set up using either coordinates co-moving with the celestial sphere (the most useful one for celestial phenomena) or by projecting earthly latitude and longitude outward. But things do not behave differently, depending on their angular position. This is why we should regard the distinguished direction in which terrestrial objects fall as a matter of spacetime structure, and a direction distinguished, say, as the direction towards some particular star, as not.

Of course, the center point is not only dynamically distinguished; it distinguished by the distribution of matter, as it is the location of the center of the earth. But this fact does not count as spacetime structure, because, according to Aristotelian dynamics, the natural home of terrestrial matter is not the center of the earth, wherever it may be, but the center of the cosmos; it is because terrestrial matter tends towards the center that the earth is located there, and not the other way around. It is the function of dynamical laws, not only to account for the actual motions of things, but to say how things would behave if they were arranged differently. Aristotle is clear on this

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phenomena without explaining them. Our discussion of Aristotelian dynamics will respect this compromise. In the Aristotelian context, read "dynamical laws" as "dynamical laws pertaining to terrestrial objects."

point; if the earth were displaced by force from the center, it would tend to fall back to it (*De Caelo*, 296b 10–20).

Copernicus's cosmos is, like Aristotle's, finite in extent and spherical in shape. But the Copernican displacement of the earth from the center requires also a shift from Aristotelian dynamics, a shift barely adumbrated in Copernicus' book and left by him for subsequent generations to complete, as, on the Copernican system, the earth is continually in motion in an orbit displaced from the center, with no tendency to fall towards the center and come to rest there. This means that the center of the cosmos is no longer dynamically distinguished, a fact that opened up the possibility of a space without a center, an infinite space, a possibility embraced by Thomas Digges, Copernicus' first prominent defender in England.

Copernicus, of course, had nothing to say about the causes of motion and did not provide a dynamics appropriate to his system, though, since his work turned the earth into an object in the same class as the wandering stars, the new system was at odds with the compromise of Geminus. Kepler attempted to extend physics to the celestial realm, as indication in the subtitle of his *Astronomia Nova*, but it was Newton who did so successfully, standing on the shoulders of Galileo and Huygens.

On Newtonian gravity, gravitation of terrestrial objects is not towards any fixed point in space, nor, indeed, solely towards the center of the earth; every body gravitates towards every other body. If, further, all forces are forces of interaction between bodies, directed on the lines between them, then we have a dynamics that makes no distinction between points in space, and the appropriate spacetime structure involves a space symmetric under translations.

Newton formulated his laws of motion as if there is an absolute distinction between rest and uniform motion. But his dynamical laws make no use of this distinction, as Newton was well aware. This led, eventually, to the view that there is no absolute distinction between rest and motion, and to the formulation of Newtonian theory against a background of what we now call "Galilean spacetime," which Stein has referred to as the "the true structure of the spacetime of Newtonian dynamics" (1967, 183). And even this, it has come to be realized, contains excess structure. Saunders (2013), reflecting on Newton's Corollary VI of the Laws of motion, has argued that the spacetime appropriate to Newtonian dynamics is one with an absolute standard of rotation but without absolute acceleration; see Knox (2014), Weatherall (2016), Dewar (2016), and Wallace (forthcoming) for further discussion of this point, and its relation to the Newton-Cartan geometrized formulation of Newtonian gravitation.

Electromagnetism, as originally formulated, appears to make ineliminable reference to the relative motion between ponderable matter and a background aether. It was Einstein's insight that this is mere appearance, and that the theory can be reformulated in such a way that only the relative motion of pieces of ponderable matter plays a role; the aether, then, according to Einstein, becomes superfluous. The key move was to subject the concept of simultaneity to conceptual analysis and conclude that, in the context of electromagnetism at least, an absolute notion of distant simultaneity gains no purchase, because we have no notion of simultaneity independent of physical interactions that could, in principle, establish synchronization between systems that play the role of clocks. The conclusion is that the true spacetime structure of classical electromagnetism is one that possesses no notion of distant simultaneity, the structure that has come to be called Minkowski spacetime.

