On Kinematic versus Dynamic Approaches to Special Relativity

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Janssen argues that special relativity is preferable to Lorentzian dynamics due to its kinematic structure. Brown, along with others, raises an objection, arguing that a dynamical understanding of special relativity is explanatorily prior and hence more fundamental than the principle theory-based kinematic structure of Minkowski spacetime. This article challenges this objection, arguing that both Janssen and Brown miss the essential aspect of the principles of special relativity that underwrite its interpretational success. It is not its kinematic structure but the constitutive nature of the principles it employs, by providing a coherent conceptual framework, that does the foundational work.

1. Introduction. In this article I will discuss the debate between two views on the foundations of special relativity, what might be called the kinematic view, on the one hand, and the dynamic view, on the other. In particular, I will be discussing the views of central players in the debate—Michel Janssen (2002, 2008), Yuri Balashov and Janssen (2003), and Harvey Brown and colleagues (Brown 2005; Brown and Pooley 2006; Brown and Timpson 2006). This article attempts to shed light on the debate between Janssen and colleagues and Brown and colleagues on interpreting special relativity—by exploring the different concepts of explanation as understood by the respective sides. My analysis shows that both parties make crucial points but that both also mischaracterize the fundamental explanatory function that can be played by a principle theory such as special relativity. It is not its kinematic structure, as such, but, rather, the constitutive nature of the principles it employs, that does the relevant foundational work by providing a coherent conceptual framework for physics.

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2. Janssen on Einstein versus Lorentz. In various places, Janssen (2002, 2008) and Balashov and Janssen (2003) are concerned to show that special relativity is preferable to Lorentzian dynamics due to the explanatory power of its kinematic structure, the geometry of Minkowski space-time. Janssen argues that standard accounts of how Lorentzian dynamics fails and Einstein's special theory of relativity succeeds are mistaken.[1] Following Janssen (2002), the standard claim is that Lorentz's theory proposes to resolve the conflicts between Newtonian mechanics and electrodynamics but that it is ad hoc in the manner of its explanation, while special relativity is not, especially with respect to the Michelson and Morley (1887) experiment's null results.[2]

Instead, Janssen argues that the fundamental characteristic that sets special relativity apart as a superior theory is that it offers a common-cause explanation for various phenomena. For Lorentzian dynamics, conversely, the obvious connections between those various phenomena remain unexplained coincidences. Janssen compares this with the historic rivalry between Ptolemaic models and the Copernican model of the solar system. In this case, there are two formalisms, both of which accurately reflect the motion of the sun, planets, and the earth in terms of making empirical predictions and describing the phenomena. What Copernicus offers is a reinterpretation of the formalism that is superior on the basis of a common-cause argument. While for the Ptolemaic system, the correlations between the various movements of the planets with the sun remain unexplained coincidences, for the Copernican system, since the planets revolve around the sun, these correlations are explained in terms of a single model. The correlation between the apparent motion of the sun with the motion of the planets is due to the motion of the earth around the sun.

Janssen argues that the same situation is the case in the rivalry between Lorentz's theory and Einstein's. In order to account for the null result of the Michelson-Morely experiment, or any similar experiment, Lorentz hypothesized that the matter configuration of objects must contract as it moves through the ether. This is a theory in which all laws governing matter are Lorentz invariant, as are those governing electromagnetic fields. What is lacking, however, is any reason for this invariance in the laws governing matter. Why should such disparate and apparently unconnected types of forces such as those governing fields and those governing matter all be Lorentz invariant? One possible solution, considered at the time by Lorentz and others, was that matter is simply governed by the laws governing electric and magnetic fields. This, however, turned out to be prob-

1. Those accounts are proposed by Einstein, Popper, and Grünbaum.

2. For a more complete discussion, see Janssen (2002, 431–41).

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lematic and unfeasible to formulate. Janssen concludes that there remain significant unexplained coincidences in Lorentz's theory.

