Minkowski Spacetime and Lorentz Invariance:
the cart and the horse or two sides of a single coin?

Pablo Acuña (pablo.acuna@ucv.cl)
Universidad Católica de Valparaíso

Michel Janssen and Harvey Brown have driven a prominent debate concerning the direction of an alleged arrow of explanation between Minkowski spacetime and Lorentz invariance of dynamical laws in special relativity. I critically assess this controversy with the aim of clarifying the explanatory foundations of the theory. First, I show that two crucial assumptions shared by the parties—that the debate is independent of issues concerning spacetime ontology, and that there is an urgent need for a constructive interpretation of special relativity—are problematic and negatively affect the debate. Second, I argue that the whole dispute relies on a misleading conception of the link between Minkowski spacetime structure and Lorentz invariance, a misconception that in turn sheds more shadows than light on our understanding of the explanatory nature and power of Einstein's theory. I state that the arrow connecting Lorentz invariance and Minkowski spacetime is not explanatory and unidirectional, but analytic and bidirectional, and that this analytic arrow grounds the chronogeometric explanations of physical phenomena that special relativity offers.

Harvey Brown states that a widespread view in foundational studies of special relativity is that Minkowski spacetime structure explains the dynamical behavior of physical objects. Brown rejects this view by means of two arguments. First, he states that it is problematic in ontological terms. Even if we assume a self-standing spacetime with a definite structure, physical objects do not have spacetime feelers that allow them to know that structure and behave accordingly. Brown's second argument states that, as a matter of logic alone, the structure of a self-standing spacetime does not determine the form of the corresponding dynamical laws. Based on these arguments, Brown states that it is much more natural and intelligible to maintain that the arrow of explanation goes from Lorentz invariance to Minkowski spacetime: spacetime has a Minkowskian structure *because* the laws of physics are Lorentz invariant.

Michel Janssen states that the arrow of explanation at issue points in the opposite direction. He states that in special relativity physical phenomena are accounted for without reference to the microstructural constitution of matter. Einstein's theory, he claims, shows that physical effects connected to Lorentz invariance are ultimately kinematic in the sense of being examples of standard spatiotemporal behavior—behavior that, in turn, is encoded and grounded on Minkowski spacetime structure. Janssen also states that in Brown's interpretation the fact that all the laws of physics are Lorentz invariance is left unexplained and constitutes a cosmic coincidence. On the contrary, in his proposal, that the laws of physics are Lorentz invariant gets explained in a unified and universal way by Minkowski spacetime structure. Janssen thus affirms that his interpretation is superior to Brown's because it involves a *common origin inference* that explains Lorentz invariance as a universal property of physical laws.

The first thesis I defend consists in that the debate is undermined by two problematic assumptions. First, both Brown and Janssen explicitly assert that the arrow of explanation must be *constructive*, in the sense of Einstein's distinction between theories of principle and constructive theories. Our authors agree in that constructive explanations are essentially superior to explanations of principle, and that the latter are actually epistemically poor and superficial. Thus, they claim, there is an urgent need to provide a constructive interpretation of the explanatory foundations of special relativity, for an exclusively principle-version of the theory renders it explanatorily deficient. I argue that this urgent demand is problematic and unjustified. It relies not only on a comparative evaluation between explanations of principle and constructive explanations when they are both available for the same realm of phenomena—as in the case of thermodynamics and statistical mechanics. The demand rests also on the metaphysical principle that for any realm of phenomena for which there is an explanation of principle, there is also a constructive explanation. It is clear that the truth-value of this principle cannot be determined empirically. That a realm of phenomena resists to be explained in constructive terms may be a manifestation of our theoretical inability, *or* it may mean that the ultimate explanation of those phenomena is not constructive. The latter scenario could be the case for relativistic phenomena. Thus, the urgent *demand* for a constructive version of the theory relies on an uncritical commitment to a metaphysical principle.