3. Spacetime symmetries are dynamical symmetries, and *vice versa*

The principles that, implicitly or explicitly, guide these shifts in conceptions of spacetime structure are explicitly formulated by Earman (1989, p. 46) as adequacy conditions on theories of motion. The conditions require a match between dynamical symmetries and spacetime symmetries.[2]

SP1 Any dynamical symmetry of *T* is a spacetime symmetry of *T*.

SP2 Any space-time symmetry of *T* is a dynamical symmetry of *T*.

Earman emphatically denies that these have the status of meaning postulates. SP1, for Earman, involves an invocation of Occam's razor, whereas SP2 involves the idea that laws must be universal, and hold throughout space-time.

What the discussion in the previous section is meant to suggest is that these principles do, in fact, hold in virtue of considerations of meaning. If we reflect on how we ascribe structure to spacetime, it is on the basis of dynamical considerations, and shifts in dynamics and shifts in spacetime structure go hand in hand. I suggest that principles linking dynamical structure and spacetime structure need not rest on dubious metaphysical principles, but are, rather, analytically true. Talk of spacetime symmetry is a codification of talk of dynamical symmetry. In this I am in substantial agreement with Pablo Acuña, who writes,

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[2] A comment on SP1. It excludes from consideration symmetries of the laws having to do with internal degrees of freedom, as we don't typically count those as spacetime symmetries. That is, it presupposes that we have a distinction between internal degrees of freedom and spatiotemporal degrees of freedom, and that the dynamical laws under consideration are those that pertain to the spatiotemporal degrees of freedom. This presupposition will be maintained in my discussion.

> Minkowski structure and Lorentz invariance need not be conceived in such a way that one must explain the other. Instead, they are better understood as the two sides of a single coin: the arrow between them is not explanatory, but *analytic* … (2016, p. 2).

Let us consider SP1. If it is not analytically true, then it makes sense (even if we take it to be false) to talk about a spacetime asymmetry with no corresponding dynamical asymmetry. Any attempt to do so, I claim, fails. To speak, for example, of a state of rest with no dynamical significance is to abandon any sense the word has in physical discourse and not replace that sense with anything else. This is only non-obvious because we are using a familiar word. Suppose, instead, I asked you to consider a theory involving Galilean invariant dynamics, set in a spacetime that consists of Galilean spacetime with a distinguished set of parallel timelike lines, which are called *splendid*. You might reasonably ask: distinguished, in what sense? There are uncountably many sets of parallel lines that are just like the one called "splendid"; what difference is the label meant to pick out? The mere introduction of a word does not suffice to introduce a corresponding difference. We need not, and, indeed, *cannot* invoke Occam's razor to eliminate structure unless we can say what structure is to be eliminated; Occam's razor won't be of any help unless we can tell the barber what to shave. We are no better off if, instead of "splendid," we call the distinguished set a "state of rest," if "rest" is stripped of any dynamical significance and none provided in its place.

As for SP2: what justifies us in thinking that the preferred downward direction in an Aristotelian universe is a matter of spacetime structure, what distinguishes that sort of structure from other ways a direction may be indicated, *e.g.* by reference to asymmetries in the matter distribution, is that in an Aristotelian universe, this direction is *dynamically distinguished*. For any asymmetry required to formulate the dynamics there is a corresponding spacetime asymmetry, simply because this is what it means to take an asymmetry to be a spacetime asymmetry rather than some other kind.

Some readers will balk at this. Spacetime substantivalism, the view familiar to us from primers on the philosophy of spacetime, is perfectly intelligible, it will be said, whether one takes it to be true or false. I can picture, in my mind's eye, a substantival space that is the stage on which the events of the world take place, which is in itself immoveable and hence defines a state of rest with respect to itself, though that state of rest is forever hidden from us because the mutual relations of *sensible* things are the same whether moving or at rest with respect to that state. This substantival space is, in my mind's eye, a rather deep shade of greyish blue.

To that it must be replied: pictures and metaphors are all well and good, provided that there is a non-metaphorical sense that can be attached to them. The stage of your metaphor is of wood or concrete or linoleum, and exerts a dynamical effect in the form of friction on things in contact with it and moving with respect to it. You ask me to imagine something just like that, but stripped of its friction, made invisible, indeed, stripped of all connections with dynamical properties—that is, stripped of everything that makes it a stage—but otherwise, just like a stage.

