Minkowski's space-time and the interpretation of physical theory

The theory of relativity might not appear to pose profound questions of interpretation of the sort that are posed by quantum mechanics. On the one hand, there are continuing metaphysical debates about the nature of relativistic space-time (concerning, e.g., whether it is "substantival" or "relational"), and methodological questions about the role played by conventions. On the other hand, however, the theory does not appear to allow the variety of fundamentally different interpretations that one finds in the case of quantum mechanics. For, in the case of quantum mechanics, different interpretations represent profoundly divergent conceptions of what the theory "is about". In the case of relativity, a peculiarly compelling conception of what the theory "is about" was expressed in Minkowski's (1908) account of Einstein's theory as a theory of space-time geometry founded on Lorentz invariance.

It might appear to be surprising, therefore, that in recent literature the interpretation of relativity has become a matter of controversy. This controversy arises in part from a penetrating and subtle re-examination of the meaning of Lorentz invariance (cf. Brown 2005), from which a re-examination of the nature, and the ontological significance, of Minkowski's space-time inevitably results. On what once seemed an obvious interpretation, Lorentz invariance is a central part of what, according to Einstein, characterizes special relativity as a "principle-theory": a theory that expresses "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" (Einstein 1919). On Lorentz's theory, by contrast, Lorentz invariance is to be explained by a "constructive theory," i.e. a theory that "builds up a picture of the more complex phenomena out of the materials of a relatively simple formal scheme." That is, where Einstein's theory derives Lorentz invariance from fundamental empirical postulates, Lorentz's explains it "constructively" as the dynamical effect of interactions between moving particles and the ether. According to Brown, the dynamical, "constructive" account of Lorentz invariance deserves a careful reconsideration.

Such a reconsideration crucially depends, I suggest, on a particular understanding of the distinction between principle and constructive theories. It construes the distinction as something very much like the distinction between theories that are fundamental and those that are merely phenomenological, a construal encouraged by Einstein's characterization of principle-theories as expressing "empirically-discovered" principles. On this account, Einstein accepted Lorentz invariance as something fundamental—that is, as not further explicable by any "constructive" account—only provisionally, in the absence of the deeper understanding that a constructive account ought to provide. It follows from this view that Minkowski space-time cannot be regarded as the ontological basis of special relativity, or as in any way explanatory of Lorentz invariance; it is instead merely a "codification" of the behavior of moving bodies and clocks that still awaits a proper explanation.

This view is challenged by (among others) Janssen (2007), who defends the view of special relativity as a fundamental theory and articulates a sense in which Minkowski space-time is indeed explanatory. While I am in broad agreement the force of this challenge, I offer a different account of the explanatory role of Minkowski spacetime. In this account, particular attention is paid to one aspect of principle theories, that they express "criteria" which natural processes "have to obey." The question I consider is how certain principles come to have the force of *criteria* in this sense. Instead of a dynamical explanation of how processes or systems come to satisfy these criteria at the phenomenological level, or even a deductive-nomological explanation of how they follow from an underlying structure, I consider the sense in which these criteria are *definitive*, or *constitutive*, of fundamental physical properties of dynamical systems. This, in turn, requires us to reconsider the epistemological arguments given by Einstein in 1905, and the role that they play in Minkowski's arguments of 1908. These arguments concern *how well defined* are the fundamental concepts presupposed by Lorentz's theory, and what physical assumptions are required in order to construct a framework of space and time in which such a theory can make sense. If these arguments are compelling, then the principle-theory is not merely a phenomenological description whose deeper explanation is wanting; it is the demand for a dynamical explanation that is wanting, in the sense that the concepts of the spatio-temporal framework that it presupposes—the concepts of simultaneity, length, and time—require a physical interpretation that has yet to be adequately defined.

This analysis provides a perspective on what Minkowski's space-time theory accomplishes as an interpretation of special relativity. In one sense Minkowski space-time does not *explain* the Lorentz invariance, in the sense of specifying an underlying reality of which the latter is a phenomenological consequence. In another sense, Minkowski's space-time explains the significance of Einstein's theory for our understanding of the world, and of the nature of space-time; it explicates the conceptual revision that Einstein's theory forces upon us. This, I suggest, is at least one useful way of thinking about the interpretation of a physical theory: a compelling interpretation is one that is, at the same time a compelling explanation of the ways in which the theory forces us to re-conceptualize our experience of the physical world, and to revise our fundamental physical concepts.

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