The second problematic assumption consists in that both Brown and Janssen claim that their arguments are not committed to a specific position regarding the ontology of spacetime. Brown argues that his views, which at face value seem quite akin to a relationist stance, hold also in a substantivalist setup. He states that Lorentz invariance explains Minkowski structure even if we assume that the latter is a property of a self-standing entity. The reason is that for spacetime structure to have an operational metric significance, rods and clocks must be reliable spacetime surveyors. Now, this can be so only if the dynamics that governs rods and clocks corresponds to the spacetime structure. On the other hand, Janssen claims that his proposal, that at first sight looks rather substantivalist, also works for the relationist. He argues that Minkowskian structure is the *formal* encoding of default spatiotemporal behavior, so that Minkowski spacetime does not feature as an *entity* that explains Lorentz invariance. I argue that, despite these remarks, both sides in the dispute require a specific commitment concerning spacetime ontology. I show that Brown's views about the relation between the operational meaning of spacetime metric and the dynamics of rods and clocks forecloses the possibility that Lorentz invariance can explain Minkowski structure in a substantivalist context. If spacetime is a self-standing entity, for rod and clocks to operate as metric surveyors Minkowski structure and Lorentz invariant dynamics must be independently postulated, so that their mutual match becomes a cosmic coincidence. On the other hand, Janssen's view is necessarily committed to a substantivalist stance. He explicitly states that Minkowski spacetime constructively explains Lorentz invariance. Now, given the very definition of constructive explanations—Janssen himself states that they explain by unraveling the reality behind the phenomena—it is impossible that Minkowski spacetime can constructively explain anything unless it is reified.

The arguments put forward by Janssen and Brown are committed to a specific stance regarding spacetime ontology. Thus, an interpretive issue concerning the foundations of a physical theory gets involved in a metaphysical dispute that transcends the meaning of the theory: in and by itself, special relativity is agnostic about the ontology of spacetime. Moreover, both sides in the contend share an unjustified demand for a constructive version of Einstein's theory. Both these features negatively affect the debate. Now, my second thesis states that the debate as a whole relies on a misleading overinterpretation of the nature of the connection between Lorentz invariance and Minkowski spacetime. Rather than connected by an explanatory and unidirectional arrow, they are connected by an analytic and bidirectional arrow. I mean 'analytic' in a somewhat Kantian sense. For Kant, in analytic propositions, the predicate concept is included in the subject concept, so that they offer an explication or a definition of the subject concept, not an explanation of it. I claim that Lorentz invariance and Minkowski structure are like the subject and predicate of an analytic proposition. After all, what Minkowski did was to unfold in precise and complete terms the spatiotemporal conceptual scaffolding included in Einstein's work. Furthermore, our subject and predicate concepts can shift roles—Minkowski structure can be obtained from Lorentz invariance by taking the relativistic invariant interval as an expression of the spacetime metric, and the coordinate transformations between inertial frames in Minkowski spacetime are the Lorentz transformations. Thus, the analytic arrow is bidirectional, so that asking which is the *explanandum* and which is the *explanans* results in a circle: why is spacetime Minkowskian? Because the laws are Lorentz invariant. Why are the laws Lorentz invariant? Because spacetime is Minkowskian. Finally, the conception I propose of the relationship between Lorentz invariance and Minkowski structure, unlike the one assumed in the Janssen-Brown debate, illuminates the explanatory nature and power of special relativity. Einstein's original work provided an explanation of principle for physical phenomena. Minkowski's work did not turn special relativity into a constructive theory, but it showed that it also offers chronogeometric explanations: special relativity postulates a chronogeometric conceptual scaffolding that makes physical phenomena scientifically intelligible.

References:

Balashov, Y. & Janssen, M. (2003). "Presentism and Relativity", *British Journal for the Philosophy of Science* 54: 327-346.

Brown, H. (2005). *Physical Relativity: space-time structure from a dynamical perspective*. Oxford University Press.

Brown, H. & Pooley, O. (2006). "Minkowski Space-Time: a glorious non-entity", in D. Dieks (Ed.) *The Ontology of Spacetime*, 67-89. Elsevier.

Janssen, M. (2009). "Drawing the Line between Kinematics and Dynamics in Special Relativity", *Studies in History and Philosophy of Modern Physics* 40: 26-52.