Special Relativity as a “constructive” theory

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from Robert DiSalle's abstract. . .

[Minkowski's analysis of special relativity] is not merely the representation of special relativity in a four-dimensional form. Nor is it the "explanation" of special relativity by means of the hypothesis that there exists a certain underlying spacetime structure. Rather, it is Minkowski's attempt to show that our knowledge of the invariance group of electrodynamics is, in virtue of Einstein's analysis of time, knowledge of the structure of spacetime. In other words, the claim at the heart of Minkowski's analysis is, at the same time, extremely far-reaching and extremely modest: it is the claim that a world in which special relativity is true simply is a world with a particular spacetime structure.

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Weyl, Pauli, Eddington, Swann, Bell,
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6. Geometry and explanation

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The relativity principle seen "as a restricting principle for the natural laws, comparable to the restricting principle of the non-existence of the *perpetuum mobile* which underlies thermodynamics"

(*ibid.*)

Constructive theories *vs* principle theories

> Most [theories in physics] are constructive. They attempt to build up a picture of the more complex phenomena out of the materials of a relatively simple formal scheme from which they start out. Thus the kinetic theory of gases seeks to reduce mechanical, thermal, and diffusional processes to movements of molecules. . .
> [Principle theories] employ the analytic, not the 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. . . have to satisfy. . . The theory of relativity belongs to the latter class.
>
> (Einstein, *The Times*, 1919)

Why look for a constructive version of special relativity?

> When we say that 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. . .
>
> (Einstein, 1919)

Einstein on the deficiencies of his principle approach

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In a letter to Sommerfeld of 1908, he wrote:

> The theory of relativity is not more conclusively and absolutely satisfactory than, for example, classical thermodynamics was before Boltzmann had interpreted entropy as probability. If the Michelson-Morley experiment had not put us in the worst predicament, no one would have perceived the relativity theory as a (half) salvation. Besides, I believe that we are still far from having satisfactory elementary foundations for electrical and mechanical processes.

John Bell independently (?) draws the analogy

If you are, for example, quite convinced of the second law of thermodynamics, of the increase of entropy, there are many things that you can get directly from the second law which are very difficult to get directly from the detailed study of the kinetic theory of gases, but you have no excuse for not looking at the kinetic theory of gases to see how the increase of entropy actually comes about.

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(Physics World, 1992)

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Principle theories:	thermodynamics	special relativity
Constructive theories:	kinetic theory of gases	

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Principle theories:	thermodynamics	special relativity
Constructive theories:	kinetic theory of gases	???

FitzGerald and Lorentz on the Michelson–Morley result

- We know that electric forces are affected by the motion of electrified bodies relative to the ether and it seems a not improbable supposition that the molecular forces are affected by the motion and that the size of the body alters consequently (FitzGerald, letter to *Science*, 1889)
- In 1892 Lorentz shows that a longitudinal contraction (by γ) occurs in the dimensions of a system of charges held in equilibrium when it is put into motion
- In both cases the deformation hypothesis is seen to gain support from the effect of motion on electrostatic forces, but neither FitzGerald nor Lorentz:
    1. identify molecular forces with electromagnetic forces
    2. advocate a purely longitudinal contraction
- Letter from FitzGerald on learning of Lorentz's hypothesis

To repeat. . .

- Einstein did not reject this approach because he thought it was wrong-headed in principle
- He rejected it because he did not believe (partly as a result of his own work on light quanta) that the necessary tools, in the form of an adequate constructive theory of rigid bodies, were available

Two early advocates of the dynamical approach

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> Should one, then,. . . completely abandon any attempt to explain the Lorentz contraction atomistically? We think the answer to this question should be No. The contraction of a measuring rod is not an elementary but a very complicated process. It would not take place except for the covariance with respect to the Lorentz group of the basic equations of the electron theory, as well as of those laws, as yet unknown to us, which determine the cohesion of the electron itself. We can only postulate that this is so, knowing that then the theory will be capable of explaining atomistically the behaviour of moving rods and clocks.
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> (Pauli, *Theory of Relativity*, 1921)

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> There is really nothing mysterious about the FitzGerald contraction. It would be an unnatural property of a rod pictured in the old way as continuous substance occupying space in virtue of its substantiality; but it is an entirely natural property of a swarm of particles held in delicate balance by electromagnetic forces, and occupying space by buffeting away anything that tries to enter.
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- In the eyes of these authors, Einstein's 1905 derivation of the Lorentz transformations, and Minkowski's 1908 analysis of them, did not render redundant the atomistic, dynamical understanding of length contraction.

