DYNAMICS AND CHRONOGEOMETRIC STRUCTURE IN SPACETIME THEORIES

Harvey Brown's celebrated *Physical Relativity* (2005) introduced a dynamical-constructive interpretation of relativity theory. A main claim in this interpretation is that Lorentz invariance has a more fundamental place in special relativity than Minkowski spacetime structure. Actually, Brown claims, the former explains the latter.

Brown finds historical and conceptual support in the approach in electrodynamics undertaken by late 19th century physicists such as Larmor, Fitzgerald and Lorentz. They allegedly provided a dynamical foundation—crowned in Lorentz's model of the electron in his ether theory—for physical effects which today we characterize as paradigmatically relativistic, e.g., clock-retardation and length-contraction. The 19th century explanation of these effects is supposed to be given by the (Lorentz invariant) laws governing the interaction between matter and the ether. In simple terms, the "relativistic" behavior of physical bodies results from the way they are made, not from the structure of an embedding spacetime. Brown does not propose a return to ether physics, of course, but he argues for an interpretation of relativity theory along these lines—where the ultimate dynamical foundation and explanation of Minkowski spacetime structure is provided by a (Lorentz invariant) quantum theory of matter.

I will contest Brown's interpretation and propose a more nuanced view concerning the relation between dynamics and spacetime structure. I will look back to the 19th century too, but this time to arguments concerning the epistemology of geometry introduced by Helmholtz (1977) and Poincaré (2001).

Helmholtz's main insight was that for the question of the geometric structure of physical space to make sense at all, dynamical considerations must be involved from the outset. He stated that if the notions of congruence and rigidity are not previously defined and operationalized—an issue that involves dynamical laws governing physical bodies—the measurements that can tell about the geometric structure of physical space are neither defined nor possible. In other words, a geometric structure cannot even refer to the physical world unless dynamical principles define notions like congruence and rigidity. Only once this is accomplished, measurements of spatial structure are meaningful and possible.

Now, a crucial point is that the converse is also true, i.e., dynamics makes physical sense only on a geometric structure background. This important insight is implicit in Helmholtz's work: that is why measurements performed with rigid bodies can be taken as empirical evidence for a certain geometric structure in the first place. If dynamics—and hence the corresponding definition and operationalization of rigidity and congruence—were geometrically neutral, those measurements would be idle with respect to the geometric structure of physical space.

This point can be clearly seen if we consider Poincaré's argument for the conventionality of geometry, in the context of the predictive equivalence and rivalry between Lorentz's ether theory and special relativity. We can take this historical episode in physics as an instance of Poincaré's parable of a single world that can be correctly described by two incompatible (chrono)geometric structures. The mathematical form of the dynamical laws in both theories is exactly the same, but they have a different meaning. For example, in the ether theory, $\Delta x' = \Delta x/\gamma$, where $\gamma = 1/\sqrt{1 - v^2/c^2}$, refers to the longitudinal contraction of an object that moves with respect to the ether with velocity v; whereas in special relativity the same formula refers to the different measurements of the length of the same object in two frames that move with respect to each other with velocity $\pm v$. For this difference in meaning to be possible at all, $\Delta x' = \Delta x/\gamma$ must be setup on different chronogeometric structures. For the ether theory to be able to pick a privileged ether-rest frame, Newtonian spacetime must be the chronogeometric background for the law. In turn, in special relativity the formula is about kinematics in different frames since the chronogeometric structure on which it is defined is Minkowski spacetime. On the other hand, if the law were chronogeometrically neutral we could not assign it any of the two meanings—or any physical meaning at all.

We can thus draw a Helmholtzian conclusion. If the chronogeometric structures we call spacetimes are to have a physical meaning at all, dynamical principles that operationalize them in terms of the behavior of physical objects are necessary[1]. On the other hand, if the mathematical equations we call dynamical laws are to have a physical meaning at all, they must be setup on a chronogeometric structure background. Borrowing a Kantian expression, spacetime structure without dynamics is empty, and dynamics without spacetime structure is blind. Hence, Brown's thesis that Lorentz invariance explains and is more fundamental than Minkowski spacetime structure cannot be right. The thesis here presented is a generalization of the argument in (Acuña 2016): there it is argued that in special relativity Minkowski spacetime and Lorentz invariance are like the two sides of a single coin, here I argue that the same relation holds between spacetime structure and dynamics in all spacetime theories. Actually, the approach of 19th century physicists is not substantially different from Einstein's in this respect: the dynamical "ether laws" that explain length-contraction and clock-retardation are as chronogeometrically laden as special relativistic laws.

This thesis can provide further insight regarding the discussion about the ontology of spacetime. If chronogeometric structure has no physical meaning when disentangled from dynamics, and if it plays the role of making dynamical laws intelligible, the view that spacetime represents an entity—whatever its mode of existence may be—becomes unmotivated. On the other hand, if dynamical laws are not (kinematically) intelligible unless they are setup on a chronogeometric background, it is not possible to conceive spatiotemporal relations between bodies prior to the introduction of chronogeometric structure—so that the relationist thesis gets challenged as well. I will then suggest that the thesis I am introducing promises a dissolution of the substantivalism/relationism debate.

REFERENCES

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[1] Helmholtz was wrong in that rigidity is a necessary concept to operationalize geometric structure. In special relativity there are no rigid bodies. His main point stands, though. How the operationalization is achieved is a different issue.