A New Approach to the Relational-Substantival Debate

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(Forthcoming in *Oxford Studies in Metaphysics*)

Abstract

We should see the debate over the existence of spacetime as a debate about the fundamentality of spatiotemporal structure to the physical world. This is a non-traditional conception of the debate, which captures the spirit of the traditional one. At the same time, it clarifies the point of contention between opposing views and offsets worries that the dispute is stagnant or non-substantive. It also unearths a novel argument for substantivalism, given current physics. Even so, that conclusion can be overridden by future physics. I conclude that this debate is a substantive one, which the substantivalist is currently winning.

1. Introduction

The traditional relational-substantival debate is about whether space—in modern terms, spacetime—exists. The substantivalist says that it does. The relationalist says that it doesn't. According to the relationalist, all that exists, in the physical world, is material bodies related to one another spatiotemporally; there is no further thing in which these bodies are located.

This is a debate with a long history. Yet there is still surprisingly little agreement not only on what is the right answer, but also on how to understand the very question at issue and the potential answers to it—and even on whether there is any genuine dispute here. For example, we can try to formulate the debate in a way that harkens back to the traditional Leibniz-Newton dispute, as the question of whether space exists as a substantial entity. But then what it means to call something a substantial entity is disputed, so that it may start to seem like the two sides are simply talking past each other.

Some people have concluded that the debate is not substantive. Perhaps it is merely a verbal dispute about which things to call 'space' versus 'matter', with no objectively correct answer to be had (Rynasiewicz, 1996). Others have

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thought that the dispute has stagnated or become divorced from physics.[1] A review of the historical dispute and its central examples (Newton's bucket and globes, Leibniz's shifts, Kant's glove, as well as the more recent hole argument, all of which live on in today's discussions) may reasonably suggest a stagnated debate. Each of these aims to show that the opposing side recognizes either too few or too many spatiotemporal facts for the physics; but there are various maneuvers, well hashed-out in the literature, allowing each side to escape the charge. Relatedly, given the variety of different understandings of the dispute, you might think that there is no overarching, well-posed question in the vicinity (Curiel, 2016). David Malament is not alone in wondering whether there is any clear-cut dispute between the two sides: "Both positions as they are usually characterized…are terribly obscure. After they are qualified so as to seem intelligible and not too implausible, it is hard to retain a firm grasp on what divides them" (1976, 317). Certainly all of this hints at "the fragile health of the substantival-relational debate" (Belot, 1999, 38).

These are reasonable concerns when leveled at traditional conceptions of the dispute. Nonetheless, I believe that there is a debate that is substantive, not stagnant, and relevant to physics. The debate that I will present is not exactly the traditional one. But it is close enough in spirit that I think it is the best way of understanding that dispute, updated to take into account more recent developments in physics and philosophy. And once we frame the debate in this way, we unearth a novel argument for substantivalism, given current physics. At the same time, that conclusion could be overridden by future physics. A seemingly subtle shift yields surprising progress on a longstanding issue that many people feel has stagnated.

In the following section, I discuss an idea that will play a central role: structure in general, and spatiotemporal structure in particular. I will argue that, regardless of whether you are a relationalist or substantivalist, you should think that there are objective, determinate spatiotemporal facts about a world: you should be a realist about spatiotemporal structure in my sense. This follows from a general principle we rely on in physics. (The traditional debate was about the existence of space and time separately. I discuss the question of spacetime, or spatiotemporal structure, updating things to the terms of

[1] Claims that the traditional debate is non-substantive, unclear, or removed from physics, either in certain contexts or in general, can be found in Stein (1970, 1977b); Malament (1976); Horwich (1978); Friedman (1983, 221-23); Earman (1989); DiSalle (1994); Leeds (1995); Rynasiewicz (1996, 2000); Belot and Earman (2001, sec. 10.7); Dorato (2000, 2008); Pooley (2013, sec. 6.1, 7); Curiel (2016); Slowik (2016). Earman (1989) advocates the need for a *tertium quid*.

modern physics.) In section 3, I will argue that, regardless of whether you are a relationalist or a substantivalist, you *can* be a realist about spatiotemporal structure. I do this by framing the debate in terms of fundamentality and ground, notions that have gotten lots of press recently in metaphysics. I show that this way of putting things captures traditional conceptions of the dispute, while allowing us to formulate the most plausible—if not entirely traditional—versions of the two main positions on it. (Although I put things in terms of ground, what's most important is that we make use of some notion of relative fundamentality.) Finally (sections 4-5), I put all the pieces together to show that there is a powerful argument for substantivalism, or at least a powerful challenge to relationalism, given much of current physics.

At the end, I briefly discuss how the conclusion in favor of substantivalism may change with future developments in physics. Yet however the physics turns out, the question of relationalism versus substantivalism should be settled by means of the new type of argument offered here. If I am right, therefore, the substantivity of the debate is secured regardless of future developments in physics, while the conclusion in favor of one view or the other will ultimately be decided by the physics.

2. Spatiotemporal structure and the matching principle

I'll begin by arguing that both the relationalist and the substantivalist should posit enough, and not too many, spatiotemporal facts for the physics. As I will put it, they both should countenance the spatiotemporal structure that is needed for the physics. (In the next section I turn to whether they both can do this.) I argue that there is a certain methodological principle we are used to relying on in physics, even if it is not usually mentioned. This principle guides our inferences from the mathematical formulation of a theory to the nature of the world according to the theory. I show by example that we do generally, and successfully, rely on this principle. The conclusion about spatiotemporal structure will follow from it.

Consider classical Newtonian mechanics. What does this theory tell us about the world? Newton thought it tells us that absolute space, a space that persists through time, exists. He argued that phenomena involving inertial (unaccelerated) and non-inertial (accelerated, in particular rotated) motion reveal this. (Think of his bucket experiment and the spinning globes example.) Although we nowadays agree that the phenomena indicate a real distinction between inertial and non-inertial motion, we think that Newton was wrong about what's required to account for this distinction.

In today's terms, Newton was arguing for substantivalism about what is often called Aristotelian, or Newtonian, spacetime.[2] This spacetime has the structure to support Newton's idea of absolute space, for it has structure that identifies spatial locations over time. But we now know (as Newton did not) that Galilean, or neo-Newtonian, spacetime also supports the distinction between accelerated and unaccelerated motion, without absolute space.

Spelling this out. Aristotelian spacetime has all the structure of Galilean spacetime, but it also has absolute space, or an absolute standard of rest or preferred rest frame. To remind you of what this means, think of an observer on a platform and another observer on a train moving with constant velocity relative to the platform. Each observer feels that he or she is at rest and that the other is moving. Galilean spacetime says that neither one is "correct" or at rest in any absolute, observer-independent sense. Each is simply in motion relative to the other, and at rest in her own frame of reference. (Think of a reference frame as a coordinate system attached to an observer, representing her own point of view.) According to an Aristotelian spatiotemporal structure, there *is* an observer- or frame-independent fact, from among all the observers in constant relative motion, about which one is *at rest* in an absolute, frame-independent sense—namely, the one at rest in absolute space. For there is a frame-independent fact about whether a given spatial location is the same location over time, so that an object located there is at absolute rest. In other words, there is a preferred rest frame: the one that's at rest with respect to absolute space.

Intuitively, an Aristotelian spatiotemporal structure has *more* structure than a Galilean one. It has all the same structure, plus an additional absolute-space, or absolute-velocity, structure. It recognizes all the same spatiotemporal facts, but it also says that there are facts about how fast an object is moving with respect to absolute space.

It turns out that these additional facts are not needed for, or recognized by, the physics here. Newton's laws are the same in any inertial frame—they are *invariant* under changes in inertial frame—which means that they can be formulated without mentioning or presupposing a preferred frame. Since a preferred frame isn't needed in the mathematical formulation of the laws, we infer that it doesn't correspond to anything physical in the world. An absolute standard of rest isn't part of the theory's, or world's, spatiotemporal structure.

[2] Not to be confused with the spacetime that Earman (1989, 2.6) discusses under this heading.

The physics does not recognize objective, frame-independent facts about what velocity an object has. Conclusion: Aristotelian spacetime has excess, superfluous structure, as far as Newton's laws are concerned. It recognizes more spatiotemporal facts than the laws do.

These laws do recognize facts about objects' accelerations (as Newton argued). Think of Newton's first law: an object travels with uniform velocity unless acted on by a net external force. This law assumes that there is a distinction between accelerated and unaccelerated motion, since it tells things to behave differently depending on whether they are accelerating or not. In terms of spatiotemporal geometry, the law assumes a distinction between straight and curved trajectories or paths through spacetime, with the straight ones corresponding to inertial motion, the curved ones to non-inertial motion. And Galilean spacetime has the structure to support this distinction. It has an affine connection, or inertial structure, which provides a standard of straightness for these trajectories. We might put it like this: this spatiotemporal structure supports a notion or quantity of absolute acceleration but not of absolute velocity—"absolute" not in Newton's sense, which assumes the existence of absolute space, but in the sense of being invariant or frame-independent.[3]

All of this suggests that a Galilean spatiotemporal structure is the *right* structure for Newton's physics. This is the structure that's required for, or presupposed by, the dynamical laws; the structure that recognizes the spatiotemporal facts that the laws do.[4] Newton was wrong to think that a classical world must contain absolute space and a concomitant quantity of absolute velocity: the physics doesn't require it. (If the laws were not invariant under changes in inertial frame, then we would infer that extra structure. Such laws would implicitly refer to a preferred frame.) Notice that we reached this conclusion about the structure needed for the laws independently of the relationalist-substantivalist debate, an idea that I will return to soon.[5]

[3] I believe that this sense evades Rynasiewicz's (2000) arguments against the clarity of any absolute/relative distinction.

[4] Although the inference to a Galilean structure is now relatively standard (Earman (1970); Stein (1970); Huggett (1999, 194-5); Maudlin (2012, ch. 3)), there is room for debate. Saunders (2013) and Knox (2014), in different ways, argue that Newtonian physics requires a different structure. I continue as though the above inference is correct. It is in any case agreed that absolute space is not needed, and whatever structure is required, the example illustrates our reliance on the upcoming principle.

