Does the geometry of spacetime play an explanatory role in Special Relativity?

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My goal is to build on a claim by Knox (2017, pp. 7) to the effect that: "[. . .] Lorentz covariance and Minkowski structure are two sides of the same coin, and the analytic connection between them does not allow for sensible arguments about the arrow of explanation". I agree with her that there is an analytic connection between the Lorentz covariance and the Minkowski structure. I also agree that it is not sensible to argue about the arrow of explanation. Nevertheless I think I can answer the question in the positive — that I can sensibly argue that the geometry of spacetime ~~does not~~ play an explanatory role in Special Relativity (SR), albeit not an exclusive one.

I need the following premises. First, *physical explanation is causation*: we are extremely averse to accepting an explanatory role in physics that is not a causal role. Second, *entailment excludes causation*: if A by itself entails B, then A by itself does not cause B. Third, *spacetime is a functional concept*: following Knox (2017, pp. 5) I will argue that spacetime is defined in terms of what it does, not in terms of what it is. Fourth, *Lorentz covariance and Minkowski structure entail each other*: when conjoined with the standard principles of SR and spacetime functionalism, Lorentz covariance entails Minkowski structure and vice versa.

From premise two and four, it follows that Minkowski structure cannot cause Lorentz covariance — and vice versa. From this and premise one, it follows that neither can explain the other — and so it is indeed nonsensical to bicker over the direction of explanation (Knox's point).

After establishing these premises and their consequences, I will have shown that Minkowski structure cannot *exclusively* play an explanatory role in SR. If it plays an explanatory role, so does Lorentz covariance. Can they both play an explanatory role?

Once we accept spacetime functionalism, I think it becomes clear that they can and do. And thus it seems to follow that the geometry of spacetime plays an explanatory role in SR.

§1 *Physical explanation is causation.* That is, any physical phenomenon for which we could not provide a causal explanation would be unexplained by physics. This is generally held as a background assumption in the philosophy of physics, and Brown seems to implicitly assume its truth (Brown 2005, pp. 135) — he does not even clearly distinguish between explanation and causation (which I take to be a result of implicitly embracing this very premise). I will argue that we can see its plausibility more vividly by contrasting a caricature of Aristotelian physics with General Relativity.

In an attempt to explain gravitational phenomena (such as apples falling when thrown into the air), Aristotle claimed that every body had a natural motion. Bodies on earth tended to move towards the center of the universe, which he took to be the center of the earth. Bodies in the heavens (planets, moons, and stars) tended to (roughly speaking) orbit the earth. Unless they were continuously affected by external forces, they would tend to return to their natural motions (Bodnar 2016). Suppose now that Aristotle did not attempt to provide a causal explanation of natural motions. Instead, let us suppose he provided a non-causal explanation of the motion of bodies: gravitational phenomena are caused by natural motions, but natural motions are themselves essential to bodies. That is, the reason that a rock falls is that it is a rock; the reason that a planet orbits the earth is that it is a planet. Nothing caused it to be that way, it merely is that way. So there is a causal gap in the theory. And thus it is nonsense to say that the theory has explained gravity — it has merely relocated the mystery.

General Relativity can illuminate why the above sounds utterly implausible as an explanation. Very roughly speaking, it explains gravitational phenomena by a causal interaction between massive bodies and the geometry of spacetime itself. Massive bodies follow straight lines (or, more precisely, geodesics) in spacetime when they are not acted on by external forces. But according to GR, massive bodies also distort the geometry of spacetime. Thus, the straight-line motion of a massive body curves in the presence of other massive bodies (and vice versa). We see this curvature in terms of falling apples and orbiting planets. The cause-effect relation is now well-defined: spacetime acts on massive bodies and vice versa. So GR explains gravitational phenomena because it explains them causally: it closes the causal gap of my caricatured Aristotelian physics.

While this narrative does not suffice to conclusively establish that physical explanation is causation, it shows that it is a very plausible claim: we are extremely averse to physical theories that posit non-causal explanations, and a crucial part of physics is to close the causal gaps of our theories. Thus, I will assume henceforth that physical explanation is causation — anything else that claims to be an explanation is merely a putative explanation, at least until it can close its causal gaps.

§2 *Entailment excludes causation.* Suppose that A by itself entails B. Then A by itself does not cause B. Entailment is a priori (Beall and Restall 2016, §1) but causation, at least insofar as it is of interest to physicists and scientists, is a posteriori: it is discoverable only by empirical observations, not by mere rumination. But anything that is a priori is (a priori) not a posteriori: the two categories are by definition mutually exclusive. Hence, my second premise is true.

§3 *Spacetime is a functional concept.* What are the conditions for anything to be spacetime? Knox argues (2017, pp. 4) that once we rid ourselves of the illusory appeal of metaphors for spacetime as a container for the universe, we are left with a concept that has only functional conditions:

> A structure that plays the spacetime role in a theory just *is* spacetime; once one has analysed the role and understood what fills it, there are no further questions to be asked about the 'real' spacetime structure. Spacetime is spacetime by virtue of what it does, not what it is. (Knox 2017, pp. 4)

In particular, spacetime plays the functional role of defining "a structure of local inertial frames" (Knox 2017, pp. 5). This will be crucial in what follows.

