Brown and Janssen on the Arrow of Explanation in Special Relativity

Abstract

I examine the debate between Michel Janssen and Harvey Brown over the arrow of explanation in special relativity. Brown argues that the symmetries of the dynamical laws explain the symmetries of space-time, whereas Janssen argues for the converse. Janssen has recently argued against Brown's position on the grounds that it recommends trying to infer information from the relativistic effects, e.g., length contraction, in a way wasteful of time and resources. I show how Brown can respond to Janssen and trace the dispute not to a methodological difference, but to opposing positions on the meaning of spatio-temporal symmetries. According to Janssen, the symmetries of space-time are constraints on dynamical laws. According to Brown, symmetries of space-time arise jointly from matter distributions and the laws governing matter. Finally, I provide some considerations in favor of Brown's position.

1 Introduction

Michel Janssen and Harvey Brown are engaged in a dispute about whether the symmetries of space-time explain the Lorentz invariance of dynamical laws or the Lorentz invariance of dynamical laws explains the symmetries of space-time. This is the *arrow of explanation debate* in special relativity. Brown's and Janssen's positions are respectively:

> **B**. The symmetries of the dynamical laws explain the symmetries of space-time.
>
> **J**. The symmetries of space-time explain the symmetries of the dynamical laws.

In a recent article, Janssen (2009) makes what I call the methodological argument. He argues that accepting B causes one to waste time trying to infer information about dynamical laws from the relativistic effects, e.g., length contraction. I will argue for two claims in this paper. The first claim is that accepting B does not have the stated implication. The second is that the interesting, potentially problematic difference between Janssen and Brown concerns their claims about the meaning of spatio-temporal symmetries. These claims motivate B and J, and in turn have interesting consequences for how the spatio-temporal symmetries of a theory's models are evaluated. If one accepts B, then they are evaluated on a case-by-case basis, whereas if one accepts J, the models automatically share their spatio-temporal symmetries.

In the remainder of this section, I put the dispute into context. In Sec. 2, I present the methodological argument and in Sec. 3, I respond on behalf of Brown. I then identify in more detail the difference between J and B in Secs. 4-6, which requires precisifying B.

In the background of this disagreement, Janssen and Brown share a view on the nature of space-time theories, at least to some extent. They both think that it is possible to provide a constructive version of special relativity. I am not interested in the principle/constructive theory distinction, except insofar as it reveals what is important about their positions. Constructive theories explain phenomena by positing a model behind the phenomena or by making a claim about the nature of the entities involved (Janssen, 2009, 38, fn. 27; Balashov and Janssen 2003, 331). Brown's theory is constructive in the first sense: "The explanation of length contraction is ultimately to be sought in terms of the dynamics of the microstructure of the contracting rod" (Brown 2005, 133). Janssen's is constructive in the latter sense. It explains certain effects by showing them to be natural, "default," or "generic" (Janssen 2009, 49).

In a previous paper, Balashov and Janssen defended a "space-time interpretation" of special relativity (2003, 330). Brown describes this interpretation as postulating "space-time as an ontologically autonomous entity" (2005, 133). The relativistic effects are then explained through the mirroring of space-time's structure by matter. Brown takes issue with this type of theory, noting two similar problems. First, how is the postulation of an additional entity supposed to explain the symmetry of laws? If space-time is autonomous, it need not constrain the laws governing entities in the space-time (Brown 2005, 143). Second, why is the behavior of matter constrained to reflect the structure of space-time? I take Brown to be claiming that there is a space-matter interaction problem and a space-law interaction problem for this theory, both redolent of the mind-body interaction problem.

Janssen (2009), though, objects to this characterization of his position. He thinks the space-time interpretation, i.e., one that explains relativistic effects in terms of the structure of space-time, works even if space-time is not an "autonomous entity." In fact, Janssen and Brown agree that in special relativity space-time is a "glorious non-entity" (Brown and Pooley, 2006; Janssen, 2009, 27). Despite their agreement on a broadly relationist outlook, Brown and Janssen disagree on the particular form of this relationism. Janssen accuses Brown of wanting to "*reduce*" space-time to matter fields (Janssen 2009, 27). I will discuss the nature of this reduction more thoroughly in Sec. 5.