[5] A similar point is made by Stein (1970, 271-2), although he goes on to say that, "the question whether…this structure of space-time also 'really exists', surely *seems* to be supererogatory" (277). In a way I agree, but I also think that there remains a substantive

First let me say a bit about "structure." On my understanding (and as it is often used in physics and mathematical physics),[6] structure has to do with the invariant features or quantities, which are the same in all allowable reference frames or coordinate systems. Inertial structure, for example, is part of a classical spatiotemporal structure: there is an absolute, frame-independent notion of accelerated versus unaccelerated motion. But there is no "absolute velocity structure." An object's velocity depends on the inertial frame we use to describe it. Since Newton's laws are invariant under changes in inertial frame, we infer that the choice of frame is an arbitrary choice in description, and that any quantity depending on that choice, like velocity, is merely frame-dependent, not out there in the world apart from that choice.

Similarly, we think that a choice of origin is just an arbitrary choice in description, not corresponding to genuine structure in the world. Choose a coordinate system with a different origin, and the laws always remain the same. Since the laws are invariant under changes in origin—they "say the same thing"[7] regardless—we infer that this choice is merely a conventional or arbitrary choice in description. There is no preferred-location structure in the world, no coordinate-independent fact about whether a given point is "really" the origin. By contrast, the laws of Aristotle's physics are not invariant in this way. According to them, there is a preferred-location structure in the world—a location toward which certain elements naturally fall and away from which others naturally rise—and preferred coordinate systems for describing this structure, namely those with an origin at that location.

We likewise think that different choices of unit of measure are conventional or arbitrary choices in description. Change from feet to meters or some other unit for measuring distances, for instance, and the physics always remains the same. Since the physics says the same thing regardless, we infer that there is no "preferred-unit-of-measure structure" in the world.

As I see it, structure corresponds to the intrinsic, genuine, objective features or quantities, which don't depend on arbitrary or conventional choices in description. By contrast, frame-, coordinate-, or unit-dependent quantities depend to some extent on our arbitrary or conventional choices in description—arbitrary, since according to the physics any choice is equally legitimate. Such quantities aren't wholly about the world as it is in itself, but are in part about our descriptions of the world. Whereas structural features

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dispute.

[6] More is in North (2009).

[7] Brading and Castellani (2007) discuss different ways of spelling out this idea.

are agreed upon by all the allowable descriptions, and so correspond to genuine features of the world apart from any of those descriptions. No matter which description you use, after all, you get the same result.

Spatiotemporal structure in particular concerns the intrinsic, genuine, objective spatiotemporal features of a world, which don't depend on arbitrary or conventional choices—that two objects are separated by some amount under a Euclidean metric, say, or that a particle's trajectory is straight according to a given inertial structure. Notice that this idea of structure is neutral between substantivalism and relationalism. Both of these views can recognize that there is a distinction between spatiotemporal facts that are more objective, and those that are frame-, observer-, unit-, or coordinate-relative.

We are still working up to the general principle. Here's an idea that we have reached so far, which will motivate the principle. As we can see from the inference to a Galilean structure for Newton's laws, any physical theory will constrain, or help dictate, a world's spatiotemporal structure. We infer the structure from the physics in this way. This is because any theory will require or presuppose a certain spatiotemporal structure. In particular, it will require the structure needed to support the laws, in that the laws cannot be stated or formulated without assuming it—they wouldn't make sense without it.[8]

Two examples illustrate this. Recall Newton's first law, which tells objects to behave differently depending on whether they are traveling inertially, with uniform velocity, or not. This law would not make sense if there weren't a distinction between uniform and accelerated motion: it presupposes it. So the world must be such that there is this distinction. The world's spatiotemporal structure should distinguish between inertial and non-inertial trajectories. Assuming that the laws are about the objective nature of the world, there must be objective facts about whether objects are traveling inertially or not.[9]

Consider a different example that I'll return to later. If the laws are not time reversal invariant—if they "look different" when we flip the direction of time, swapping past and future—then this suggests a structural, physical distinction in the world between the two temporal directions. Newton's laws are symmetric in this sense: any behavior allowed by the theory can also happen backward in time. The film of any Newtonian process (a ball thrown in the air, billiard balls colliding), run backward, also depicts a process that evolves with the laws. These laws don't distinguish past versus future: they say

[8]Consider Earman's statement that, "laws of motion cannot be written on thin air alone but require the support of various space-time structures" (1989, 46).

[9]Compare Maudlin (2012, 9-12); Pooley (2013, sec. 3).

the same thing regardless of the direction of time. By contrast, the second law of thermodynamics says that entropy increases to the future, not the past: gases expand, ice melts, not the reverse. A reverse-running film shows something disallowed by the law. Non-time reversal invariant laws like this mention or presuppose the distinction between past and future, telling things to behave differently depending on the direction of time. Such laws would not make sense if there weren't a past-future distinction in the world, corresponding to an asymmetric temporal structure, or objective facts about past versus future: they presuppose it. (If you are worried about this conclusion in the case of the second law, stay tuned: I return to it at the end.)

Finally, the principle. The above examples are familiar instances of how we draw certain conclusions about the physical world from the laws that govern it. These examples all suggest that we rely on a certain methodological principle, which says to posit in the world the structure that's presupposed by the laws. We generally posit physical structure in the world corresponding to the mathematical structure needed to formulate the laws—such as a Galilean spatiotemporal structure for Newton's laws, an asymmetric temporal structure for non-time reversal invariant laws, or a preferred-location structure for Aristotle's laws. We infer to the world whatever the laws presuppose, whatever there must be in the world for the laws to make sense and be true of it. There should be a *match* in structure between the laws and the world. Theories obeying what I will call the *matching principle* are "well-tuned," to borrow a phrase that John Earman (1989, ch. 3) uses for a somewhat different idea.[10] (I take it this is motivated by a kind of realism. I won't argue for realism here.)

As with any guiding methodological principle, this principle won't yield conclusive inferences, yet it is still a reasonable guide. We cannot be certain that there is no absolute space in a Newtonian world, but it is reasonable to infer that there isn't. Or take special relativity. The matching principle lies behind the thought that there is no preferred simultaneity frame. Since the laws are invariant under changes in Lorentz frame, we infer that there is no absolute, frame-independent simultaneity relation. We can't be certain about this, and some people argue that we have other reasons to posit this structure (for presentism or for certain theories of quantum mechanics, for example). Still, we do generally, and reasonably, rely on this principle. We take it to be successful. As the case of special relativity shows, we need an extra reason to disobey it. To put it another way: all things being equal, we should infer a

[10]Earman suggests that there should be a match between the symmetries of the laws and of the spacetime, as a condition of adequacy on theories.

match in structure between laws and world. Those who believe in a mismatch are saying that other things are not equal, and must argue as much.[11]

It is sometimes said that the reason to posit a Galilean rather than Aristotelian structure in a Newtonian world is that the latter would yield in-principle undetectable physical facts.[12] Since Newton's laws are invariant under changes in inertial frame, no experiment could ever detect which is the preferred frame. Choose any frame in which to run your experiment, and the laws always predict the same results. That's right. But I think that there is a deeper reason for the inference to a Galilean structure, which is the match between the mathematical structure of the theory and the physical structure of the world. This match is part of our *evidence* that we have inferred the correct structure of the world. This is a more fundamental reason for the inference than the verificationist-sounding principle to avoid undetectable physical facts.

I have argued that the matching principle is a core methodological principle we use to guide our inferences from a physical theory to the nature of the world according to that theory. Now we can see that this principle tells us to posit, or countenance, or somehow be able to talk about, spatiotemporal structure. For the laws generally talk about, they mention or presuppose, a particular spatiotemporal structure. We should countenance the particular spatiotemporal structure or facts required for the laws; ipso facto, we should countenance spatiotemporal structure or facts in general. In other words, the matching principle says that we should be realists about spatiotemporal structure, since the laws presuppose such a thing, and we should generally posit in the world the structure that's presupposed by the laws.

Importantly, this conclusion is independent of the relational-substantival debate. Regardless of your position on that debate, the matching principle tells you to believe that there are objective facts about the spatiotemporal structure of a world; to recognize the spatiotemporal facts that are recognized by the laws. You should believe that a Newtonian world has a Galilean spatiotemporal structure, for example (although this claim may be understood differently by the relationalist and substantivalist, as I discuss below). Who would reject the principle? The conventionalist, for one, like Reichenbach or Poincaré, who denies that there is an objective fact about the "right" spatiotemporal structure of a world: there are no objective spatiotemporal facts. Against such

[11] Those who argue from quantum mechanics aren't proposing a mismatch, but that the laws of quantum mechanics trump special relativity when it comes to inferring this structure.

[12] Mentioned, with varying support, in Earman (1989, ch. 3), Ismael and van Fraassen (2003), Roberts (2008), Dasgupta (2009), Maudlin (2012, ch. 3), Pooley (2013, secs. 3-4).

a view, the matching principle suggests that spatiotemporal structure is out there in the world. It is not conventional or arbitrarily chosen, as is an inertial frame or origin or unit of measure.[13] This structure exists; it is part of reality. There is an objective, determinate fact about what spatiotemporal structure a world has, evidenced by its laws.

(The matching principle is not Quine's criterion for ontological commitment. Quine says that we are ontologically committed to what the variables of our theories must range over in order for those theories to be true. This has to do with ontology, with what entities exist. The matching principle is about what structure we should posit. It says to align physical structure in the world with the mathematical structure required to formulate the laws. This has to do with what spatiotemporal facts we should recognize, which is not simply a matter of ontology. To see that these come apart, notice first that a given spatiotemporal structure, say a Galilean one, can be understood by different people as involving different entities: by a certain substantivalist[14] as involving points of spacetime and a relationalist as involving material bodies. [As Tim Maudlin puts it, to attribute "a mathematical structure to physical items" is to say that those items "have some physical features that make them amenable to precise mathematical description in some respects" (2015). In particular, it is not yet to say what the items must be.] Second, two people might agree on what entities exist—say, points of spacetime—but disagree on the spatiotemporal structure, for instance on whether the points are arranged in a Galilean or Aristotelian way. This will become clearer as we proceed.)