It might be said that there is nothing easier than to imagine a space whose parts are spatial points that persist in time, the temporal stages of which bear the same relation of genidentity that the temporal stage of you that is reading these words bears to your remembered self of a few minutes ago. This analogy, also, breaks down; your temporal stages bear causal relations and relations of similarity to each other not shared with stages of other persons. In the complete absence of all of that, it would make no sense to regard your temporal stages as stages of the same person.

None of what warrants ascription of genidentity to your temporal stages holds for the points of a homogenous spacetime.

I do not deny that one has a strong feeling—dare one say it, an *intuition*—that it does make sense to imagine a dynamically inert background space that defines *true rest*. But an intuition is a potentially dangerous thing for a philosopher to have. Iintellectual hygiene demands that we ask of our intuitions whether they can survive scrutiny and be transformed into considered judgments. In this case, I don't think that the intuition survives such scrutiny.

If we accept this, then there is no option beside the dynamical perspective. In particular, a substantivalist attempt to speak of a self-subsisting spacetime with properties that are ontologically independent of dynamics fails to assert anything at all. It is not false, but, rather, devoid of sense.

This denial that certain apparent disputes are genuine, on the grounds that the putative opponents fail to express contrary positions, is a descendent of a long lineage of such claims, made most notably in the twentieth century by logical empiricists on the grounds of a verificationist thesis about meaning. As such, it will appear to some to smack of verificationism, and some readers will be suspecting that the author is unaware the well-known shortcomings of verificationism. Though I am sympathetic to the view that many apparent questions are pseudo-questions, and hence to the *spirit* that drove attempts to distinguish sense from nonsense in terms of verifiability, I think that the attempts in the first half of the preceding century to draw a clean line of demarcation between sense and nonsense were too simplistic. But the absence of a simple and clean distinction between sense and nonsense does not mean that there is no difference, and does not mean that we are incapable of speaking nonsense no matter how hard we try. Nor does it free us of the obligation to take care not to inadvertently fall into nonsense. On the contrary, it only *sharpens* the obligation to beware of nonsense, as there is no easy safeguard.

The problem with verificationism is that the world is under no obligation to ensure that all physical distinctions be ones that can be empirically decided by beings like us. There may be genuine physical facts, that have their place in the physical scheme of things, which are beyond our reach.

For an example, consider the de Broglie-Bohm pilot wave theory. On this theory, ordinary physical objects are composed of corpuscles that travel on non-Newtonian trajectories. The dynamics of any theory of this sort, in order to be empirically adequate, require a distinguished relation of distant simultaneity. If we had access to the details of the trajectories of the Bohmian corpuscles, we could discern from them the distinguished relation of distant simultaneity, as the temporal order of two interventions performed at a distance from each other makes a difference to the trajectories. However, on a theory of this sort, as a matter of principle, the details of the trajectories are unavailable to us, as any attempt to monitor them disturbs them (and this is not an *ad hoc* postulate of the theory, but rather, a consequence of the theory's dynamics). Since the dynamics require a distinguished relation of distant simultaneity, the proper spacetime of Bohmian mechanics is one that contains that structure, even if the observable phenomena are Lorentz invariant. This is an example of a theory with unobservable spacetime structure.

The limitation on knowledge of some details of the physical world embedded in de Broglie-Bohm pilot wave theory is unlike the positing of putative spacetime structure with no dynamical connection to anything observable. Though individually imperceptible (usually), Bohmian corpuscles are not unconnected with experience, as, according to this theory, every object that we see is composed of such corpuscles. Nor are they causally inert (despite what is sometimes said);

on the most sensible way of construing causal relations on this theory, the particles do indeed act on one another.[3] My considerations about how concepts get a grip on the world do not require all meaningful statements about Bohmian trajectories to be verifiable. Bohmian trajectories in a Bohmian world are not of the same cloth as putative dynamically inert spacetime structure. The latter is something that we are completely causally unconnected with, and nevertheless we are asked to imagine that we can refer to it.