It should be noted that this anti-substantivalist agreement is restricted to special relativity. In the context of general relativity, Brown takes a different position. Unlike the Minkowski metric, the metric in general relativity "becomes a dynamical agent" (Brown 2005, 150). Therefore, Brown seems to argue, it represents an entity, unlike its special relativistic counterpart. However, only in some models of general relativity does the metric represent something properly called "space-time." Consistent with Brown's reductive project, the metric is actually a matter field, and whether it has spatio-temporal significance depends on the same sort of considerations relevant to the reduction of space-time to matter in special relativity (Brown 2005, 151, 159). With this initial characterization in hand (which I will supplement in Secs. 4-5), I will proceed to the methodological argument.

2 The Methodological Argument

To explicate Janssen's argument, it will be useful to have a distinction between the specific dynamics, the general dynamics, and the kinematics of a theory. The *kinematics* is the coordinate transformations and generic relationships between spatio-temporal quantities, such as, $x[t] = \frac{1}{2}\ddot{x}t^2 + \dot{x}t + x[0]$. In special relativity, the kinematics involves the Lorentz transformations between coordinate systems and their consequences, for example, the length contraction and time dilation formulas. The *general dynamics* states the relationship between a force of any kind and position or one of its derivatives. In special relativity, the general dynamics is given by

$$\mathbf{F} = m\mathbf{A} = \frac{d\mathbf{P}}{d\tau}, \quad (1)$$

the relativistic analog of Newton's second law. The *specific dynamics* states the laws for a particular kind of force. An example would be

$$\mathbf{F} = \begin{pmatrix} \gamma q \vec{v} \cdot \vec{\mathcal{E}} \\ \gamma q (\vec{\mathcal{E}} + \vec{v} \times \vec{\mathcal{B}}) \end{pmatrix}, \tag{2}$$

in addition to the appropriate field equations for Maxwellian electrodynamics.

I do not claim that this distinction is an explication of what is usually meant by "kinematics" or "dynamics."[1] Rather, Janssen's account (2009, 28) of the distinction is closely related to mine. He distinguishes between broadly kinematical, narrowly kinematical, and dynamical phenomena, as well as kinematical and dynamical parts of physical theory, but defines only the former set of concepts. We can relate kinematics and dynamics as parts of physical theory to kinematical and dynamical phenomena through the following definitions. A phenomenon is broadly kinematical if it is explained by the kinematics or the general dynamics. A phenomenon is narrowly kinematical if it is explained by the kinematics or the space-time symmetries of the general dynamics. A phenomenon is dynamical otherwise.

The interesting feature of my way of drawing the distinction is that it is also acceptable to Brown, even though he says that there is a "true *lack* of a clear distinction between kinematic and dynamic effects (in particular in the context of length contraction and time dilation)" (Brown 2005, 144).

[1] See (Martínez 2007, 212-13) for information on the historical origin of the distinction.

For Brown, the kinematics is dependent on, and explained by, the dynamics (Brown 2005, 26, 40). Thus, length contraction, e.g., is only proximately explained or "codified" by the kinematics (Brown 2005, 9). Brown, while he can make a distinction between the kinematical and dynamical parts of a *theory*, thinks that kinematical *phenomena* are also ultimately dynamical. Thus, the phenomena do not divide into two exclusive classes, while the theory divides into two exclusive, dependent classes.

Here is the methodological argument. Part of the content embodied in the claim that space-time is Minkowskian is the form of the coordinate transformations or kinematics. Therefore, if B is true, then the kinematics of a theory are dependent on the dynamics. Hence, as noted in the previous paragraph, if B is true, then the relativistic effects cannot ultimately be explained by the symmetries of space-time. This is because the effects are ultimately dynamical rather than kinematical. If a phenomenon is not fully explained by some theory (the special relativistic kinematics in this case), one will have to look for additional physics to complete the explanation. Moreover, one will look to the phenomena to give insight into the particular form of that explanation. (Up to this point, the argument is not problematic for Brown. The next premise is the crucial, ultimately faulty one, I will argue). In the present context, looking to the relativistic effects for insight into the form of the dynamical laws is a waste of time. One such example is Morley and Miller testing for the null-result with apparatuses made of different materials, a "textbook example of the waste of time and resources that can occur if experimenters rely on faulty explanations to guide them in their work" (Janssen 2009, 48). In sum, Janssen argues that B implies that one should try to glean dynamical information from the relativistic effects in a problematic way.