Question: how should we formulate the laws? It seems as though different formulations can presuppose different structures. If so, then in order to adhere to the matching principle, we will first need to know how to formulate the laws, which is a big question. Trust me for now that we can make progress in advance of answering this question. I will return to it at the end.

Some have argued for a third view, neither substantivalist nor relationalist, called 'structural spacetime realism.'[15] Since that view emphasizes realism about spacetime structure, you might think that it is what I am advocating.

[13] We can agree with Reichenbach and Poincaré that those things are arbitrary, since the laws indicate that different choices are equally legitimate. Spatiotemporal structure is different. We cannot arbitrarily alter the metric, for instance, and keep the laws the same, not without major compensating changes elsewhere.

[14] See section 3.3.

[15] Different versions are in Dorato (2000, 2008); Slowik (2005); Bain (2006); Esfeld and Lam (2008); Ladyman and Ross (2009).

I don't have space to address the alternative in detail,[16] but I will note that, despite superficial similarities, it is importantly different from my overall approach. First, I claim that both the relationalist and the substantivalist should (and can: below) be realists about spatiotemporal structure, whereas spacetime structural realism aims to be distinct from either of those views. Second, I understand the idea of spatiotemporal structure differently, to encompass any objective, intrinsic spatiotemporal fact about a world. In particular, countenancing spatiotemporal structure in my sense does not mean eschewing fundamental physical objects (alternatively, intrinsic properties) altogether, nor the possibility of our knowing about such things, as the structural spacetime realist often seems to do. That said, below we will see one way in which my account mirrors certain claims of the spacetime structural realist.

3. A disagreement about ground

In order to say that the relationalist and substantivalist both should countenance spatiotemporal structure, I must be able to say that they both can do this. You might wonder: how can the relationalist believe in spatiotemporal structure? Isn't this the very sort of thing the relationalist rejects? On the other hand, if the relationalist can believe in spatiotemporal structure, you might then wonder what could be left for the two views to disagree about.

I'll now suggest that the notion of ground gives the sense in which the relationalist as well as the substantivalist can countenance spatiotemporal structure, and that this yields a real disagreement that's relevant to physics. The basic idea will be this. Both views can countenance, or believe in the existence of, spatiotemporal structure. (Whether each one is able to recognize the particular structure needed for the laws is a question that I will be sidestepping here, for reasons to come.) The views differ on what underlies this structure. Essentially, the substantivalist says that spatiotemporal structure is fundamental to the physical world, whereas the relationalist says that it arises from the relations between and properties of material bodies.

Putting this in terms of ground. A grounding relation is an explanatory relation that captures the way in which one thing depends on or holds in virtue of another, without implying that the dependent thing doesn't exist. Ground captures a "metaphysical *because*" in answer to questions about why something exists or some fact holds. (I use the general idea, without entering into debates over its metaphysics. I won't take a stand on whether ground is

[16] See Greaves (2011).

properly a relation between facts or objects, but deliberately use both ways of talking. It is generally thought that the grounding relation is transitive and irreflexive, and that the grounds metaphysically necessitate the grounded. None of these assumptions have gone uncontested, but I assume them here.[17])

Using the notion of ground, the relationalist and substantivalist can each say that spatiotemporal structure exists, that there are objective spatiotemporal facts about a world. They disagree on what the spatiotemporal structure holds in virtue of; what metaphysically explains the spatiotemporal facts. The relationalist says that a world's spatiotemporal structure is grounded in the features and behaviors of material bodies. All the spatiotemporal facts are grounded in the facts about material bodies. The substantivalist says that spatiotemporal structure isn't grounded in anything else more fundamental to the physical world; in particular, it is not grounded in material bodies. There are fundamental spatiotemporal facts that are not grounded in facts about material bodies. Both views can countenance spatiotemporal structure or facts; they disagree on what, if anything, grounds this structure or those facts.

I spell out the two views more in a moment. First, a few notes on the use of ground in this context. Jonathan Schaffer (2009, 363) and Shamik Dasgupta (2011) also suggest that we can understand this debate in terms of ground, but they put things a little differently. They say that the relationalist and substantivalist both believe that spacetime exists, while differing on what grounds the existence of spacetime. I say that both (can and should) believe that spatiotemporal structure exists, while differing on what grounds the existence of that structure. I prefer this way of putting things because, we'll see, it allows us to flesh out the competing views in different ways, all the while maintaining a genuine dispute that the physics will weigh in on.

It may seem unexciting to exchange a debate about the existence of spacetime for one about the fundamentality of spatiotemporal structure. There has been much discussion in metaphysics of late about doing a similar kind of exchange with other existence debates (as in Schaffer (2009)), so that this instance may feel like old hat. There have been some related thoughts about the spacetime debate in recent philosophy of physics as well. Thus Carl Hoefer (1998) frames the question in terms of fundamentality, as that of how "to understand the basic ontology of the physical world," although he formulates aspects of the dispute more traditionally, saying for instance that substantivalism is committed to the existence of "a substantial, quasi-absolute

[17] Different accounts are in Fine (2001); Schaffer (2009). Rosen (2010) defends the idea.

entity."[18] Gordon Belot (1999, 2000, 2011) says that the relationalist, like the substantivalist, can be a realist in the sense of "attribut[ing] to reality a determinate spatial structure," while disagreeing on "the nature of the existence of space" (2011, 1).[19] This is close to my own way of putting things, although his account is not spelled out in the same way (it does not use notions like ground or my conception of spatiotemporal structure, and it focuses on certain traditional examples), nor does he draw the same conclusions. The more prevalent attitude in philosophy of physics, especially among those who complain about the substantivity of the dispute, is that the debate concerns the existence question. So although the current understanding of the dispute is not without precedent, even then there are differences, and it is anyway not the prevalent viewpoint. If you disagree with that assessment, though, it will soon be clear that novel avenues of argument open up once we are completely explicit about this shift.

3.1. Relationalism in terms of ground

The relationalist says that certain material bodies, and various of their properties and relations, are fundamental, and a world's spatiotemporal structure holds in virtue of them. All spatiotemporal structure or facts are grounded in (facts about) material bodies. In saying that "certain material bodies are fundamental," this means whichever material objects turn out to be most fundamental: certain particles, say. (I assume the fundamental relations can include spatiotemporal ones, although the relationalist might want a different kind of relation to be fundamental, causal ones being a familiar candidate.[20] I leave this open here. The upcoming argument takes aim at all these versions of relationalism equally.[21])

So, for example, the fact that a world has a Euclidean spatial structure is grounded in, holds in virtue of, the fact that its particles are, and can be, arranged in various ways, with various distance relations between them. (I return to this "can be" phrase soon.) The world has a Euclidean structure *because* (in the metaphysical sense) its particles are, and can be, arranged in

[18]Hoefer similarly argues that this is a substantive dispute, which is likely to remain so with future physics, and that general relativity supports substantivalism. Yet he puts various things differently from how I do, drawing these conclusions for different reasons.

[19]Belot also says that this formulation, while unorthodox, yields a debate that is substantive, relevant to physics, and reminiscent of the traditional dispute.

[20]See for example Nerlich (1994a, ch. 1).

[21]I also assume that the objects and relations are equally fundamental, though there may be a view with only one fundamental "ontological category" in the sense of Paul (2013).

those ways; this is what the spatial structure consists in. Similarly, the fact that a Newtonian world has a Galilean spatiotemporal structure is grounded in the fact that its particles do, and can, behave in various ways, with various spatiotemporal relations between them. The fact that a world has a particular spatiotemporal structure is made true by the facts about material bodies. A world has the spatiotemporal structure it does because material bodies (can) behave in certain ways.

Three notes on this use of ground. First, a grounding explanation is importantly different from a causal explanation. In Kit Fine's words, ground yields "a distinctive kind of metaphysical explanation," in which the objects or facts are connected by "some constitutive form of determination" (2012, 37). Particle behaviors don't cause a Euclidean spatial structure. This is rather what the spatial structure consists in or depends on, in a metaphysical sense. Compare this to more familiar cases, such as the grounding of facts about the macroscopic world in facts about subatomic particles, or the grounding of mental facts in non-mental facts, or moral facts in non-moral facts. Ground captures this metaphysical "in virtue of" explanation.[22] As I understand it, when we say that "the fact that x grounds the fact that y," this just means that "the fact that y holds in virtue of the fact that x"; i.e., that the holding of the grounded fact consists in nothing more than the holding of the grounding fact.

Second, ground aims to give a "looser" connection between the facts or objects involved than that given by a definition. An analogy. I am thinking of ground in such a way that it can articulate the view that the biological facts are nothing over and above the facts about these systems' particles. (You may not hold such a view, but ground can specify what it amounts to.) The history of failed attempts in twentieth-century philosophy of science to spell out a "tighter" connection between the reduced and reducing facts by means of correspondence rules that *define* the biological quantities in terms of physical ones suggests that this won't work. Yet there is still a way of capturing the sense in which the biological facts "are nothing but" the physical facts, which is to say that the biological facts are grounded in the physical ones. In an analogous way, the relationalist can say that the facts about spatiotemporal structure are "nothing but"—are grounded in—the facts about material bodies, even if she can't explicitly define the spatiotemporal structure in terms of the relations between material bodies. A grounding relation can hold even in the absence of a definitional connection. (This is one reason the notion of ground can help

[22] Loewer (2001) discusses the relevant sense of "in virtue of."

the relationalist, since finding such explicit definitions is notoriously difficult. Of course, it is not easy to give an account of the grounding of spatiotemporal structure in material bodies either, but replacing the definitional requirement with the looser constraints of ground can ease some of the burden.)

Third, there must be some account of *how* the facts that the relationalist takes to be fundamental manage to ground all the spatiotemporal facts needed for the physics. (For instance, there can't be two worlds with the same fundamental relationalist facts but different spatiotemporal structures, since the fundamental facts necessitate the grounded facts.) Simply being a realist about spatiotemporal structure does not guarantee the ability to generate the particular structure required by the laws as the matching principle demands. You might be skeptical that the relationalist can do this. Much of the literature is taken up with this question of how, and whether, the relationalist's more meager ontology can recognize all the spatiotemporal facts we want.[23]

This is a big question, but I won't try to answer it here. I won't try to tell you exactly how the relationalist grounds all the spatiotemporal facts in facts about material bodies.[24] As we'll see, I think there is an argument for substantivalism that goes through even if we grant the relationalist the ability to ground all the relevant facts in ones she takes to be fundamental. So for the purposes of that argument, I am going to grant the relationalist that ability.