We can understand the two different theories of Lorentzian dynamics and special relativity in terms of a distinction presented by Einstein in 1919 in "What Is the Theory of Relativity?" where he distinguishes principle theories of theory from constructive theories, saying,

> We can distinguish various kinds of theories in physics. Most of them are constructive. They attempt to build up a picture of the more complex phenomena out of the materials of a relativity simple formal scheme from which they start out. . . . When we say we have succeeded in understanding a group of natural processes, we invariably mean that a constructive theory has been found which covers the processes in question.
>
> Along with this most important class of theories there exists a second, which I will call "principle-theories." These employ the analytic, not synthetic, method. The elements which form their basis and starting-point are not hypothetically constructed but empirically discovered ones, general characteristics of natural processes, principles that give rise to mathematically formulated criteria which the separate processes or the theoretical representations of them have to satisfy. . . .
>
> The advantages of the constructive theory are completeness, adaptability, and clearness, those of the principle theory are logical perfection and security of the foundations. (Einstein 1954, 228)

Lorentzian dynamics represents a constructive theory, while special relativity is a principle theory. For Janssen, special relativity, in the two principles of the relativity postulate and the light postulate, subsequently formulated in the structure of Minkowski space-time, offers a common cause with which physics can explain all of the phenomena Lorentz leaves as coincidences. It is this recognition of a new space-time structure, as opposed to Newtonian space and time still used in Lorentz, that alters the framework for doing physics and thereby provides a common structure that explains the Lorentz invariance of both electromagnetic and material phenomena.

3. The Critique. In a later presentation, Janssen (2008) is concerned to ward off objections posed by Brown (2005) and Brown and Pooley (2006) that Minkowski space-time is not the sort of thing that can do any explanatory work. Rather, it is simply taking the facts that are described by Lorentz and asserting them as fundamental principles. As Lorentz himself puts it, "I cannot speak here of the many highly interesting applications which Einstein has made of this principle [of relativity]. His

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results concerning electromagnetic and optical phenomena . . . agree in the main with those which we have obtained in the preceding pages, the chief difference being that Einstein simply postulates what we have deduced, with some difficulty and not altogether satisfactorily, from the fundamental equations of the electromagnetic field" (2003, 229–30).

Brown and Pooley contend, "In our view, the appropriate structure is Minkowski geometry precisely because the laws of physics, including those to be appealed to in the dynamical explanation of length contraction, are Lorentz covariant" (2006, 10), and, "From our perspective, of course, the direction of explanation goes the other way around. It is the Lorentz covariance of the laws that underwrites the fact that the geometry of space-time is Minkowskian" (14). Brown and Pooley have a number of points to make. The first is that whatever type of explanation Minkowski space-time may offer, it is not the sort of explanation found in a constructive theory. Minkowski space-time does not causally explain why laws are Lorentz invariant, nor does it tell us how, for example, length contraction comes about dynamically. Second, as noted above, the order of explanation is wrong in Janssen. The fact that dynamical laws are Lorentz invariant makes Minkowski space-time the appropriate geometric structure to use, as opposed to the geometry explaining the invariance. Finally, Minkowski space-time is better understood as a structural device used as shorthand for saying that all laws are Lorentz invariant. As such, it is not a real structure. It has no ontological or causal role to play as a substance. Therefore, the common-cause argument in favor of special relativity is a nonstarter.

Janssen (2008) modifies his language slightly from "common cause" to "common-origin inference," but the argument is still that the superiority attributed to special relativity over Lorentzian dynamics lies in the fact that it can provide a common origin for all of the Lorentz invariant laws that must hold given the structure of Minkowski space-time, a kinematic theory. There is also a shift in emphasis to the kinematic structure not present in his earlier paper, perhaps to add weight to the common-origin argument while shifting away from the causal language by focusing on the kinematic/dynamic explanatory distinction.

What Janssen is struggling with is how to coherently argue that the structure of Minkowski space-time can be a common cause or act as a common origin in any genuinely explanatory fashion. It is essential that Janssen be able to establish something along these lines to show why special relativity is more fundamental than Lorentzian dynamics. One can agree with Brown or remain agnostic about the substantival nature of space-time or its capacity to "cause" anything, and there are good reasons to be skeptical of reifying the geometry in this way. However, this is not all there is to say, as Janssen responds.

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This debate confounds two distinct modes of scientific explanation. The language used by both Janssen and Brown suggests that it is the causal-mechanical view of scientific explanation that characterizes Minkowski space-time (or fails to) and, hence, special relativity as explanatory (or fails to). Causal-mechanical explanation is within the purview of constructive theories, and Brown presents the choice as one between two constructive approaches, his dynamical one and one where space-time is likewise treated as a causal mechanism. Brown argues that Minkowski space-time cannot give rise to common-cause explanations. What Janssen presents, however, is really a hybrid between a causal model of explanation and a version of explanation by unification. Indeed, the bulk of Janssen's work seems to lean toward unification rather than a substantival causal story. Considering his conscious progression away from using causal language, an alternate understanding of Janssen's argument is not as a constructive explanation but as a unificationist model of explanation. As Francisco Flores (1999) has argued, principle theories, in setting out the kinematic structure, are more properly viewed as explaining by unification, from the top down, a model of explanation in the Friedman (1974) and Kitcher (1989) sense.