3 Ambiguity in the Description of Relativistic Effects

Having finished explicating Janssen's argument, I will respond on behalf on Brown. First, I need to identify an ambiguity in the explananda, i.e., in what exactly the relativistic effects are taken to be. Drawing on Skow (2006), we need to distinguish the explananda:

> **E1**. Why are there systems of length L, stable and resting in the inertial reference frame $\mathcal{F}$, that obey the length contraction formula in the inertial reference frame $\mathcal{G}$ moving relative to $\mathcal{F}$?
> **E2**. Why are there systems of length L, stable and resting in $\mathcal{F}$, that obey the length contraction formula once accelerated to a constant speed relative to $\mathcal{F}$?

Although I stated this distinction in terms of length contraction, it can easily be phrased so as to apply other relativistic effects such as time dilation and the velocity dependence of mass. There are a myriad of other relevant distinctions in the area that combine different numbers of reference frames, different numbers of rods, and the presence or absence of accelerations. The main difference that E1 and E2 illustrate is that some of what are called "relativistic effects" involve accelerations, whereas other do not.

When discussing E1 and E2, we tend to read them with our "relativistic goggles" on. There are actually multiple phenomena mentioned in E1 and E2. Thus, the second relevant distinction to draw is that different *explananda* assume different background information:

> **E1***. Why are there systems of length L in $\mathcal{F}$ that obey the length contraction formula in the inertial reference frame $\mathcal{G}$ moving relative to $\mathcal{F}$, *given* that there are systems stable over time and at rest in the inertial reference frame $\mathcal{F}$?
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> **E2***. Why are there systems of length L, stable over time and at rest in $\mathcal{F}$, that obey the length contraction formula once accelerated to a constant speed relative to $\mathcal{F}$, *given* that there are systems of length L stable over time and at rest in $\mathcal{F}$?
>
> **E2****. Why are there systems of length L, stable over time and at rest in $\mathcal{F}$, that obey the length contraction formula once accelerated to a constant speed relative to $\mathcal{F}$, *given* that there are systems of length L stable over time and at rest in $\mathcal{F}$, and *given* that such systems regain equilibrium once accelerated?

In E1 and E1*, there are two reference frames. In E1*, the existence of stable rods is assumed. In E2, E2*, and E2**, there is one reference frame. In E2*, one assumes that there are stable rods. In E2**, one assumes that the rod regains equilibrium, and one assumes the existence of stable rods.

To illustrate the difference, assume a spring at rest in one reference frame obeys the length contraction formula in another. If we ask for an answer to E1, we need to explain first why there are stable springs, a task that clearly must appeal to the specific dynamics because the stability of matter is explained only in quantum mechanics, and second, why such springs obey the length contraction formula in other reference frames, a task that will appeal to the kinematics. If we ask for an answer to E1*, however, we need only appeal to kinematics, or for Brown, whatever part of the dynamics on which the kinematics depends, namely, according to B, the symmetries of those dynamics.

Now assume that the spring is accelerated and it obeys the length contraction formula afterwards. To answer E2, we will have to appeal to dynamics *twice* and kinematics once. The first appeal to dynamics will explain why there are stable springs. The second appeal to dynamics will explain why the system was able to regain equilibrium after acceleration. Clearly, this will involve appeal to the specific dynamics in order to say why, for example, the spring was not stretched beyond its elastic limit during the acceleration process. Lastly, we appeal to the kinematics (for Brown, the relevant part of the dynamics), once we have explained why the acceleration was not traumatic for the spring. In answering E2*, however, one less appeal to the dynamics is needed; E2* does not ask about the stability. In answering E2**, no appeal to the dynamics is needed (except for the part relevant to Brown).