It is worth mentioning one thing that I do think will be required to ground that structure, which is some version of "modal relationalism." I suspect that the relationalist will have to countenance facts not only about the actual features and behaviors of material bodies, but about their possible ones as well—facts about what spatiotemporal relations *can* hold, in some sense. This is because the actually instantiated relations won't in general suffice to fix the full spatiotemporal structure required for the physics. (As long as the relationalist can embed the actual relations uniquely into a certain structure, it seems as though she can talk of the spatiotemporal structure of a world. The problem is that the actual relations may not uniquely fix the structure [up to isomorphism] needed for making predictions about material bodies.[25]) In order to adhere to the matching principle, the relationalist will have to

[23]A repeated complaint against the varieties of relationalism surveyed by Pooley (2013) is that the relationalist's resources are too thin to yield predictions of the phenomena.

[24]From this perspective, those such as Manders (1982), Mundy (1983, 1992), Huggett (2006), Belot (2011) can be seen as giving accounts of how this grounding project might go.

[25]Examples are in Mundy (1986); Maudlin (1993, 193-94, 199-200); Nerlich (1994a); Belot (2000, 2011, ch. 2). Field (1984) argues that the modal view is necessary for the relationalist to solve the problem of quantity. An alternative is conventionalism (Earman, 1989, 8.6).

go modal. I refer you to Carolyn Brighouse (1999) and Belot (2011) for discussion of ways the relationalist might do this and what sort of modality may be involved.[26]

(Modal relationalism arguably allows the view to countenance vacuum worlds, which seem possible according to both classical and relativistic physics. Such worlds contain no material bodies and yet can have a spatiotemporal structure. Now, it is open to to the relationalist to deny that vacuum models correspond to physically possible worlds. Nonetheless, the modal relationalist should be able to allow for these possibilities. All the facts about spatiotemporal structure will still be grounded in facts about material bodies—in facts about how these bodies would behave, if there were any. Such a relationalist can arguably even countenance different spatiotemporal structures in different vacuum worlds, as general relativity seems to allow for. This is not to say exactly how the relationalist can do this, just as I haven't said how the relationalist can ground any particular structure in material bodies. Yet once we grant the [modal] relationalist the ability to ground all the spatiotemporal facts in facts about material bodies, there needn't be a special problem for vacuum worlds.)

Keep in mind that the relationalist might not deny the fundamentality of *any* spatiotemporal fact or structure. Depending on the version of the view (see the beginning of this subsection), the fundamental facts may include ones such as that two particles are separated by some distance, or that one particle lies between two others.[27] What's important is that the relationalist only allows certain kinds of spatiotemporal facts (if any) to be fundamental, namely those that essentially involve material bodies and their relations—facts that the substantivalist takes to be nonfundamental. The fact that a world has a given spatiotemporal structure is grounded in the facts about material bodies, even though these latter facts may include certain spatiotemporal ones. More exactly: there is no fundamental spatiotemporal fact or structure apart from the structure of, or facts about, material bodies. (Since some spatiotemporal facts or structure may be fundamental, hence ungrounded [assuming that fundamental facts are ungrounded, which some dispute].) For ease of exposition, I put this as the claim that all spatiotemporal facts

[26]The view may sound newfangled, but even Leibniz, according to many, held it: Belot (2011, Appendix D). The liberalized relationalism of Teller (1991) is a precursor to more recent versions. See also Sklar (1974, III.B2); Horwich (1978); Mundy (1986). Objections are in Malament (1976); Field (1984); Earman (1989, 6.12); Nerlich (1994a).

[27]Which of these depends on whether the relationalist thinks that fundamental relations can be quantitative.

are grounded in facts about material bodies. All spatiotemporal structure is grounded in the relations between and properties of material bodies.

So: using the notion of ground, the relationalist can say that there are facts about a world's spatiotemporal structure, which are distinct from the facts about material bodies and their relations, but are also nothing over and above those facts about material bodies—just as one might say that there are real facts about macroscopic systems, which are distinct from the facts about their particles, but are also nothing over and above the facts about the particles.

This is a non-standard (if not wholly unprecedented) way of formulating relationalism, which captures traditional thoughts about the view, for instance that spacetime doesn't "really exist": "spacetime" is nothing but various features of material bodies; certain material bodies are fundamental, and any spatiotemporal talk or fact is really about them. At the same time, this formulation allows the relationalist to say that spatiotemporal structure exists, there are objective truths about what spatiotemporal structure a world has, as the matching principle says we should do. It's just that these things all hold in virtue of what's true about material bodies.

3.2. Substantivalism in terms of ground

The substantivalist denies that all spatiotemporal facts hold in virtue of facts about material bodies. A world's spatiotemporal structure is not grounded in features and behaviors of material bodies. The fact that a world has a given spatiotemporal structure is a fundamental fact about the physical world; in particular, it is not grounded in facts about material bodies. (Clarifications below.) The facts about a world's spatiotemporal structure, in turn, ground the facts about the spatiotemporal relations between material bodies. (The former may only partially ground the latter, since the grounds may include occupation relations that material bodies bear to spacetime points or regions, depending on the version of the view: section 3.3.)

For example, the fact that two particles are some distance apart is grounded in, made true by, the fact that they are separated by that amount according to the fundamental metric structure (where the metric will itself be understood in different ways by different substantivalists—see section 3.3—but will in any case not be grounded in features of material bodies). The fact that a particle is traveling inertially in a Newtonian world is likewise grounded in facts about the fundamental spatiotemporal structure: the particle is following a straight trajectory because (in the metaphysical sense) its path is straight according to the world's Galilean structure. (The substantivalist then recognizes nonfundamental spatiotemporal facts or structure of a sort, about the spatiotemporal relations between material bodies. More exactly, the view holds that there are fundamental spatiotemporal facts or structure not grounded in [facts about] material bodies. Notice that certain facts about material bodies, for instance about their fundamental intrinsic properties, will be fundamental. What's not fundamental are the spatiotemporal facts about them.) By contrast, for the relationalist, a world's spatiotemporal structure is Galilean because the particles behave in certain ways. On that view, the facts about material bodies metaphysically explain the fact that a world has the given structure.

For the substantivalist, facts about the spatiotemporal relations between material bodies are nothing over and above facts about how these objects are arranged according to a given spatiotemporal structure. Facts about a world's spatiotemporal structure, on the other hand, are not grounded in facts about material bodies, and in that way are "over and above" any facts about material bodies. This captures the traditional conception of the view as holding that spacetime exists "independently of" material bodies: there is spatiotemporal structure that is not metaphysically due to material bodies.

You may worry that this conception of substantivalism is already disconfirmed by our current best theory of spacetime. According to general relativity, the presence of matter affects the local spatiotemporal geometry, which in turn affects the behavior of matter; whereas on my conception of substantivalism, there is spatiotemporal structure that is independent of matter. This worry is evaded by noticing that the inter-dependence between spatiotemporal structure and material bodies in general relativity is of a different, causal or nomological, kind from that given by ground. Although the substantivalist says that there is spatiotemporal structure that is independent of material bodies in not being grounded in them—these facts about spatiotemporal structure are "metaphysically over and above" the facts about material bodies—she can still allow that the behavior of material bodies causes a certain spatiotemporal structure in accord with the physical laws. Compare: although the dualist says that mental events are not grounded in physical events—mental events are "metaphysically over and above" physical ones—she can still allow that physical events cause mental events in accord with the scientific laws.

Substantivalism and relationalism, as I understand them, *disagree about the fundamental nature of the physical world*. They both countenance spatiotemporal structure or facts, but disagree on whether all such structure or facts hold in virtue of material bodies. Both views can recognize the fact that two particles are separated by some distance under a Euclidean metric, for instance, or that a world has a Euclidean metric structure. But they will disagree on whether the metric is itself fundamental or grounded in the behavior of material bodies. To borrow a phrase that Helen Beebee uses for a different debate, these views "have completely opposite conceptions of what provides the metaphysical basis for what" (2000, 580). The substantivalist sees a world's spatiotemporal structure as the metaphysical basis for the spatiotemporal relations between material bodies. The relationalist sees material bodies and their relations as the metaphysical basis for a world's spatiotemporal structure. If we ask, of a Newtonian world, "why (in the metaphysical sense) does it have a Galilean spatiotemporal structure?", the relationalist will answer: "because the particles (can) behave thus and so." The substantivalist will have no answer (or if there is any answer, it won't reference material bodies: see below). This is a substantive debate about what makes it the case that the spatiotemporal structure needed for the physics holds.

3.3. Further clarifications

The substantivalist might not take a world's spatiotemporal structure to be absolutely fundamental. Newton held that absolute space is a necessary consequence of God's existence, so that the facts about the world's spatial structure are not fundamental but grounded in facts about God. Yet Newton is still a substantivalist, on my understanding, since the facts about the spatial structure are more fundamental than the facts about bodies' spatial relations.[28] To put it another way: the facts about the spatial structure are fundamental *to the physical realm*. Analogously, the relationalist will say that all spatiotemporal facts are grounded in facts about material bodies, regardless of her other metaphysical views, such as whether there is something yet-more-fundamental that lies outside the physical realm. The views still disagree over whether spatiotemporal structure apart from material bodies is fundamental to the physical world. For ease of presentation, I continue to put the dispute as the question of whether spatiotemporal structure is fundamental (to the physical world).