What justifies the rejection of Lorentzian dynamics in favor of a Minkowski space-time structure or, in other words, the shift from a dynamical theory to a kinematic one, is not simply the fact that special relativity is a principle theory. Being a theory of kinematics is not inherently superior. This claim requires justification. Why should we suppose that the kinematic explanation is superior? For Janssen, it is contained in the idea that Minkowski space-time provides the source of explanation for various previously unexplained phenomena, where the dynamical theory fails to forge a link between different types of Lorentz-invariant laws. The problem with this is that the ability to provide a common-cause or a common-origin explanation does not arise simply in virtue of a kinematic structure. Indeed, a well-placed dynamic or constructive hypothesis can give rise to such a common-cause explanation as well. An example of this can be found in the kinetic theory of gases. Here, rather simple constructive hypotheses serve to unite and explain the various principles of thermodynamics by way of providing the common cause of interacting gas molecules. This shows that a good common-cause explanatory theory need not be a kinematic theory, so it is not kinematic emphasis, as such, that is important.

One might argue instead that Minkowskian kinematics is preferable just because it is the simplest single structure that accounts for all of the phenomena in question. That is, rather than providing a causal explanation, Janssen's argument might be understood to be invoking a unificationist model of explanation. This may certainly be a viable notion of scientific explanation, and perhaps the one most strongly at work in prin-

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ciple theories. However, while this may be the case, it does not provide definitive desiderata regarding Janssen's versus Brown's arguments.

If it is granted, a la Brown, that Minkowski space-time is not a causal entity, the difference between asserting that all laws operate according to Minkowskian geometry is really only a formal step away from saying that all laws are Lorentz invariant. The unification does seem to be imposed by fiat, in virtue only of its simplicity. The essential question remains: which is the explanans, and which is the explanandum? Because the step is a formal one, the argument from a common origin for different laws being Lorentz invariant does not have much force for Brown and Pooley:

> We agree that . . . according to our preferred dynamical interpretation, the Lorentz covariance of all the fundamental laws of physics is an unexplained brute fact. This, in and of itself, does not count against the interpretations: all explanation must stop somewhere. What is required if the so-called space-time interpretation is to win out over the dynamical interpretation . . . is that it offers a genuine explanation of Lorentz covariance. This is what we dispute. Talk of Lorentz covariance "reflecting the structure of space-time posited by the theory" and of "tracing the invariance to a common origin" needs to be fleshed out if we are to be given a genuine explanation here. . . . Otherwise we simply have yet another analogue of Moliere's dormative virtue. (2006, 13)

Janssen (2008) accepts that Minkowski space-time does not offer a causal explanation, as it were. However, shifting to a kinematic perspective in order to cover more phenomena under one structure leads to a situation where the choice, with no other deciding factors, comes down to explanatory preferences. On this front, neither Brown and Pooley nor Janssen makes a definitive case. I would argue that different types of scientific explanation may play different but perhaps equally legitimate roles in science.[3] It seems clear from what has been said that Janssen is arguing that special relativity is the more fundamental theory because it can explain by unification, while Brown and Pooley argue that the dynamical theory is more fundamental because it can explain causal-mechanically. It would appear that the two parties are arguing past one another due to the lack of a shared conviction regarding what counts as explanation. Determining which is the cart and which is the horse requires bringing more considerations into the picture.

The protractedness of the debate itself between Janssen and Brown and

3. Of course the primacy of various types of scientific explanation remains a highly debated area. I need not defend this explanatory pluralism for the purposes of this article since nothing rests on it.

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others serves as evidence that a new approach is warranted.[4] It is important to note that the relative perseverance of both positions speaks to the fact that both have a handle on an element of truth. At the heart of the issue, though, is that both parties are employing somewhat circular arguments from the perspective of a preferred route to explanation. From the Brown and Pooley perspective, to say that all laws are Lorentz invariant without explanation of that fact is simply to say that all laws operate in a Minkowski space-time geometry. They are equivalent formulations; one just posits as facts what the other posits as a geometrical structure, but no more explanatory or other philosophical benefit is gained. Describing phenomena from a Minkowski framework adds nothing over and above the Lorentzian view. It gives no common-cause explanation for the fact that "all laws are Lorentz invariant," nor is it any more unifying than accepting that statement as brute fact. And since Lorentzian dynamics provides the possibility of a causal explanation for phenomena, it is to be preferred.