4. Neither substantivalist nor relationist

If, as we should be, we are realist about dynamical laws, then spacetime structure, regarded in this way, as encoding certain properties of the dynamics, is real. As the laws don't depend on what we think of them, spacetime structure does not depend on what we think of it, and, as there is a matter of fact about what the dynamical symmetries are, there is a matter of fact about what the spacetime structure is. Nor are these facts dependent on relations between material objects, as the relevant facts about the dynamical laws encode both possible and actual trajectories of material objects.[4]

This is, therefore, realism about spacetime structure. But it is not substantivalism.[5] Spacetime is not a thing (it is a non-entity, as Brown and Pooley put it). Just as trajectories

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[3] A full defense of this claim would take us beyond the scope of this paper.

[4] It should be clear that I am not adopting a Humean conception of dynamical laws.

[5] Some will claim that "substantivalism" is merely the word in vogue for a broad class of realist conceptions of spacetime, with no connotation of spacetime being substantival. I am not convinced that it is possible to strip the word of that sort of connotation, and for that reason regard it as a poor terminological choice to stretch the scope of the term so far. But this is merely a terminological matter. The substantive point is that the view defend here is a realist view, but not one that takes spacetime to be a substance or anything like one.

permitted by dynamical laws are actual or potential trajectories of things or collections of things, spacetime relations are actual or potential relations between things.

It is not relationism, either. Spacetime structure is not to be construed in terms as *actual* relations between material things, as a typical relationist view would have it.

The idea that there are basically two positions in the philosophy of spacetime, the substantivalist and the relationist, has never, in my view, been a useful tool for thinking about the role that spacetime concepts play either in our ordinary discourse or in our physical theorizing. It is time for it to be discarded.

5. Carts, horses, and two-sided coins

If we accept that the connection between spacetime structure and dynamical symmetries and asymmetries is analytic, then to say that the metric of spacetime is Minkowski, and to say that all dynamical laws are Lorentz invariant, is to say the same thing. It is true that moving rods contract because of the nature of the forces that keep them rigid (though not because of any details of the forces involved in this or that rod, but because of features that all forces share). But it would be incorrect to say that it is *not* because spacetime is Minkowski that moving rods contract, as to say that spacetime is Minkowski is not to say anything other than that all forces are Lorentz invariant.

It must be acknowledged that, though there are passages in *Physical Relativity* that clearly suggest the view I have been defending, there are others in tension with it. On the one hand, we have passages such as the following, in harmony with the view defended here.

> In special relativity, the Minkowskian metric is no more than the Kleinian geometry associated with the symmetry group of the quantum physics (p. 9).

> It is more natural in theories such as Newtonian mechanics or SR to consider the 4-connection as a codification of certain key aspects of the behaviour of particles and fields (p. 142).

On the other hand there are passages that suggest that spacetime structure and dynamical behaviour are distinct.

> A moving rod contracts, and a moving clock dilates, *because of how it is made up and not because of the nature of its spatio-temporal environment"* (p. 8).

This echoes Brown and Pooley's response to a claim of Balashov and Janssen (2003) about explanatory priority of spacetime structure over dynamics. Balashov and Janssen write,

> Does the Minkowskian nature of space-time explain why the forces holding a rod together are Lorentz invariant or the other way around?
>
> Our intuition is that the geometrical structure of space(-time) is the *explanans* here and the invariance of the forces the *explanandum*. To switch things around, our intuition tells us, is putting the cart before the horse (pp. 340–341).

In response, Brown and Pooley write,

> From our perspective, of course, the direction of explanation goes the other way around. It is the Lorentz covariance of the laws that underwrites the fact that the geometry of spacetime is Minkowskian (2006, p. 84).

There's something awry here. If talk of spacetime structure codifies facts about dynamical symmetries, there can be no question of explanatory priority of one over the other. Every moving rod indeed contracts because of the nature of the forces that hold it rigid, but it is not correct to say that it is *not* because of the spacetime environment that rods contract, if attributes of that spacetime environment are codifications of symmetries shared by all forces that could be responsible for the behaviour of moving rods. This is a point that has been lucidly been made by Pablo Acuña . Since, as he puts it, "Minkowski structure and Lorentz invariance are like the two sides of a single coin (2016, p. 11), "rather than a unidirectional explanatory arrow, what connects Lorentz invariance and Minkowski spacetime structure is a bidirectional explicatory arrow" (p. 12). I think we should take passages in *Physical Relativity* that seem to suggest the distinctness of spacetime symmetries and dynamical symmetries as slips, symptomatic of the fact that the usual ways of talking about spacetime issues are hard to shake.

