Fundamentality and the Dynamical Approach to Relativity

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TWO SLOGANS

Rods and clocks do what they do because spacetime's geometry is what it is

versus

The geometry of spacetime is what it is because rods and clocks do what they do.

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The view to be defended:

Rods and clocks do what they do because spacetime’s geometry is what it is

TWO VIEWS

THE GEOMETRICAL APPROACH:

- The geometry of spacetime being what it is (in part) explains why rods and clocks do what they do.
- The geometry of spacetime need not be fundamental, but it is not grounded in the behaviour of rods and clocks, nor in the symmetries of the dynamical theories in terms of which the behaviour of familiar rods and clocks might be modelled and explained.

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- The geometry of spacetime is what it is *in virtue of* the behaviour of rods and clocks.

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THE DYNAMICAL APPROACH:

- The geometry of spacetime is what it is in virtue of the behaviour of rods and clocks.

  the Minkowskian metric is no more than a codification of the behavior of rods and clocks, or equivalently, it is no more than the Kleinian geometry associated with the symmetry group of the quantum physics of the non-gravitational interactions in the theory of matter (Brown, 2005, 9)

1. Common Ground
2. The Spacetime Explanation of Dynamical Symmetries
3. The Dynamical Explanation of Spacetime Geometry
4. Dynamical Geometry and the Status of $g_{\mu\nu}$

COMMON GROUND

1. The principles of “principle theories” are not explanatory
2. Explanation is context-dependent and pluralistic
3. Explaining why a material rod or clock of some specific type exhibits characteristically relativistic behaviour need not (should not?) appeal to the details of the dynamics
4. Explaining why the rod/clock functions as a rod/clock in the first place will appeal to details of its dynamics.

CONSTRUCTIVE VERSUS PRINCIPLE THEORIES

PRINCIPLE THEORIES:

- regularities in the phenomena are used to derive “a theory which will apply in every case”

Applied to Einstein’s 1905 derivation:

- The “principles on which it rests”:
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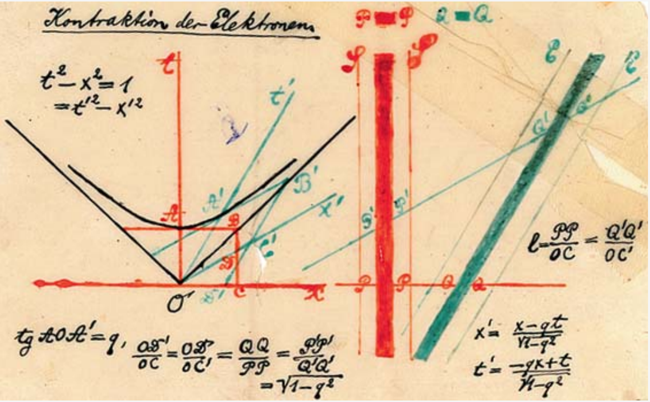
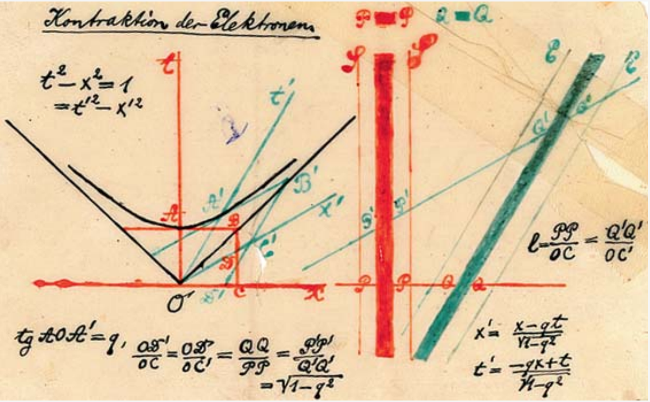
CONSTRUCTIVE THEORIES:

- “build a picture of complex phenomena out of some relatively simple proposition”—“when we say that we understand a group of natural phenomena, we mean that we have found a constructive theory which embraces them”

THE PRINCIPLE THEORY PERSPECTIVE ON LENGTH CONTRACTION





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- the relativity principle and the light postulate
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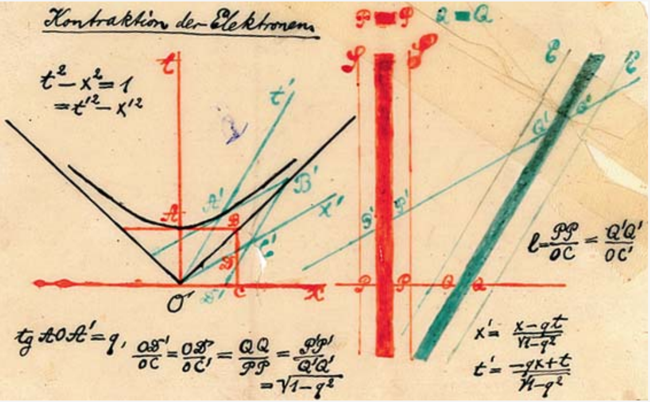

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Note: the “boostability” of rods is not an (additional) assumption.