From Janssen's perspective, that "all laws are Lorentz invariant" is a fact that requires explanation. There is no dynamical or causal-mechanical explanation that is any 'deeper', but special relativity, with its Minkowski space-time structure as a unifying theory, does the explaining. What we have here, though, is a situation where we have two theories, one constructive (Lorentzian dynamics) and the other principle (special relativity), that have the same empirical content. Two issues make it difficult to select one over the other as explanatorily prior based on the framing of this debate. The first is that in any situation such as this, there is no principled method for choosing the causal-mechanical explanation over the unificationist explanation of the same phenomena. Both purport to explain but in different ways.

In this particular case, however, the problem cannot be reduced to a debate about the nature of scientific explanation. Neither approach entirely succeeds in the particular type of explanation pursued according to its own terms as put by either Janssen or Brown. While the dynamical theory does have a mechanism, contraction, that explains phenomena, the mechanism itself and, in particular, why all things obey it is left causally unexplained. As far as unification goes, the kinematics of Minkowski space-time, taken on its own, is not more unifying, per se, than the claim that "all laws are Lorentz invariant." So, although it is a unifying geometrical structure, it is not by itself any more explanatory. It is codification as opposed to unification.

4. See Janssen (2002, 2008), Balashov and Janssen (2003), Brown (2005), Brown and Pooley (2006), and Brown and Timpson (2006).

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4. A Resolution. I do want to argue, along with Janssen, that special relativity is explanatorily more fundamental than Lorentzian dynamics. However, the reason behind this has been missed by both Janssen and Brown.

To demonstrate this, let us recall Janssen's comparison of special relativity with the Copernican system employed to make the argument that it is the common-cause aspect of special relativity that renders it superior to Lorentzian dynamics. As Janssen notes, the transformation in the physical worldview was not completed with Copernicus but continues through the work of Galileo and Kepler and culminates with Newton. I would add that what really cements the place of the Copernican system over the Ptolemaic model is not simply a common-origin explanation attributed to the structure of the system with the sun at the center of the solar system. Rather, it came only after some time with Newton's introduction of a common-cause explanation that also united that structure along with other phenomena. On the one hand, we might view this as the hypothesizing of a true common cause—the force of gravity in the universal law of gravitation. This, then, would explain the success of a constructive theory finally offering a causal explanation for the various phenomena we now know to be attributable to gravitational forces. However, the story is not so simple, due to the mysterious and historically contentious nature of this action at a distance. The lack of a causal mechanism means that no completely satisfactory causal explanation can be offered. What assured the ascendancy of Newtonian mechanics despite this objectionable action-at-a-distance, and thus the Copernican revolution, was the foundational analysis by Newton, who not only provided a single model to explain multiple facts, such as falling bodies, planetary motion, and tidal events, but recognized that the description of such facts could only be made coherent within a framework where the notions of force and motion had clear empirical meaning.

DiSalle's (2006) in-depth analysis, from Galileo through Einstein, demonstrates a consistent pattern of conceptual analysis in theory generation. It also shows that this analysis specifically addresses only particular kinds of theories. These are theories that serve as preconditions for the possibility of scientific knowledge by establishing a consistent conceptual framework that defines the meaning of empirical investigations under it. For example, according to DiSalle, the breakdown Einstein recognized, and which inspires special relativity, occurs because the "intuitive theory of simultaneity" fails to meet the "intuitive criterion of simultaneity" (2006, 111). That is, operating to form the contemporary theory of simultaneity was a conception of its role in the theory of space and time. However, Einstein determines that the actual theory departs from the commonsense conception of the role simultaneity ought to play. Specifically, "[Einstein] seeks a criterion of simultaneity that is independent of

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position and motion, that has a foundation in physical laws that are independent of any observer, and that makes simultaneity a symmetric and transitive relation" (DiSalle 2006, 110). The condition that Einstein establishes is that "we establish by definition that the 'time' required by light to travel from A to B equals the 'time' it requires to travel from B to A" (Einstein 1905, 894). This satisfies the criterion Einstein requires.

The invariance of Maxwell's equations could be explained by the universal contraction hypothesized by Lorentz. However, what the Newtonian framework of Lorentzian dynamics lacks, Einstein's theory of special relativity has, and that is a clear and meaningful definition of simultaneity and, therefore, a clear and meaningful definition of time, space, and motion, including dynamical descriptions. Einstein recognized the implicit role that signaling had in defining the inertial frame but that it had been possible to overlook this until then. In overlooking it, however, the concept of an inertial frame had not been given a clear meaning. In defining simultaneity in this way, Einstein's theory establishes universal Lorentz invariance.