Though, from the dynamical perspective, there is no question of explanatory priority between spacetime structure and dynamics, there *is* an issue of ontological dependence on which the dynamical perspective is in disagreement with substantivalism. On a traditional sort of substantivalist view, spacetime structure can be self-subsistent, independent of any facts about the dynamics of material systems, and it is this independence that permits the substantivalist to entertain the possibility of explanatory priority of spacetime over dynamics. On the dynamical view, there is no possibility of this sort of independence.

6. Norton's challenge

John Norton (2008) poses a challenge for views of this sort which Norton calls "constructive relativity." Constructive relativity, according to Norton, requires that we recover the geometry of spacetime from a matter theory "devoid of spatiotemporal presumptions" (p. 825). This, Norton argues, is a tall order, and, indeed, one that cannot be fulfilled, as, in order for the project to get off the ground, our matter theory must presuppose some spacetime structure, the very structure to be derived.

Norton is right about the dim prospects of the constructive project that he envisages, namely, that of recovering spacetime structure from a matter theory formulated without any spatiotemporal presumptions. This is because the matter theory will have to include dynamical laws, that is, laws of motion, and it is simply nonsensical to talk of motion in the absence of spatiotemporal presumptions. If the view defended here requires the feasibility of a project of that sort, then, indeed, it is doomed, barring some as-yet-unconceived conceptual innovation that would permit one to formulate a dynamical theory with no spatiotemporal presuppositions.

But is the view indeed committed to the feasibility of such a project? Let us consider how we actually do apply spacetime concepts to arrive at dynamical laws, and then refine our conception of spacetime on the basis of those laws.

It is a dialectical process. To arrive at dynamical laws, we do experiments, and these involve measurements of lengths and duration that implicitly assume some spacetime structure. It does not follow that the spacetime structure we ultimately arrive at is precisely the one that is presumed at the outset. We can start with Aristotelian presuppositions about spacetime and investigate, by means of experiments with balls rolling on smooth wooden planes, whether objects have an inherent tendency to come to rest. An inertial physics may be formulated with presuppositions that include a distinguished state of rest; it is possible then to realize, on the basis of that physics, that the supposed notion of rest in fact plays no role and has no significance. Electromagnetism may be formulated against a background of Galilean spacetime (presupposing a stationary aether that defines a background state of rest) and its properties investigated, leading to the realization that the theory involving only the fields and ponderable matter is invariant under Lorentz transformations and that the presumed aether rest frame is, contrary to first appearances, playing no role. And one route to general relativity involves formulating a field theory against a flat background that, in the final analysis, ends up having no dynamical significance.

These shifts involve stripping away superfluous structure. One formulates a theory against a presumed background that contains all the structure needed to formulate the theory, and more, and then realizes that some of the presumed structure is actually playing no role. One could, also, go the other way; a researcher with Newtonian presuppositions who found herself in an Aristotelian universe could discover that bodies do, in fact, tend to approach a preferred state of rest.

The shift from special relativity to general relativity is more complicated. General-relativistic spacetimes tend to have lots of local inhomogeneities not present in the background spacetime of special relativity, so it's not, like the other shifts, *merely* a matter of stripping away posited asymmetries. But the shift from special relativity did involve a conceptual analysis that led to the conclusion that the presumed absolute distinction between inertial and accelerated motion in fact plays no role; in its place is a physically meaningful distinction between free fall motion and motion that, under the influence of non-gravitational forces, deviates from a free fall trajectory. Here, again, the key move was conceptual analysis that revealed that a distinction that had seemed necessary to formulate laws of motion was actually failing to play a role in the dynamics, and hence failing to get a grip on anything in reality.

7. Theories with a dynamical spacetime structure

Earman's principles SP1 and SP2 are formulated in the context of theories with non-dynamical spacetime structure, spacetime structure that is "absolute," in Anderson's terminology (Anderson, 1967). Theories, such as general relativity, in which some of the spacetime structure is itself dynamical, complicate things a bit, as they require us, when talking of dynamical symmetries, to specify which dynamics we are talking about; the full dynamics of the theory, including the dynamical spacetime structure, or the dynamics of test particles in the setting of that spacetime structure?