What if there is no fundamental physical level? In that case, the views might still be distinguished by means of the relative fundamentality of the behaviors of material bodies and a world's spatiotemporal structure, depending on the details. This may suggest that the debate should be framed in terms of relative fundamentality. Substantivalism would then be the view that the facts about a world's spatiotemporal structure are more fundamental than the spatiotemporal facts about material bodies, and relationalism would be the

[28] Some argue that Newton wasn't a substantivalist: Stein (1970); DiSalle (2002).

view that the facts about material bodies are more fundamental than the facts about spatiotemporal structure. But I don't want to put it this way. That way of putting things would imply that either relationalism or substantivalism is bound to be true, regardless of future physics, so long as the two kinds of facts are not equally fundamental. Yet intuitively, if nothing like either spatiotemporal structure or material bodies turns out to be fundamental to the physical world, then neither view has been vindicated. You could insist that substantivalism would still be correct so long as the facts about the world's spatiotemporal structure are more fundamental than the spatiotemporal facts about material bodies, and contrariwise for relationalism. This strikes me as too far removed from the original views. More generally, I don't think that one of these views must be correct regardless of future physics, and it will depend on the details of that future physics whether one or the other, or neither, is correct.

There is another way to put the difference between the views, which I want to be careful with. The substantivalist says that there exists a fundamental physical space(time); the relationalist denies this. Similarly: the relationalist denies, whereas the substantivalist accepts, the existence of spacetime points (or regions) as fundamental physical objects. This way of putting things is familiar and in keeping with traditional conceptions of the dispute.[29] The problem is that it is not entirely clear what it means to say that a physical space—this "peculiar entity" (Belot and Earman, 2001, 227)—does, or doesn't, exist; relatedly, whether spacetime points or regions exist as concrete entities. I suspect that this is an underlying reason for the unclarity of the debate in many people's minds, especially in the philosophy of physics community. Some philosophers of physics have worried about taking spacetime points to be concrete physical entities in particular. As Malament says, in the context of discussing whether spacetime points are nominalist-friendly, "They certainly are not concrete physical objects in any straight-forward sense. They do not have a mass-energy content.... They do not suffer change. It is not even clear in what sense they exist in space and time" (1982, 532). Others have worried more generally that this kind of ontological dispute—a dispute that is just about what things exist—is non-substantive or merely verbal.[30] Howard Stein, in discussing the spacetime debate, says that, "For me, the word 'ontological' itself presents seriously problematic aspects"; in particular, "Quine's usage [is]

[29]See e.g. Field (1980, ch. 4); Mundy (1983); Earman (1989, 12); Brighouse (1994).

[30]This seems the spirit behind Stein (1970, 1977a), Curiel (2016), perhaps Belot (2011) and some others in note 1; in a different way Wallace (2012). There have been similar thoughts in metaphysics, for example in Hirsch (2011), but it's not clear that this is exactly the same idea.

not a very useful one for philosophy of physics" (1977a, 375).

As I see it, the debate is about the fundamentality of spatiotemporal structure, in particular about whether there is any spatiotemporal structure (fact) not grounded in the structure of (facts about) material bodies, where the substantivalist says that there is and the relationalist says that there isn't. Within this framework, there is some flexibility as to how exactly to put the dispute. Neither the matching principle nor my conception of spatiotemporal structure says how we must construe the nature of spatiotemporal structure; and I have not taken a stand on whether ground is primarily a relation between objects or facts. As a result, although we can put the disagreement as being about whether there exists a fundamental physical spacetime or fundamental spacetime points, we do not have to. Anyone squeamish about putting things in ontological terms can still see the debate as being about the fundamentality of spatiotemporal structure, understanding this as being not about whether there exist certain objects (over and above material bodies), but about whether there are certain facts (over and above the facts about material bodies): the relationalist says that the fact that a world has a certain spatiotemporal structure holds in virtue of the fact that material bodies behave thus and so; the substantivalist denies this, seeing it as a fundamental fact about the physical world. This allows us to discuss the dispute, and to evaluate the evidence for either side, while remaining neutral on how the substantivalist wants to understand the instantiation of that structure or the ontology behind this fact.

This dovetails with an idea in spacetime structural realism. Jonathan Bain (2006) argues that classical field theory (this includes general relativity), standardly given in terms of a tensor formalism, can be formulated in ways that do not presuppose a differential manifold of points. He describes three alternative formalisms one could use (twistor theory, Einstein algebras, and geometric algebra), none of which treat points as fundamental. My understanding leaves it open for the substantivalist to spell out the spatiotemporal structure in any of these ways, or even to refuse to choose among them, as Bain himself proposes. (Bain argues that we should be realists about spacetime structure and not any particular instantiation of it. He sees this as a third view, since according to him the substantivalist is committed to spacetime points, but it counts as substantivalist by my lights.)

To be explicit, there are four different kinds of view that my conception of substantivalism is meant to encompass, each of which holds that there are spatiotemporal facts or structure not grounded in material bodies. First is what we might call Bainianism, on which one is a realist about spatiotemporal structure but not about any particular instantiation of it, i.e., not about any of the (non-material) objects that could be said to instantiate it. On this view, the different possible descriptions or formulations or instantiations of spatiotemporal structure do not really differ from one another: one is an anti-realist about those. Second is what we might call uncommitted substantivalism, on which one is a realist about a particular instantiation of spatiotemporal structure—there is a single best way of describing or formulating the spatiotemporal-structure facts, in terms of a certain kind of non-material object—but one doesn't know what that instantiation or best formulation is; hence we cannot state the view as propounding one or another such formulation. Third is what we might call committed substantivalism, on which one is a realist about a particular instantiation of spatiotemporal structure, one thinks that there is a best formulation of it, and one does claim to know what it is; e.g., it might be the one in terms of points (in which case the view approaches traditional substantivalism). Fourth is the "qualitativist" substantivalism of Dasgupta (2009, 2011), on which the fundamental spatiotemporal facts are purely qualitative, not mentioning any entities at all; spacetime is not an entity but a "purely qualitative structure." One of the things I am claiming is that, when it comes to the relational-substantival debate, we needn't choose among these versions of substantivalism. The argument in section 4 will support each of them in the same way.

3.4. Something old, something new

There are too many different notions of "relational," "substantival," and related concepts in the literature to survey them all here and compare them to my own account.[31] It should be clear that this is a non-standard conception of the dispute, which captures core ideas behind more familiar conceptions, both contemporary and traditional. For example, my understanding captures the thought that the substantivalist believes in "the independent existence and structure of space and time" (Sklar, 1974, 163)—that spacetime exists "independently of material things…and is properly described as having its own properties, over and above the properties of any material things that may occupy parts of it" (Hoefer, 1996, 5)—so that "space is something as real as matter and whose existence does not require matter, but which is not the same stuff as matter" (Huggett, 1999, 129). It encompasses the idea that for the substantivalist, "space-time points (and/or space-time regions) are entities that exist in their own right" (Field, 1980, 34); "[s]pace is an entity in its own right—a real live thing in our ontology" (Nerlich, 1994a, 3), a "genuine entity

[31] See the many notions listed in Horwich (1978); Friedman (1983); Earman (1989).

of a fundamental kind" (Pooley, 2013, 526). These ideas are captured by the claim that spatiotemporal structure is fundamental to the physical world. There is spatiotemporal structure that is not grounded in, and is in that way independent of, any material bodies.

My conception also captures the thought that the relationalist "denies that space, or spacetime, is a basic entity, ontologically on a par with matter" (Brown and Pooley, 2002, 183, n1), so that "the universe consists solely of objects and events exemplifying various properties and relations" (Horwich, 1978, 397): "all that exists is material bodies" (Arntzenius, 2012, 153). As a result, "all our talk of space and time can be reconstructed out of talk about spatial relations between objects" (Brighouse, 1999, 60), and we "regard the use physical theory makes of space-time and its geometrical structure merely as a convenient way of saying something about the spatio-temporal properties and relations of concrete physical objects" (Friedman, 1983, 216). These statements are captured by the claim that spatiotemporal structure apart from material bodies is nonfundamental; whereas certain material bodies, and certain of their properties and relations, are fundamental.

At the same time, this is a non-standard, non-traditional take on things, which allows us to sidestep many of the reasons people feel that the usual dispute has stagnated or become non-substantive. Most importantly, it leaves room for future physics to provide an answer, so that this dispute cannot be "merely verbal" or "purely metaphysical." We think that there is a real difference between a world in which spatiotemporal structure is fundamental, and one in which it arises from some pre-spatiotemporal structure, for instance. Physicists treat these as genuinely different possibilities, governed by different theories. This is evidence of a genuine difference between the views as I see them.

Against tradition, I claim that the relationalist as much as the substantivalist can recognize "absolute" or frame-independent facts about—quantities of, structures that support—objects' motions.[32] In particular, it needn't be the case that "all motion is relative" for the relationalist, since there can be objective facts about objects' motions even in a world devoid of other material bodies.[33] The traditional question about the relativity of motion, then, is not of primary concern.[34] In addition, we needn't distinguish the two views by

[32]Hoefer notes that traditional relationalism "is connected essentially to the denial of absolute motion" (1998, 460).

[33]Huggett and Hoefer (2009) note other relationalist views denying the relativity of motion.

[34]This aligns with a similar shift away from that question in recent literature, exemplified in Stein (1970, 1977b); Sklar (1974); Friedman (1983); Earman (1989); DiSalle (2006); Belot

means of how they count possibilities, contrary to tradition as well as some recent accounts.[35] Further, against some other understandings of the dispute, this one allows for both sides to believe in, to be realists about, spatiotemporal structure.[36] (I have argued that they both should do this, in order to respect our usual inferences in physics.) I even leave it open for the relationalist to posit the same spatiotemporal structure to a world as the substantivalist, whereas some have taken the dispute to be over the relevant structure.[37]

My conception also avoids having to draw some of the distinctions that people have been skeptical of. It does not require that we definitively distinguish between container and contained, substance and non-substance, absolute and relative, to name a few.[38] There are three distinctions presupposed by my understanding of the dispute, but they are not as unclear as those required by more traditional conceptions. First, there is the distinction between the fundamental and the nonfundamental. This is a distinction that we have a reasonably clear pre-theoretic grasp of, clear enough to be useful here even without spelling it out in more detail. Second, my conception requires that we can identify what structure counts as spatiotemporal. This is something that the physical laws give us a handle on, in ways discussed earlier, though I admit that there is more that could be said. Perhaps there is nothing else that makes some fact or structure spatiotemporal; perhaps there is.[39] Either way, I take the idea to be relatively familiar from physics. At least we have some clear cases of spatiotemporal structures, such as those discussed here.