Making these distinctions helps reveal why Brown will not make a methodological mistake. Brown will basically divide the explanation into a length contraction part and a (possibly null) stability/effects of acceleration part, just as Janssen would. If one must explain stability or the effects of acceleration, Brown will look to the phenomenon for information about the specific dynamics. But this is certainly justified, as Janssen himself admits (Janssen 2009, 47-48). Thus, if there is problematic difference in the way an adherent of J or B explains, it must be located in the part of the explanation concerning length contraction and not acceleration or stability. Brown will ultimately explain the length contraction part through the symmetries of the specific dynamics, but this will not cause him to look to the phenomena for information beyond the symmetry of the dynamics. This is the key point, for length contraction in the sense of E1* or E2** does provide information about dynamical symmetries. Therefore, Brown is immune to the methodological argument, which assumes that he would appeal to the specifics of the specific dynamics, i.e., aspects beyond their symmetry, in answering E1* or E2**.

My basic claim in this section is that the difference between J and B does not imply a time-wasting difference in methodology. The next sections therefore reexamine the root of the disagreement in order to delineate the difference between J and B.

4 How does Space-time Theory Explain?

As I have indicated, I understand Janssen as trying to illuminate a type of theory called a space-time theory. I have already mentioned the important aspects of these theories. They are constructive in that they characterize the generic behavior of certain entities, but they do not postulate space-time as an autonomous entity. So, what does it mean for such a theory to be a space-time theory?

To postulate a space-time means to place a requirement on the symmetries of the general and specific dynamical laws. The space-time theory of Janssen, then, requires that all laws be Lorentz invariant. This claim is more fundamental than claims about the laws of particular types of forces; it "transcends" them (Janssen 2009, 28). Commenting on the transition from Lorentz's theory to relativity, Janssen says, "Lorentz invariance is no longer *accidentally* [my emphasis] shared by all dynamical laws governing systems in Newtonian space and time but reflects the structure of a new relativistic space-time" (Janssen 2009, 39). To postulate a space-time does not mean to postulate the existence of some entity, although Janssen concedes to Norton (2008) that some reification might be necessary (Janssen 2009, 39). In any case, a space-time theory is in the first instance about laws.

Janssen tentatively cites Lange (2007), who uses the concept of a "meta-law." A meta-law is a law about laws, just as first-order laws are laws about "ordinary facts and events" (Lange 2007, 458). Meta-laws possess a "stronger variety of nomological necessity" than the laws themselves (Lange 2007, 458). For example, in the closest possible world where Maxwell's laws are false, the laws are still Lorentz invariant because of the space-time meta-law requiring Lorentz invariance (cf. Lange 2007, 468). Someone who disagrees can do so by saying that the symmetries of space-time are a mere "byproduct" of the actual force laws, not a requirement on them (Lange 2007, 469). In a space-time theory understood as postulating meta-laws, the symmetries of space-time explain the symmetries of the specific and general dynamical laws by making them "inevitable, unavoidable-necessary" (Lange 2007, 458). Although space-time theory is about the laws in the first instance, it also applies fairly directly to matter itself. This is because certain phenomena follow directly from coordinate transformations (e.g., length contraction) and the symmetries of the general dynamical law (e.g., velocity dependence of mass) (Janssen 2009, 40). A space-time meta-law theory includes this content.

In Sec. 1, I said that we should read Janssen as responding to Brown's question how space-time theories can explain. Brown thought such an explanation is problematic because first, space-time cannot casually interact with matter and second, positing an autonomous space-time need not constrain the form of dynamical laws. Understanding Janssen as a meta-law theorist advances the debate by providing a response to these two challenges.[2]

[2]Lange's account of the distinction between laws and meta-laws appeals to nomic necessity, which Janssen finds "questionable" (Janssen 2009, 28, fn. 7). As long as the distinction can be made it is helpful in understanding Janssen's position; an account of

5 Brown's Reductive Approach to Space-time

In this section, I emphasize the reductive part of Brown's position on space-time, which extends beyond special relativity. This reveals the need for a precisification of B. This aspect of Brown's position is characterized nicely by Norton:

> *Construction of Minkowski space-time.* It is possible to recover the geometry of Minkowski space-time from Lorentz covariant matter theories devoid of spatio-temporal presumptions. (Norton 2008, 825)