Consider GR. The dynamics of the theory are given by the Einstein Field Equations, supplemented by dynamics for whatever forms of matter there might be. If these are such that the equations of motions for any material systems that could be used as measuring devices for durations or distances satisfy what has been called the "comma-goes-to-semicolon" rule—which roughly can be characterized as formulating them as if they were special relativistic equations and then replacing the Minkowski metric $\eta_{\mu\nu}$ with the dynamical tensor field $g_{\mu\nu}$, and replacing derivatives by covariant derivatives—then those systems will behave as measurers of the dynamical tensor field $g_{\mu\nu}$, thereby endowing that tensor field with chronogeometric significance.

As Brown rightly emphasizes, it is only because material rods and clocks couple in this way to $g_{\mu\nu}$ that we can regard it as having anything to do with a spacetime metric.

How might we apply Earman's principles to this theory, or any theory having similar properties? The dynamical equations require no background spacetime structure besides the topological and differential structure of the manifold. This is the sort of thing that is meant when it is said that general relativity realizes a wider class of spacetime symmetries than special relativity does, namely, the group of diffeomorphisms of the manifold.[6] There is a sense in which arbitrary diffeomorphisms represent both symmetries of the background spacetime, and dynamical symmetries.

On the other hand, one can also consider the dynamics of test particles, and of rods and clocks, with sufficiently small mass-energy that they have negligible effect on the metric tensor field, for whom the metric tensor field plays the role of a background against which their motions play out. Any model of general relativity gives us a spacetime with its own affine structure and metric. This spacetime structure will have its own symmetries and asymmetries. Since, at each point, there are coordinates in which the metric takes the form of the Minkowski metric, there will be *local symmetries* (which, for each point, hold approximately in a sufficiently small neighbourhood of that point), given by the Lorentz group. These symmetries typically cannot be extended globally, though, for particular solutions, there might be global symmetries, such as the rotational symmetries of the Schwarzschild solution. It is this structure that is spoken of when it is said that general relativity doesn't obliterate all distinctions between motions, but merely replaces the inertial/accelerated distinction of special relativity with free-fall/not free-fall.

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[6] And, of course, there is a long history of confusion about this, stemming from Einstein's thought that general covariance of the dynamical equations ensured this sort of background independence. See Norton (1993), Pooloey (2010).

So, in applying Earman's principles, we must ask: which dynamics, and which spacetime structure? The dynamical symmetries of the full theory are arbitrary diffeomorphisms, and the background spacetime of the theory is one that is invariant under arbitrary diffeomorphisms, a spacetime with no intrinsic structure other than its differential and topological structure. If, however, we consider the dynamics of test particles, then the dynamical symmetries are the symmetries of the metric tensor field, and that metric gives the spacetime structure of the dynamics of the test particles.

8. Theories with multiple metrics

There is a path to general relativity that involves starting with a background Minkowski spacetime, and, as a linear approximation to the full theory to be developed, defining a gravitational tensor field $h_{\mu\nu}$, that satisfies a relativistic wave equation with matter energy-momentum as source.[7] The dynamical equations for matter are taken to couple, not to the background metric, but to a linear combination of that metric and the gravitational tensor field $h_{\mu\nu}$, which we will denote $g_{\mu\nu}$. If the kinetic energy of free particles couples to $g_{\mu\nu}$, their trajectories will be geodesics of $g_{\mu\nu}$, and, if the forces governing the internal workings of material systems also couple to $g_{\mu\nu}$, then physical clocks and rods will measure its distances and times, not distances and times according to the flat background metric. One obtains the full, nonlinear theory via an iterative process that involves including the energy-momentum of the linearized gravitational field as a source, resulting in nonlinear equations, which entail corrections to the field; the energy-momentum of this yields further corrections to the source term, and so on. The iterative process yields, finally, a fully

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[7] See Misner, Thorne, and Wheeler (1973), 424–425, 435–437, and Ohanian and Ruffini (1976) Ch. 3 for textbook expositions. For a more thorough treatment see Deser (1970, 2010). Deser (1987) generalizes the treatment to a curved background, driving home the irrelevance of the metric of the initial background spacetime.