Third, my conception requires a distinction between material bodies and other things in the world. Although people have worried about the clarity of this distinction,[40] I think that it is clear enough for our purposes. At the least, I suggest that we understand the debate in this way, on the assumption that we will be able to locate such a distinction. For now I follow Earman, who says that, "It is a delicate and difficult task to separate the object fields into those that characterize the space-time structure and those that characterize its physical contents," while also noting that "the vagaries of this general problem

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(1999, 2000, 2011).

[35] Huggett (1999, ch. 8) discusses the traditional arguments. More recent examples are in Earman and Norton (1987); Belot (2000).

[36] Statements intimating that the relationalist cannot believe in spatiotemporal structure are in Field (1984, 34); Nerlich (1994a); Pooley (2013, 542); Maudlin (2012, 66).

[37] Earman (1989) suggests this at points.

[38] Rynasiewicz (1996, 2000) worries about the clarity of all these (and other) distinctions.

[39] Belot (2011) and Brighouse (2014) are two different accounts.

[40] See especially Rynasiewicz (1996).

need not detain us here, since there are clear enough cases for our purposes" (1989, 155-6). For those wanting argument that the distinction can generally be made, I refer you to Carl Hoefer (1998) and also David Baker (2005).

One will find, in contemporary discussions, the thought that the relationalist can believe in the existence of spacetime, understanding this as being (somehow) constructed out of material bodies and their features. So it may seem like even the traditional dispute (and contemporary versions of it) was never about the existence of spacetime but its fundamentality, and my own formulation may seem like just a new label for an old dispute. This however is something of an anachronism. Traditional participants, like Newton and Leibniz, weren't focused on questions of fundamentality: they were not thinking explicitly in those terms. Neither, of course, were they thinking in spatiotemporal terms. At the same time, to the extent that we can understand what they were saying in these terms, this shows that my understanding is, as I claim, an updating of the traditional dispute, using more recent developments in physics (involving spacetime and its structures) and philosophy (fundamentality and ground).

4. An argument for substantivalism

I now suggest that if we do understand the debate in this way, then there is a powerful argument for substantivalism, given much of current physics.

Above I argued that the relationalist should go partway[41] toward adhering to the matching principle by countenancing spatiotemporal structure, and that she can do this by understanding all the facts about spatiotemporal structure as being grounded in facts about material bodies. I am now going to argue that really the relationalist can't adhere to this principle, properly understood. The argument differs from the more familiar charge that the relationalist cannot countenance a particular spatiotemporal fact or structure.

Recall that the matching principle says to posit in the world the structure presupposed by the laws. Posit physical structure in the world corresponding to the mathematical structure needed to state the laws.

Now here is something else about the principle I haven't yet mentioned. It applies, in the first instance, to the fundamental laws. (By saying "in the first instance," I mean to indicate that the principle applies at least to the fundamental laws, and that this is where we begin constructing our picture

[41] Partway, since I haven't shown that the relationalist can ground the particular structure needed.

of the world from physics, in that we build a world "from the bottom up." I leave it open whether an analogous idea holds for nonfundamental laws.) Given the *fundamental* laws, we should posit in the world the structure they presuppose. This is clear from our usual inferences about spatiotemporal structure. Assuming that Newton's laws are fundamental, we infer a Galilean structure to the world. From different fundamental laws, we infer a different spatiotemporal structure—such as a Minkowskian structure for special relativity, a preferred-location spatial structure for Aristotle's physics, or a variety of different spatiotemporal structures for general relativity.

The matching principle also tells us to posit, in the *fundamental* level of the physical world, whatever those laws presuppose. The fundamental laws, after all, are *about* what's fundamental. They don't "care about" or "know about" or mention the nonfundamental. I take it this is part of what we mean when we say that they are fundamental. I also take it that this is a familiar thought. (Michael Townsen Hicks and Jonathan Schaffer (2015) call it orthodoxy.[42]) For example, it lies behind our dislike of quantum laws that mention things like "measurement" or "the observer." This isn't to deny that fundamental laws have consequences for nonfundamental things. These laws yield predictions for nonfundamental phenomena when we plug in initial conditions and use various bridge principles. On their own, though, fundamental laws only mention or presuppose or know about things at the fundamental level.[43]

Another way to see this comes from the idea of "the structure presupposed by the laws." The sense in which the laws presuppose or require some structure is akin to an idea familiar from mathematics. In mathematics, we can define different levels of structure by starting with a lowest level, such as a set of points, and then defining other objects that add more structure. These levels of structure form a hierarchy. The ones "higher up" assume or presuppose or constrain levels lower down, in that the higher-level objects cannot be defined until the lower-level ones have been assumed or defined. For example, think of adding differential structure to a topological space. This structure indicates, from among the continuous curves specified by the topology, which

[42]They argue against the idea, concluding that fundamental laws can, and do, mention nonfundamental properties. I agree that an alternative formulation can be useful in practice, but I think that the best formulation won't mention such things.

[43]This is different from Sider's (2011, ch. 7) purity principle. Purity is a very general principle about what the fundamental facts or truths can mention. (It says that they cannot mention nonfundamental concepts.) The above is specific to the physical laws and what they presuppose and therefore tell us about the physical world.

ones are smooth to varying degrees. In this way the differential structure assumes or presupposes a topology: it cannot be defined, it doesn't make sense, absent a topology. Higher-level structure is not similarly constrained by levels lower down—as different metrics, or none at all, can be added to a differential manifold. In other words, a given level of structure only "knows"—requires, constrains, presupposes, assumes—things about that level and below.[44]

Analogously for the structure required by the physical laws. This structure is presupposed by the laws in that it must be assumed in order for the laws to be formulated or make sense. The laws don't similarly know about—require, constrain, presuppose, assume—higher-level structure. For fundamental laws, the result is that they only know about fundamental structure. Note that the fundamental laws may constrain things higher up in a different, metaphysical sense: given the fundamental laws and ontology, everything else may be "fixed" in some sense. This is a different sense of constraining from the mathematical notion, which concerns what is needed for something to make sense or be defined. The other sense is a metaphysical notion that requires additional metaphysical principles concerning the relation between different levels of reality.

An example illustrates and motivates the primary reading of the matching principle. Recall the discussion of non-time reversal invariant laws. Earlier I said that if the laws are asymmetric in this way, then we infer an asymmetric temporal structure in the world. The idea is that such laws presuppose this structure, for they mention or presuppose a distinction between past and future, by telling things to behave differently depending on the direction of time. But there is more to the story. Take the second law of thermodynamics. This law is not time reversal invariant, so it may seem to indicate an asymmetric temporal structure. However, the second law of thermodynamics is not a fundamental law. It doesn't mention a system's particles or other fundamental constituents. It is formulated in terms of higher-level macroscopic quantities like entropy. Whether to infer an objective past-future distinction in the world then really depends on what fundamental theory accounts for the second law, and whether *that* theory's laws are symmetric in time. (It is natural to think that if a past hypothesis account of thermodynamics is correct, then there is no asymmetric temporal structure; whereas if a non-time reversal invariant theory like GRW quantum mechanics is true [and able to account

[44]In mathematics one also talks of a higher-level structure "inducing" a lower-level one (e.g., "the topology induced by the metric"). This makes it sound as though the higher-level structure is defined first and it then constrains the lower, but in fact it amounts to the above idea (e.g., once we have defined a metric, there must already be implicitly a topology).

for thermodynamics] then there is.[45]) The nonfundamental law on its own does not tell us about fundamental temporal structure: it is too far removed from the fundamental level to do that. Only a fundamental law can tell us about this.

In other words: we posit *fundamental* structure in the world needed for the *fundamental* laws. We recognize as fundamental the facts that are recognized by the fundamental laws. The matching principle applies, in the first instance, to the fundamental laws and fundamental level of physical reality. The matching principle as discussed in section 2 says that the world should "look like" or "fit" its laws. The primary reading of the principle says that the fundamental level of the world should look like or fit its fundamental laws.

Now to the argument for substantivalism. First notice that the kinds of fundamental laws we are most familiar with are formulated to presuppose spatiotemporal facts apart from material bodies. These laws mention or presuppose a spatiotemporal structure in addition to material bodies and their features. Newton's laws presuppose a Galilean spatiotemporal structure in addition to the existence of massive particles. These laws assume or require that the world has this structure, just as the laws of special relativity assume or require a Minkowskian structure. The laws of Aristotle's physics mention a preferred-location spatial structure in addition to the elements that move toward their natural places. Similarly for the laws of general relativity, even though they allow for different spatiotemporal structures. Think of the usual way of understanding the field equations, as saying how the distribution of matter and energy relates to the spatiotemporal geometry, which in turn affects the behavior of matter. These equations are formulated directly in terms of—they mention or talk about—a spatiotemporal structure apart from material bodies, coded up in the metric tensor, distinct from the stress-energy tensor. (See Hoefer (1996, 1998) for arguments that the metric is most naturally seen as characterizing a spatiotemporal structure that is not the structure of a material field. This is not uncontroversial, but is assumed in standard presentations.) The fundamental laws that we are familiar with make reference to material bodies, but they also presuppose or make reference to a spatiotemporal structure apart from those bodies.[46]

[45] Albert (2000) discusses these two accounts. See North (2008) on why these conclusions about temporal structure are natural.

[46] There is a difference between the laws mentioning and presupposing something. That a law explicitly mentions something implies that the law presupposes it, but not vice versa. The laws of general relativity explicitly reference both material bodies and spatiotemporal structure. The usual Newtonian laws explicitly mention the former yet only presuppose

Given that the fundamental laws are typically like this, a problem arises for the relationalist. The problem is not that the relationalist doesn't recognize enough spatiotemporal facts for the physics, a concern lying at the root of classic arguments like Newton's, as well as many contemporary ones (see notes 23 and 25). *Grant* the relationalist enough stuff to ground those facts and make the relevant predictions, and there is still a problem. According to the core of the view, all the facts about spatiotemporal structure are grounded in more fundamental facts about material bodies. The kinds of fundamental laws we are used to, though, presuppose or mention spatiotemporal facts apart from material bodies—facts that, for the relationalist, are nonfundamental. This violates the principle that the fundamental level of the physical world should contain whatever is needed for or presupposed by the fundamental laws.