We can see how Einstein's postulate regarding the propagation of light takes on an a priori character. It does not operate simply as an inductive generalization. Rather, the postulate acknowledges the constitutive role of the velocity of light and uses it to impose a structural framework wherein physical explanations can be made. These concepts serve as defining principles that can impose meaning on the concept of an inertial frame. As DiSalle (2006, 118) notes, from this standpoint it makes no sense to demand an explanation for the principle itself. To do so must always be circular, just as asking for an explanation for force and acceleration in Newtonian dynamics is misplaced. These concepts serve as defining principles that can impose meaning on the concept of an inertial frame. There can be no entirely external justification for such constitutive principles. But it is the constitutive nature of Newton's laws that finalizes the Copernican revolution by establishing a coherent conceptual framework.

There are, arguably, other fundamental framework theories based on principles that serve to set the framework in which empirical questions can be asked. Examples of such theories might be thermodynamics, or even quantum mechanics. Theories of space and time occupy a special position in that the level at which they function is so high that they must be constructed as principle theories. They establish the structure within which all physics operates. This also explains the a priori character they seem to have, as recognized by Kant and the logical positivists. The justification for such theories is not solely empirical, for they actually serve to define what counts as an empirical justification in the first place. Theories of space and time, as developed by Newton and Einstein, define the structure in terms of which the notions of causal interaction and measurable physical phenomena are meaningful. We see, therefore, that

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in the particular case of space-time theories such as Newton's or Einstein's, the principle theories are, in fact, of a particularly foundational nature, and why. These broad theories establish the structure on which other theories must be built. There is, therefore, a connection between being a foundational theory of this kind and being a principle theory.

Simplicity in theory building is also undoubtedly a virtue. In this, the Copernican system represented in Kepler's laws was a preferable theory to the Ptolemaic one. However, there remains no reason why we should think of it as a more accurate model of what the solar system is like. The Ptolemaic system relies on various unexplained coincidences to save the phenomena, but Kepler's system also provides no more independent grounds for why that model is any truer of the world. The same is true of the debate between Janssen and Brown regarding Lorentz and Einstein. In defending the explanatory depth of constructive theories, Brown and Timpson remark that "principle theories are typically employed when constructive theories are either unavailable, too difficult to build, or relatively unwieldy" (2006, 5), implying that, other things being equal, a constructive approach is to be preferred. But now we can see that this is not always the case (though sometimes it may be, and Brown and Timpson's case regarding thermodynamics is strong). Principle theories may at times become necessary, not simply because a constructive theory is simply unavailable or too complicated but because one is unavailable in principle without first having a consistent conceptual framework established by a constitutive principle theory. What matters is the conceptual reconciliation introduced by special relativity in defining concepts that had previously been poorly defined, not that it is a simpler model per se.

5. Conclusion. What this tells us is that both Janssen and Brown are right in their respective criticisms of the other's standpoint, but both are mistaken in assessing what it shows. In many respects, the issue remained in stalemate, and one could not definitively determine whether Minkowski space-time explains the Lorentz invariance of all physical laws or, in contrast, whether the fact that all laws are Lorentz invariant justifies the use of the Minkowski space-time geometrical framework. Janssen is correct, however, along with what I take to be the standard view, that the kinematics of special relativity is a more fundamental theory than the dynamical approach. What differs in Einstein's special theory of relativity is the conceptual analysis of what he conclusively showed to be vague concepts like simultaneity. This points the way to the appropriate interpretation. Without the conceptual work that Einstein's principles do, there is no sound explanatory framework at all, either unificationist or causal-mechanical. Likewise, Minkowski space-time is the conceptual framework to make sense of physics, the conceptual foundation for doing physics.

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Therefore, it is primary, and it precedes the dynamics on a theoretical level. It would be wrong to say that this structure provides a common-cause explanation for the Lorentz invariance of physical laws, but it does tell us why the laws of physics must be Lorentz invariant given the conceptual foundations of space-time physics. They must be so in order for empirical claims to have meaning. This provides the possibility of explanation via conceptual resolution as well as a justification for preferring special relativity over Lorentzian dynamics.

Having said this, it follows that, among other things, a foundational theory such as special relativity will have many of the characteristics that have been under consideration above. A foundational theory, because of the role it plays, will constitute a framework and so be a principle theory; it will be a kinematic theory in at least the weaker sense of simply being predynamic; and it will often involve unification at the level of the phenomena. This goes a long way to explain why so many of these characteristics have been put forth to account for the success of theories such as special relativity, which has all of these characteristics.

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