§4 *Lorentz covariance and Minkowski structure entail each other.* The standard principles of Special Relativity are Galilean Relativity and the Light Postulate. The former states that the laws of physics will be observed by all inertial observers to be the same. The latter states that the two-way speed of light will be observed by all inertial observers to be the same. Finally, an inertial observer is anything moving at a constant velocity and which (equivalently) is not subject to any external (non-gravitational) forces. This understanding of the two principles and the inertial observer is uncontroversial. But more is needed to account for relativistic phenomena such as length contraction and time dilation: we need Lorentz covariance and Minkowski structure.

The Minkowski structure defines the geometry of spacetime. It tells us that inertial observers will have straight worldlines in four-dimensional spacetime geometry, and that we can define an invariant spacetime interval ($ds^2 = c^2dt^2 - dx^2 - dy^2 - dz^2$) that all intertial observers will measure to be the same. In short, it uses symmetries of geometry to define inertial structure.

The Lorentz covariance of the laws of physics requires that said laws will maintain their mathematical form under coordinate transformations. This means, very informally, that any inertial observer will observe any separate inertial observer in relative motion to be experiencing physical laws of the same form but with some varying parameters, and other invariant parameters. In short, Lorentz covariance uses symmetries of our physical laws to define inertial structure.

But on Knox's view, there is no meaningful difference between the two: they both define the same inertial structure. They may do so in slightly different ways, but that is immaterial. In virtue of defining the inertial structure, Lorentz covariance entails Minkowski structure. In virtue of defining the inertial structure, Minkowski structure entails Lorentz covariance. And since there is nothing more to spacetime than inertial structure, we may infer the converse entailment as well: the inertial structure of SR entails Lorentz covariance *and* Minkowski structure. Thus, we have mutual entailment.

(This is only true if one accepts that spacetime is defined exclusively in terms of what it does. Brown and Pooley (2001, pp. 18) would argue that one can have Lorentz covariance without Minkowski structure. On their view it does not follow from Lorentz covariance that the geometry of spacetime is the Minkowski structure — it could have some other structure. But if spacetime simply *is* inertial structure, and in SR it is the Minkowski structure, then the geometry spacetime could not have had a different structure in SR.)

From premise two, it follows that there is no causal link between Minkowski structure and Lorentz covariance. And from this and premise one, it follows that there is no explanatory connection between them. And so it becomes obviously nonsensical to hold that one explains the other. If spacetime functionalism is a good account of spacetime, then there is nothing that can be said to favor either side of this particular debate, for the simple reason that there is no explanatory connection at all. But then it follows trivially that neither Minkowski structure nor Lorentz covariance can be said to play an explanatory role in SR.

§5 *Joint explanation.* But that does not quite answer the titular question. For it might be that, while neither Minkowski structure nor Lorentz covariance play an *exclusive* explanatory role, they play a joint explanatory role in SR: while neither explains length contraction on its own, they jointly explain it.

Recall that on my view, explanation is causation. Thus, if they jointly play an explanatory role, they jointly play a causal role. This might appear to be troublesome. Here is a reason to suspect trouble. We might suppose that they each cause length contraction. But then we are left with two sufficient causes for one effect — that is, causal overdetermination (Kim 2003, pp. 157). But if we have causal overdetermination, we have hardly explained anything at all.

We want to know not only the set of sufficient causes, but also which element of the set is operative in any specific instance of causation. If the answer to my question "why do apples fall?" was "both because of an invisible attractive force and because of the curvature of spacetime", then I would feel cheated: which one is it? Causal overdetermination eliminates any chance of a satisfactory answer to such questions. Thus we should not think that Minkowski structure and Lorentz covariance can play a joint causal role, and thus that they cannot play a joint explanatory role.

But this objection neglects spacetime functionalism entirely, because it presupposes that Minkowski structure and Lorentz covariance have different ontological commitments — that they posit separate causes that act separately. But on spacetime functionalism this is nonsensical. They do not have different ontological commitments, but rather the exact same ontological commitment: they are both committed to a particular and exclusively functional inertial structure, and that is all there is to them. So it is not possible for them to causally overdetermine anything, for the simple reason that they are not ontologically separate in the first place.

All that remains is to show that the geometry of spacetime, as given by the Minkowski structure, plays an explanatory role in SR. But I have already done that implicitly, with the help of spacetime functionalism. The Minkowski structure is ontologically committed only to a particular and exclusively functional inertial structure. But this inertial structure *does* cause phenomena such as length contraction and time dilation. Moreover, it is plausible to say that it explains these phenomena (Maudlin 2012, pp. 124). And so Minkowski structure and Lorentz covariance jointly play an explanatory role (the same one) in virtue of defining an inertial structure for SR.

§7 *Conclusion*. My argument has rested on four premises: first, *physical explanation is causation*; second, *entailment excludes causation*; third, *spacetime is a functional concept*; fourth, *Lorentz covariance and Minkowski structure entail each other*. I have shown that each of these premises are plausible. And from these premises it follows that the geometry of spacetime plays an explanatory role in Special Relativity — albeit not an exclusive one.

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