consistent theory that is equivalent to GR. Though the process starts with field equations written on a flat background, this background drops out from the final, generally covariant field equations, and in the end has no physical significance, as it is neither measured by physical rods and clocks nor essential for the formulation of the full theory's field equations. One might be tempted to weave a skeptical scenario from this, saying that perhaps, spacetime is *really* Minkowski but our rods and clocks are distorted in such a way that obscures this fact. This attempt at generating a skeptical scenario does not succeed. The metric structure measured by rods and clocks is a genuine attribute of the dynamical laws, and is in no sense an illusion, as it is every bit as real as are the dynamical laws. And, if the supposed flat background plays no dynamical role whatsoever, there can be no sense in which it is the "true" structure of spacetime.

For different sorts of field equations, it can happen that the flat background retains some physical significance, and hence is not disposable in the way that the flat background is at the end of the path to GR that starts with a linearized theory.[8] On a theory of this sort, there will be a mismatch between the dynamical symmetries of the field equations (or of the Lagrangian from which they are derived) and the symmetries of the spacetime structure relevant to the dynamics of material objects. The former are given by the Poincaré group, the latter, the symmetries of the metric field.

This gives rise to a worry. Since, on a theory of this sort, there is a mismatch between the dynamical symmetries of the field equations and those of the spacetime metric measured by rods and clocks, then, on such a theory, one or both of Earman's principles is false. Even if we don't believe that the actual physics of our world contains a mismatch of this sort, if there are conceptually coherent physical theories, indeed, ones that were actually proposed as candidate

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[8] See Pitts (2016), and his contribution to this issue, for discussions of theories of this sort, and references to the literature.

theories of gravitation, on which Earman's principles are false, this shows that they are not *analytic*.[9]

The thing to say about these theories is, I think, similar to what was said in the previous section about GR. There, also, there is a mismatch between the metric structure presupposed by the field equations (none) and the emergent metric measured by rods and clocks. When asking whether a dynamical symmetry is a spacetime symmetry, we need to ask, "Which dynamics?" and "Which spacetime structure?" There is a dynamics governing the full theory, including the metric field, and there will be a corresponding spacetime structure that is the spacetime of that dynamics, whose symmetries match the dynamical symmetries. Given a solution of the field equations, there are dynamics of test particles and small rods and clocks, with spacetime structure yielded by the metric field tensor of that solution. Both connections between dynamical symmetries and spacetime symmetries are analytic. To say that, for test bodies, there is a real distinction between motion along geodesics of the metric and motion that is forced away from geodesics, is to simultaneously refer to a fact about the dynamics of these bodies and their spacetime environment. To say that the field equations do (or do not) require a flat background spacetime is to simultaneously refer to a fact about these field equations and their spacetime setting.

It is a strength of the dynamical perspective, emphasized by Pitts (this issue), that it does not require there to be a single true metric of spacetime. Since spacetime structure is picked out by its dynamical role, if two (or more) different metrics fulfill different dynamical roles, then each can be regarded as a legitimate spacetime metric.

9. Conclusion

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[9] I am grateful to Simon Saunders and Brian Pitts for raising this point in correspondence.

As I have said, one finds in *Physical Relativity* a view about the nature of spacetime that goes beyond the familiar dichotomy of substantivalism and relationism. Moreover, I have argued, investigation of the role that spacetime concepts play in physical theorizing shows that it is the only view possible, as the connection between spacetime structure and dynamical symmetries is a conceptual one, rendering propositions such as Earman's guiding principles analytic.

When the views entertained in Brown's volume, or similar views, are generally admitted, we can foresee a considerable revolution in the literature on the philosophy of spacetime. We will see an end to the continuing variations on the struggle between substantivalist and relationist theories of spacetime. This does not, however, leave the philosopher of spacetime with nothing left to do. Though, I claim, talk of supposed spacetime structure that plays no dynamical role makes no sense, it does not follow from this that it is a straightforward matter to determine what (in Stein's words) the true structure of the spacetime of a given dynamical theory is. Precisely because of the dialectical process discussed in the section 6, above, a dynamical theory, as originally formulated, might not wear its symmetries on its sleeve, and there may be considerable work to be done in elucidating the true spacetime of a given dynamical theory.