The evidence for reading Brown in this fashion comes from assertions such as, "I see the absolute geometrical structures of Minkowski space-time as parasitic on the relativistic properties of the dynamical fields" (Brown 2005, 100). Elsewhere, "the space-time manifold is a non-entity" (Brown 2005, 156). Brown sees "absolute space-time structure as a codification of certain key aspects of the behaviour of particles (and/or fields)" (Brown 2005, 25). In the context of general relativity, Brown argues that the geometric meaning of the metric tensor $g_{\mu\nu}$ depends on it being "surveyed" or "traced" by matter (Brown 2005, 174-75). In fact, $g_{\mu\nu}$ is itself a *matter* field (Brown 2005, 159). "The 'chronogeometric' or 'chronometric', significance of $g_{\mu\nu}$ is not given a priori" (Brown 2005, 160). These assertions show that Brown does not hold a position in which necessarily, the laws are the bearers of any spatio-temporal

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the distinction does not have to involve nomic necessity.

properties, let alone symmetries. Whether matter fields have spatio-temporal properties depends on their physically contingent behavior, and thus whether the laws represent spatio-temporal properties does as well. So, just because a law exhibits a certain symmetry, we cannot automatically identify it as a spatio-temporal one.

What does justify the identification of symmetries as spatio-temporal ones? The point, made clearly in the context of GR, seems to be this. We are justified in interpreting variables of a theory as the spatio-temporal ones if and only if those variables describe matter whose behavior reflects the metrical and affine notions used in the theory. In the case of Maxwellian electrodynamics, this would require appealing to other theories because stable rods and clocks, which are essential for reflecting space-time structure, cannot be defined in this theory (Norton 2008, 826). In a theory which *does* admit stable rods and clocks, one would also have to appeal to a thesis about the constitution of matter in order to show that there actually are such things. All of this entails that B is merely an abbreviated reading of Brown. More precisely, Brown is arguing for:

> **B2**. The symmetries of the specific dynamics, the fact that those dynamics admit stable rod and clock solutions (inter alia), and the fact those solutions describe the actual world, explain the symmetries of space-time.

This is a lot stronger than B, which would be acceptable to non-reductive relationists who reject a meta-law theory. (Of course, if one conditions on the second two parts of the explanans of B2 in the style of Sec. 3, then indeed Brown would accept B). It is worth emphasizing here that "forces and *structures* and forces" are relevant to "space-time having the structure that is has," where "structures" refers to the internal constitutive arrangement of matter (Brown 2005, 133). The problem with B is that it leaves out structures and focuses only on forces.[3]

B2 is an explanation in the following sense. For Brown, to make a claim about space-time is to say something about the behavior of matter or matter fields. Thus, to explain a property of space-time is just to explain why matter behaves in a certain way. Put this way, it is obvious that the explanation cannot involve just laws, but must also include some specification of matter's initial conditions as including entities of the right kind.

6 Symmetries of Models and Theories

With a more accurate characterization of the arrow of explanation debate, I now note how the explanatory issue connects to different positions on the content of theories and models. As the first point of comparison, take:

> **(1)**. It makes sense to think of a matter theory as devoid of spatio-temporal presuppositions.

[3]It is not obvious to me whether more than rods and clocks are needed, and if so, what precisely is sufficient for explaining the space-time symmetries. B2 is an improvement over B, but is not the final word.

Brown, but not Janssen, is committed to (1). Brown is committed to statement (1) because of his reductive project. As explained above, theoretical terms, for example, $g_{\mu\nu}$, have spatio-temporal significance only because of the fact that they are associated (Brown uses "delineated" and "read" to express the connection) with special kinds of matter or matter fields (e.g. rods and clocks) (Brown 2005, 174-76). Theories with such terms are consistent with there being no matter that behaves as a rod or clock, so spatio-temporal notions cannot be built into the theory itself, according to Brown. The connection is contingent, i.e., it holds only in some models of the theory, as Brown emphasizes in the context of general relativity (Brown 2005, 172). Janssen writes, "We can imagine that Minkowski space-time will emerge in the low-energy limit of some future theory of quantum gravity that does not include any spatio-temporal notions among its basic concepts" (Janssen 2009, 50). This quotation suggests that Janssen is open to accepting (1), although his use of "imagine" is non-committal. In any case, nothing about Janssen's position entails (1), so he is free to reject it, unlike Brown.