The story so far

- The constructive version of SR (the constructive explanation of paradigmatically relativistic phenomena such as length contraction and time dilation) is to be sought along the lines of that provided by Lorentz, updated with an appeal to our best available constructive theories of the constitution of matter (QED etc.)
- But some have thought that Minkowski spacetime itself (or Minkowski spacetime structure) can be appealed to in a constructive explanation. . .

Einstein on the reality of classical spacetime

The inertia-producing property of this ether [Newtonian space-time], in accordance with classical mechanics, is precisely *not* to be influenced, either by the configuration of matter, or by anything else. For this reason, one may call it “absolute”. That something real has to be conceived as the cause for the preference of an inertial system over a noninertial system is a fact that physicists have only come to understand in recent years . . . Also, following the special theory of relativity, the ether was absolute, because its influence on inertia and light propagation was thought to be independent of physical influences of any kind . . . The ether of the general theory of relativity differs from that of classical mechanics or the special theory of relativity respectively, insofar as it it is not “absolute”, but is determined in its locally variable properties by ponderable matter.

(Einstein 1924)

Does inertial structure explain anything?

> . . . without the affine structure there is nothing to determine how the [free] particle trajectory should lie. It has no antennae to tell it where other objects are, even if there were other objects. . . It *is because space-time has a certain shape that world lines lie as they do*.
>
> (Nerlich, *The Shape of Space*)

- Do the particles have spacetime feelers?
- Even if one does assimilate the ‘interaction’ between the affine connection field and matter fields to other interactions in physics, the chronogeometric behaviour of complex bodies in motion is different again to the inertial motion of force-free particles.

Balshov and Janssen on the constructive *vs* principle

In a theory of principle, one starts from some general, well-confirmed empirical regularities that are raised to the status of postulates (e.g., the impossibility of perpetual motion of the first and the second kind, which became the first and second laws of thermodynamics). With such a theory, one explains the phenomena by showing that they necessarily occur in a world in accordance with the postulates. Whereas theories of principle are about the phenomena, constructive theories aim to get at the underlying reality. In a constructive theory one proposes a (set of) model(s) for some part of physical reality (e.g., the kinetic theory modeling a gas as a swarm of tiny billiard balls bouncing around in a box). One explains the phenomena by showing that the theory provides a model that gives an empirically adequate description of the salient features of reality.

(Balashov and Janssen, *Presentism and Relativity*)

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> Consider the phenomenon of length contraction. . . the space-time interpretation. . . provide[s a] constructive-theory explanation. . . In the space-time interpretation, the model is Minkowski space-time and length contraction is explained by showing that two observers who are in relative motion to one another and therefore use different sets of space-time axes disagree about which cross-sections of the 'world-tube' of a physical system give the length of the system.
>
> (*ibid.*)

Friedman on Poincaré's favouring Lorentz over Einstein

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SR as a principle theory does not explain

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NO

- rods and clocks must behave in quite particular ways in order for the two postulates to be true together.
- It is *because* rods and clocks behave as they do, in a way that is consistent with the relativity principle, that light is measured to have the same speed in each inertial frame.

Geometry *does* explain

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- The twin paradox and the waywiser analogy
- The symmetry of length contraction (involving either one or two rods)
- Another analogy with Euclidean space: Cyrano’s nose

Cyrano’s nose

As Cyrano turns around to run off, Roxanne sees his nose, protruding from his silhouette against the night sky, become more and more pronounced until eventually she sees it get smaller and smaller again and vanish. This behavior of Cyrano’s nose is part of the normal spatial behavior of objects in three-dimensional Euclidean space. . .

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Inference to a common origin?

- Einstein's conductor and magnet example
- *Universal* Lorentz invariance
- "In Minkowski space-time, the spatio-temporal coordinates of different observers are related by Lorentz transformations rather than Galilean transformations. Any laws for systems in Minkowski space-time must accordingly be Lorentz invariant." (Janssen: *COI Stories*)
- Evidence or explanation?

General Relativity

- Most, if not all, of the foregoing carries over to GR (that the tangent spaces of a GR spacetime and Minkowskian, does not explain the local Lorentz covariance of the equations governing the matter fields)
- The relation between the variably curved metric of GR, and the matter field, is (more or less) precisely the same as the relationship between the metric of SR and matter fields, if. . .
- The strong equivalence principle holds
  - which it does only approximately
  - and theories which violate minimal coupling are not gerrymandered curiosities

Postscript

WE DO NOT BELIEVE
IN A PREFERRED FRAME