The history of changing conceptions of spacetime has shown us that understanding which distinctions are and are not physically meaningful may require deep conceptual analysis. This is exhibited in Einstein's critique of the notion of simultaneity, and in his "happiest thought," and also in current investigations, already mentioned, into the conceptual structure of Newtonian theory and its true spacetime structure. There is also the issue of what sense, if any, can be made of the idea, suggested by some of the literature on quantum gravity, of a theory formulated in a way that is entirely independent of a background spacetime, with all spacetime structure emergent.

There remains plenty for a philosopher of spacetime to do once the old dichotomy of substantivalism and relationism has been set aside.

References

Acuña, Pablo (2016), Minkowski spacetime and Lorentz invariance: The cart and the horse or two sides of a single coin? *Studies in History and Philosophy of Modern Physics* **55**, 1–12.

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

Balashov, Yuri, and Michel Janssen (2003). Critical Notice: *Presentism and Relativity*. *The British Journal for the Philosophy of Science* **54**, 327–346.

Brown, Harvey R. (2005). *Physical Relativity*. Oxford: Oxford University Press.

Brown, Harvey R., and Oliver Pooley (2006). Minkowski Space-Time: A Glorious Non-Entity, in Dennis Dieks, ed, *The Ontology of Spacetime* (Amsterdam: Elsevier), 67–89.

Deser, S. (1970). Self-Interaction and Gauge Invariance. *General Relativity and Gravitation* **1**, 9–18. Available at arXiv:gr-qc/0411023v3.

——— (1987). Gravity from self-interaction in a curved background. *Classical and Quantum Gravity* **4**, L99-L105.

——— (2010). Gravity from self-interaction redux. *General Relativity and Gravitation* **42**, 641–46.

Dewar, Neil (2016). Maxwell gravitation. http://philsci-archive.pitt.edu/12470/.

DiSalle, Robert (1995). Spacetime as Physical Geometry. *Erkenntnis* **42**, 317–337.

Earman, John (1989). *World Enough and Space-Time*. Cambridge, MA: The MIT Press.

Knox, Eleanor (2014). Newtonian Spacetime Structure in Light of the Equivalence Principle. *The British Journal for the Philosophy of Science* **65**, 863–880.

Misner, Charles W., Kip S. Thorne, and John Archibald Wheeler (1973). *Gravitation*. San Francisco: W.H. Freeman and Company.

Norton, John (1993). General covariance and the foundations of general relativity: Eight decades of dispute. *Reports on Progress in Physics* **56**, 791–861

———(2008). Why Constructive Relativity Fails. *The British Journal for the Philosophy of Science* **59**, 821–834.

Ohanian, Hans, and Remo Ruffini (1976). *Gravitation and Spacetime*, 2nd ed. New York: W. W. Norton & Company.

Pitts, J. Brian (2016). Space-time philosophy reconstructed *via* massive Nordström scalar gravities? Laws *vs.* geometry, conventionality, and underdetermination. *Studies in History and Philosophy of Modern Physics* **53**, 73–92.

(this issue). Space-time Constructivism vs. Modal Provincialism: Or, How Special Relativistic Theories Needn't Show Minkowski Chronogeometry.

Pooley, Oliver (2010). Substantive General Covariance: Another Decade of Dispute. In M. Suarez, M. Dorato, and M. Rédei, eds., *EPSA Philosophical Issues in the Sciences* (Dordrecht: Springer), 197–209.

Saunders, Simon (2013). Reconsidering Newton's *Principia*. *Philosophy of Science* **80**, 22–48.

Stein, Howard (1967). Newtonian Space-Time. *Texas Quarterly* **10**¸174–200.

Wallace, David (forthcoming). Fundamental and emergent geometry in Newtonian physics. Forthcoming in *The British Journal for the Philosophy of Science*. Available at http://philsci-archive.pitt.edu/12497/.

Weatherall, James Owen (2016). Maxwell-Huygens, Newton-Cartan, and Saunders-Knox Space-Times. *Philosophy of Science*, **83**, 82–92.