Brown's reductive position has the interesting consequence that theories assign spatio-temporal properties to their models on a case-by-case basis because some of the models can fail to satisfy the explanans of B2. This contrasts with meta-law theories, whose models all share some set of spatio-temporal properties. I will use the examples of quantum field theory (QFT) and a hypothetical theory of quantum gravity (QG) to illustrate the point.

Consider how Brown and Janssen will answer the question:

(2). What are the spatio-temporal symmetries of QFT?

Brown will have to take issue with this question. QFT is invariant under Lorentz transformations, but this does not mean that the theory itself has the spatio-temporal symmetries of Minkowski space-time. Recall Brown's reductive position given in B2. To talk about the spatio-temporal properties, we have to make some appeal to rod and clock-like entities. This is only possible in the context of a model of QFT. The theory itself does not have spatio-temporal symmetries because it does not make sense to talk about space and time in the some of QFT's models. That was Brown's response. Janssen's response will vary depending on whether he accepts (1) and whether he thinks that QFT is something devoid of spatio-temporal presuppositions. To talk about the spatio-temporal symmetries of QFT one may first need to supplement it with a meta-law theory. The other possibility is that QFT already contains meta-laws stating that it has the symmetries of Minkowski space-time. In either case, though, Janssen accepts that some theories themselves have spatio-temporal symmetries. Thus, all their models have the same symmetries.

Now compare Brown and Janssen responding to:

(3). What are the spatio-temporal symmetries of QG?

Here we are assuming that QG "does not include spatio-temporal notions among its basic concepts" (Janssen 2009, 50). Brown's response is precisely the same as above. His reductive position entails that this question does not make sense. Janssen, however, would here have to agree that it does not make sense to talk about the spatio-temporal symmetries of the theory. Unlike QFT, QG could not be paired with, or does not already involve, a meta-law theory about its space-time symmetries.

Instead of asking about QG itself, we can ask:

> **(4)**. What are the spatio-temporal symmetries of a model that satisfies the low-energy limit of QG?

Again appealing to B2, Brown would answer that if matter is behaving in the correct way, then this model has the spatio-temporal symmetries of Minkowski space-time. Janssen, it seems, would want to respond in the same way. It must be some feature of the model itself that gives it the properties of Minkowski space-time. Meta-laws about space-time are irrelevant; there are none for QG.

Briefly, I want to show how thinking about the arrow of explanation debate in terms of the spatio-temporal content of models *vis-á-vis* theories rather than methodologically reveals routes along which to criticize Janssen or Brown. There are two worries one may have about Brown's theory. Does it make sense to think of *matter* theories as devoid of spatio-temporal content? Descartes, at least, thought there was an essential connection between matter and space and maybe a weakened form of his thesis is still tenable (for example, one may think that necessarily, matter is spatially located). Second, one may worry that Brown's B2 implies a form of operationalism (Norton 2008, 831-33).

One can also question the asymmetry in Janssen's account. He argues that we need to think about space-time for extant theories in terms of a meta-law account. But if we encounter theories like the quantum gravity theory discussed above, Janssen needs a different account of how to think about space-time in that context, whereas Brown does not. The second worry about Janssen, which is the converse of operationalist worries for Brown, is whether it makes sense to think that models in which there are no rod or clock-like entities have spatio-temporal properties. See Zinkernagel (2008) for more on this question, though not in the context of Brown or Janssen.

By way of conclusion, let me summarize the issue in a slightly different way. Both Brown and Janssen agree that saying space-time is Minkowski is a way of codifying certain facts. For Janssen, space-time being Minkowski implies that the dynamical laws exhibit a certain symmetry. For Brown, space-time being Minkowski implies (among other things) that there are stable rods and clocks, which is not contained in a statement merely about laws. So an important difference between Brown and Janssen concerns the meaning of claims about space-time.

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