So the argument is this. First premise: the fundamental laws are about what's fundamental to the physical world; they refer to or presuppose things about the fundamental physical level. Second premise: these laws are about, they presuppose or refer to, a spatiotemporal structure, or spatiotemporal facts, apart from material bodies. Third premise: for the relationalist, this kind of structure or fact exists at a nonfundamental level, above that of material bodies. Fourth premise: the primary reading of the matching principle. Conclusion: relationalism is incorrect. Substantivalism posits the spatiotemporal structure or facts needed for the laws at the fundamental level.

General relativity provides an example. This theory establishes a nomological connection between material bodies and a spatiotemporal structure apart from them. On their own, the laws do not say whether material bodies and spatiotemporal structure are at the same level of physical reality, nor which is more fundamental if not. Without some further principle, both relationalism and substantivalism seem satisfactory: both recognize facts about material bodies as well as a world's spatiotemporal structure. Enter the matching principle. The substantivalist does, the relationalist does not, adhere to it.

You may wonder why the spatiotemporal structure presupposed by the laws is *apart from* material bodies, as premise 2 claims. After all, the relationalist, in my view, can countenance this structure, but will say that it has to do with the (actual and perhaps possible) spatiotemporal relations between material

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the latter. (Hence a difference from Quine's prescription [p. 9]: Newton's laws, as usually formulated, presuppose a Galilean spatiotemporal structure; they don't explicitly mention or quantify over that structure, which the matching principle tells us to posit.) This difference does not matter here. We use the matching principle to infer structure in the world regardless of whether it is explicitly mentioned or presupposed. Either way, the laws require it.

bodies. In what way do the laws presuppose a spatiotemporal structure that is in addition to material bodies? The answer comes from the way that the fundamental laws are usually formulated. (I turn to potential reformulations in section 5.) These laws are typically formulated to directly mention material bodies, with a term that directly refers to them—such as the mass term of Newton's dynamics, or the mass density of some formulations of Newtonian gravitation, or the elements mentioned in Aristotle's laws, or the stress-energy tensor of general relativity.[47] At the same time, these laws also presuppose that the world has a spatiotemporal structure apart from those bodies—apart in that it is presupposed by the laws in the mathematical sense given above, or else is directly mentioned by or coded up in a distinct term.

Recall that the matching principle tells us to infer that a special relativistic world lacks an absolute simultaneity structure. The laws don't require this mathematical structure, which suggests that the world doesn't have the corresponding physical structure. To fail to adhere to the matching principle is to fail to heed this evidence from the laws about what the world is like. The relationalist fails to adhere to the primary reading of the principle in the same way. The fundamental laws are giving us evidence that spatiotemporal structure is fundamental to the physical world, which the relationalist fails to heed. The relationalist may respond that there are good reasons to disregard this apparent evidence from the laws. The burden is then on the relationalist to show this, just as the burden falls on the proponent of absolute simultaneity.

You might think that there are two distinct notions, that of what's *physically fundamental* versus *metaphysically fundamental*; that the matching principle governs the first whereas substantivalism and relationalism are views about the second; and conclude that the argument from the matching principle doesn't make contact with those views. In particular, you might think it open for the relationalist to say that spatiotemporal structure is metaphysically nonfundamental, in accord with relationalism, yet physically fundamental, in accord with the matching principle—that a world's spatiotemporal structure is less metaphysically fundamental than, but more physically fundamental than, the spatiotemporal relations between material bodies. I suppose that such a view is possible, but it seems implausible on its face. Imagine an analogous reductionist who says that macroscopic systems (boxes of gas) are metaphysically nonfundamental, grounded in more fundamental microscopic objects (their particles), yet physically fundamental. This is a puzzling view. Surely

[47]In the context of this debate, both views take certain material objects to exist at the fundamental level. (Supersubstantivalism would then deny this.)

the thought that microscopic objects are metaphysically fundamental goes hand in hand with evidence from physics suggesting that they are physically fundamental. Relative physical and metaphysical fundamentality cannot plausibly go in opposite directions. More generally, I'm inclined to reject the idea that there are two distinct notions of fundamentality here.

Suppose that what I have been calling "spatiotemporal structure" involves, at least in part, facts that must be stated using universal generalizations. On a standard axiomatic approach to geometry, for instance, a given spatiotemporal structure will be defined via a universal generalization over a domain of points. Suppose further that generalizations are not fundamental but grounded in their instances, in accord with a familiar way of thinking about grounding. Then it may seem as though the substantivalist doesn't adhere to the matching principle either, simply because spatiotemporal structure, qua generalizations, cannot be fundamental. However, the substantivalist will avoid the worry, for one of the following reasons. First, one might for independent reasons think that generalizations are fundamental, a not-unprecedented (to my mind, not implausible) view, even among grounding proponents. Second, even if spatiotemporal-structure-qua-generalizations is not absolutely fundamental, it is *very close* to being fundamental, so that the fundamental structure of the world *almost directly* matches the structure for the fundamental laws. The only "gap" there is between spatiotemporal structure and the fundamental level is the one created by the gap between generalizations and their instances. This is an intuitively smaller gap than that between a world's spatiotemporal structure and features of material bodies. The former is just a "gap in logical form"—the "size" of the separation between a generalization and the collection of particular claims that grounds it—whereas the latter is a larger, physical gap. The substantivalist then adheres to the matching principle more than the relationalist does. Finally, notice that even if the generalizations that axiomatize a given structure are not absolutely fundamental, the various facts about the points still can be, and these facts are included in my conception of spatiotemporal structure; in which case there are still fundamental spatiotemporal facts or structure apart from material bodies.

(The worry also would also seem to go too far. It would force us to say that no particular collection of fundamental facts is to be preferred to any other on the basis of the physical laws, simply because any structure required for those laws takes the form of a generalization, and no generalization is fundamental. But surely a matching-type argument can sometimes work—as when we want to say that Berkeleyan idealism posits a world that radically fails to match the structure indicated by the laws. It seems we might reject that view for the reason that the fundamental nature of the world does not match the structure for the laws—even though that structure is given by generalizations, and even if generalizations are not fundamental but grounded in their instances.)

Notice that the argument for substantivalism is independent of one's view on the metaphysics of laws. The question of what makes a statement a law is distinct from the injunction to posit, assuming that a certain statement is a law, the requisite structure in the world. Even the Humean, who denies that laws of nature are metaphysically fundamental, can agree to posit, in the fundamental physical level of the world, the structure presupposed by the fundamental physical laws. To put it another way, the content of the law claim, the proposition p of the statement "it is a law that p," is what indicates structure in the world. It is irrelevant whether what makes it the case that p is a law is itself metaphysically fundamental. Whatever your account of laws of nature, you can, and should, adhere to the matching principle.

Current physics therefore gives us reason to believe that substantivalism is correct. Nonetheless, it is open for future physics to turn the tide. If a quantum theory of gravity or some other future fundamental theory contains laws that only presuppose things about material bodies and their relations, which in turn give rise to the spatiotemporal structure presupposed by current theories, we can conclude that relationalism is correct. Future laws might even suggest a view that doesn't look like either relationalism or substantivalism, presupposing facts about neither material bodies nor spatiotemporal structure but something else. (A causal set theory approach to quantum gravity, for example, might support relationalism, depending on the particulars, or it could be a case on which neither view is correct.[48]) In this way the debate will remain relevant to, and continue to be informed by, future developments in physics.

5. A challenge for relationalism

Finally, let me turn to the question raised at the end of section 2. I have been assuming that the fundamental laws we currently have are formulated to presuppose a spatiotemporal structure apart from material bodies. This reveals one other way for the tide to turn: the relationalist could try to reformulate these laws to only presuppose things about material bodies. If such a reformulation is possible, then the argument will turn on how we

[48]See Huggett and Wüthrich (2013) and the other papers in that journal issue on the emergence of spacetime in quantum gravity.

should generally formulate the laws, which is a big question that I can't fully answer here. Even so, the argument poses a significant challenge to any relationalist attempt to reformulate the laws.

Consider an illustrative example: the relationalist reformulation of Newtonian mechanics initially suggested by Bas van Fraassen (1970, 4.1) and filled out in one way by Nick Huggett (2006). According to their idea, we can reformulate Newtonian mechanics to include the statement that, "Newton's Laws hold in some frames," where these will be the inertial frames. (There is also a force law, and on Huggett's account a law about the spatial geometry.) These laws then pick out a standard of inertia or straightness of trajectories—they recognize a quantity of, or facts about, acceleration—without assuming that spacetime exists. In my terms, they only presuppose spatiotemporal facts about material bodies. This is because, according to Huggett, the facts about inertial frames—indeed, all the spatiotemporal facts—themselves supervene on facts about the history of relations between material bodies. (Huggett rejects modal relationalism.) This is a genuinely relationalist formulation, on my construal, which respects the primary reading of the matching principle. The truth of the laws in certain frames effectively substitutes for an inertial structure, so that the laws themselves do not have to mention or presuppose this structure.

The problem is that this is a worse formulation of the laws, for a couple of reasons. First, this formulation does not respect the idea that fundamental laws only mention fundamental things. These laws are given in terms of facts about inertial frames, which for Huggett are not fundamental but grounded in facts about the relations between material bodies.

Second, this formulation is given in terms of reference frames. Why is this worse? I take it that fundamental physical laws are best formulated in terms of things about the world itself, and reference frames don't fit the bill. According to Newton's laws, inertial frames are like units of measure or coordinate systems, in that a choice of frame is an arbitrary choice in description. Now, Huggett's formulation does not mention any particular frame, nor does it directly mention inertial frames. Instead it says that there are frames you can choose such that Newton's laws are true.[49] But the fact that a choice of inertial frame is arbitrary suggests that inertial frames in particular, and reference frames in general—these objects as a group or kind of thing—are merely descriptive or labeling devices we use, not inherent in

[49] See Dorr (2010) for argument that "existential quantification *as such* is a distinctive source of badness" (166; original italics).

physical systems themselves[50]; hence they should not, other things equal, be mentioned in the fundamental physical laws. I gather that this is what underlies the general feeling in foundational discussions that formulating the laws in geometric, coordinate-free terms is desirable. (Consider formulations of classical mechanics in terms of so-called generalized coordinates, which do not mention any particular coordinate system. Even this reference to coordinates is seen as ideally replaceable by geometric objects with no mention of coordinates.)

An idea from Hartry Field bolsters the thought that such a formulation is worse in this way. Field draws a distinction between 'intrinsic' and 'extrinsic' explanations. The former "explain what is going on without appeal to extraneous" entities, things "*extrinsic to the process to be explained*" (1980, 43). As a result, intrinsic explanations are better, more "illuminating" (1980, 43) or "satisfying" (1989, 18). He says,

> [E]xtrinsic explanations are often quite useful. But it seems to me that whenever one has an extrinsic explanation, one wants an intrinsic explanation that underlies it: one wants to be able to explain the behaviour of the physical system *in terms of the intrinsic features of that system*, without invoking extrinsic entities...whose properties are irrelevant to the behavior of the system being explained. If one cannot do this, then it seems rather like magic that the extrinsic explanation works (1989, 193; original italics).

The best explanations cite intrinsic features relevant to the system's behavior.

By analogy to Field's idea, call formulations of the laws in terms of reference frames or coordinate systems or the like "extrinsic formulations." Extrinsic formulations are then worse for the same reasons Field says that extrinsic explanations are worse: they reference things outside the system or world itself, whose properties aren't directly relevant to the system's behavior.[51] This makes the success of the formulation seem like magic. All things equal, it is better to have an intrinsic formulation—or what I prefer to call a *direct formulation*, since extrinsic entities, like coordinate labels, can tell us about the

[50]Compare Einstein on a coordinate system, which is "only a *means of description* and in itself has nothing to do with the *objects to be described*" (2002, 203; original italics).

[51]Consider Field's reason that a scientific explanation citing direct relations between physical objects and numbers is extrinsic and therefore worse: "[T]he role of the numbers is simply to serve as labels for some of the features of the physical system: there is no pretense that the properties of the numbers influence the physical system whose behaviour is being explained" (1989, 192-3). The role of reference frames in physics is similar.

system in question; only they do so in an indirect, and therefore less preferable, way. It's analogous to characterizing the geometry of the Euclidean plane by saying that, "there are coordinate systems in which the distance formula takes the usual pythagorean form," rather than by giving the metric tensor (or, for that matter, Euclid's axioms). That characterization gives the structure of the plane, but in a needlessly indirect way, by means of the kinds of coordinate systems we can lay down on top of it. Better to have a formulation of the laws that more directly reflects reality. (It is not uncommon for physics books to state the laws in terms of reference frames or coordinate systems. The claim is that this is not the best formulation.)

Of course, direct formulations may seem preferable only if you are a realist to begin with—only if you think that it is the job of a physical theory to tell us what the world is like. An instrumentalist may be unbothered by indirect formulations and extrinsic explanations. (The instrumentalist should be used to the charge that the success of science seems like magic.) Since it is not my aim to argue for realism here, I leave it to the anti-realist to parry the objection that such formulations are worse. Let me note, though, that indirect formulations seem particularly problematic for fundamental laws, since the elements that feature in them, like reference frames or coordinate systems, don't seem the sorts of things that can be truly fundamental or explanatory.

There are other relationalist reformulations to consider in more detail than I have space to do here. However, the above strikes me as indicative of the kinds of problems that any such reformulation will face. In order for relationalism to be victorious, the proffered reformulation must be genuinely relationalist, presupposing facts only about material bodies; it should be direct; and it should respect the primary reading of the matching principle.

A brief look at three more examples further suggests that a relationalist reformulation meeting these constraints will be hard to come by. (1) Julian Barbour's relationalist mechanics (Barbour and Bertotti, 1982; Barbour, 1982, 2000, 2001), which eschews any fundamental temporal structure, arguably presupposes a spatial structure above that of material bodies,[52] in which case the theory is substantivalist, on my understanding. Setting that aside, the theory is not formulated directly.[53] (2) David Albert (1996) suggests that in classical mechanics, the Hamiltonian energy function gives rise to a three-dimensional spatial structure. Since the Hamiltonian is defined in

[52] See the presentation in Earman (1989, 2.1, 5.2). Arntzenius (2012, 5.11); Pooley (2013, 6.2) suggest this for Barbour's reformulation of general relativity in particular.

[53] The indirectness enters in recovering the topological temporal structure and the inertial structure: Arntzenius (2012, chs. 1, 5).

terms of particle features, this may count as a relationalist theory, on my construal. (Albert is not arguing for relationalism.) Yet there is also a case to be made that the mathematical formulation presupposes a spatial structure apart from material bodies (in particular for the kinetic energy term), in which case it would either count as substantivalist, or fail to respect the primary reading of the matching principle. (3) Huggett mentions another law of his reformulation of Newtonian mechanics: "'There is an embedding of the relational history into *G*', for some specific Riemannian geometry *G*" (2006, 53), where for him the privileged embedding supervenes on the history of relations between material bodies. Facts about the embedding geometry (spatial structure) are not fundamental but grounded in facts about material bodies. This makes the law relationalist. The problem is that it, too, explicitly mentions nonfundamental things, and is formulated indirectly, in terms of a structure into which the relations can be embedded. (A similar charge applies to Albert's (2012) suggestion for a relationalist Newtonian mechanics that says: "The physically possible histories of inter-particle distances are those which can be embedded in a full substantivalist Newtonian space, or imagined as taking place in such a space, in such a way as to satisfy $F = ma$.")

This does not prove that no relationalist reformulation can succeed, and more work must be done to fully evaluate the various proposals on offer in these terms.[54] But it does suggest that it won't be easy to find a relationalist reformulation that has the features we want of fundamental laws. Current laws are generally formulated to presuppose a spatiotemporal structure apart from material bodies. The problem is that typical relationalist substitutes for that kind of structure—facts about things like reference frames or coordinate systems or embedding geometries—are not candidates for direct formulations of the laws. Future laws, however, may be different.

[54]A few more examples. On the dynamical approach of Brown (2005); Brown and Pooley (2006), a world's spatiotemporal structure holds in virtue of the behavior of material bodies via the laws and their symmetries. This seems relationalist, on my conception (in particular if the laws are grounded in facts about material bodies). They presumably reject my idea that the laws presuppose a certain structure in order to be formulated. Another relationalist theory is that of Belot (1999, 2000), which seems indirectly formulated (cf. Brown and Pooley (2002, 192-93); it also presupposes a temporal structure apart from material bodies: Brown and Pooley (2002, 194)). Another is that of Albert (2017), on which there is no fundamental, pre-dynamical spatiotemporal structure: all spatiotemporal facts are grounded in facts about the behaviors of material bodies. Albert reformulates the laws in an indirect way.

6. Conclusion

Many people have thought that the arguments for relationalism or substantivalism will have to resort to considerations like simplicity, ontological parsimony, or explanatory power.[55] Some have said that the relationalist's ontology is more parsimonious, and therefore favored by Occam's razor.[56] Others have said that the substantivalist's theory is simpler, and therefore favored by ordinary criteria of theory choice.[57] Some have argued that the relationalist's theory is more explanatory. Others have claimed that the substantivalist's is.[58]

You might conclude that the debate is hopelessly vague, since the criteria of simplicity, parsimony, and explanatory power needed to adjudicate it are themselves vague; nor is it clear which to favor when these virtues compete.[59] I don't object to relying on such considerations even so, but it is worth noting that the argument from the matching principle is different. The matching principle doesn't say to refuse to posit unnecessary entities or to go with the simplest or most explanatory theory. It says to posit in the world the structure presupposed by the laws. The argument based on this principle escapes those particular worries about the status of the debate.

The matching principle is a familiar and successful guiding principle. It applies, in the first instance, to the fundamental laws and fundamental level of physical reality. The substantivalist and relationalist, as I see them, disagree about the fundamental physical level, which is why the matching principle can distinguish between them. This is a substantive debate about the fundamental nature of the world according to physics; a debate about what makes it the case that the spatiotemporal structure required by the physics holds.

The traditional debate centered on whether we need to posit an independently existing space in order to account for objects' motions. The debate that I have presented is a natural descendant: a debate about whether we need

[55]Dasgupta (2015) discusses the effects of these criteria on the spacetime debate for classical physics.

[56]Huggett (2006); Huggett and Hoefer (2009); Pooley (2013).

[57]Huggett (2006); Arntzenius (2012, ch. 5).

[58]Earman (1989) suggests that the relationalist's theory will be worse; Brown and Pooley (2002) argue against this. Maudlin (1993, 196) says that the substantivalist's theory is more explanatory in some ways; Nerlich (1994a,b) argues that it is more explanatory in general.

[59]See Horwich (1978); Earman (1989, 3.3); Huggett (2006, 70) for this kind of complaint. Sklar (1974, 231) notes a tradeoff between the substantivalist's explanatory power and relationalist's parsimony; Mundy (1983, 207) notes one between the relationalist's parsimony and substantivalist's simplicity. Belot (2011) suggests that parsimony in fact favors substantivalism (while arguing against using simplicity considerations to draw metaphysical conclusions).

to posit a spatiotemporal structure apart from material bodies to support the theory that best accounts for objects' motions. This is a substantive debate, which we currently have reason to believe the substantivalist is winning.[60]

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[60]For comments and discussion, I am grateful to Ori Belkind, Karen Bennett, Jim Binkoski, Carolyn Brighouse, Andrew Chignell, Ted Sider, and audiences at Rutgers University, the University of Illinois-Champaign, the University of Western Ontario, the University of Wisconsin-Milwaukee, Brown University, the Philosophy of Science Association, the University of North Carolina-Chapel Hill, Tel Aviv University, the Hebrew University of Jerusalem, the University of Massachusetts-Amherst, and Oxford University. Many thanks also to the anonymous reviewers for, and the editors of, this journal. This research was funded in large part by the National Science Foundation STS Scholars Award No. 1430435.

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