CONTEXT DEPENDENCE

“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.” (Balashov and Janssen, 2003, 331) "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." (Balashov and Janssen, 2003, 331)

"In our opinion these constitute perfectly acceptable explanations (perhaps the only acceptable explanations) of the explananda in question." (Brown and Pooley, 2006, 79)

But

- It is assumed that the rod being measured, and the rods doing the measuring, conform to Minkowski geometry.
- Why do these objects conform to Minkowski geometry?

BELL-STYLE CONSTRUCTIVE EXPLANATION

"the truly constructive explanation of length contraction involves solving the dynamics governing the structure of the complex material body that undergoes contraction. There are, of course, many contexts in which such an explanation may not be appropriate, contexts that call for a purely geometrical explanation. What we wish to stress is (i) that such geometrical explanations are not constructive theory explanations in Einstein's sense and (ii) that there are contexts, and questions, to which the dynamical story is appropriate." (Brown and Pooley, 2006, 82)

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- Intuitively, such a derivation is explanatory
- According to the advocate of the geometrical approach, such an explanatory story involves appeal to geometric facts. (Compare a Newtonian explanation of the rotating bucket phenomenon.)
- The derivation is at best an explanation of the particular system's contraction. It does not recognise the universality of the phenomenon.

EXPLAINING LENGTH CONTRACTION IN GENERAL

[I]n many contexts, perhaps in most contexts, one should not appeal to the details of the dynamics governing the microstructure of bodies exemplifying relativistic effects when one is giving a<n> ~~constructive~~ explanation of them. *Granted that there are stable bodies*, it is sufficient for these bodies to undergo Lorentz contraction that the laws…that govern the behaviour of their microphysical constituents are Lorentz covariant. It is *the fact that the laws are Lorentz covariant*…that explains why the bodies Lorentz contract. To appeal to any further details of the laws that govern the cohesion of these bodies would be a mistake. (82)

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SUCH 'DYNAMICAL' EXPLANATIONS ARE NOT CONSTRUCTIVE

[O]ne might be tempted to deny that explanations which appeal to an explanans as non-concrete as the symmetries of the laws are genuinely constructive explanations. In other words, it turns out that there are even fewer contexts than one might have at first supposed in which length contraction stands in need of a constructive-theory explanation. (82–83)

A FOR NOW ANONYMOUS ILLUSTRATION

[An appropriately accelerated rod undergoes] "a sort of real physical contraction, which is itself caused by the interatomic forces binding the rod together into a rigid body"

- Why?

Our author concedes that one could do a Bell-style analysis, case-by-case, but stresses that one can also give a general argument:

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Our author concedes that one could do a Bell-style analysis, case-by-case, but stresses that one can also give a general argument:

“The key to a general analysis lies in the notion of a *rigid* body…a rigid body has an *equilibrium state* that it tends to maintain in the face of (sufficiently small) external forces, and it returns to that state when the external forces have been removed…
Complete physical understanding of an equilibrium state would require a complete account of the internal structure of the rigid system, both its composition and the forces among its parts. But even absent such a detailed account, we can make some general assertions about rigid bodies in any Special Relativistic theory.”

OUR AUTHOR APPEALS TO LORENTZ INVARIANCE

Suppose a system has an equilibrium state that it tends to maintain when it is free of external forces (and hence in inertial motion). Let's call the equilibrium state S_{EQ}. In a given Lorentz coordinate system, such as the rest frame of the system, S_{EQ} will have a particular coordinate dependent description…

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Now consider a *different* physical state S' related to S_{EQ} as follows: S' has the same coordinate-based description relative to a *different* Lorentz coordinate system as S_{EQ} has relative to its rest frame.…

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It follows, for *any* relativistic force laws, that S' will also be an equilibrium state, and that a system near the state S' and free from external forces will tend to go into the state S' [because] the laws of physics take exactly the same coordinate-based form when stated in a coordinate-based language in an Lorentz coordinate system [aka the Lorentz-invariance of the laws]. So the behaviour of S' described in terms of the new Lorentz coordinates will be identical to the behaviour of S_{EQ} described in terms of the old coordinates.

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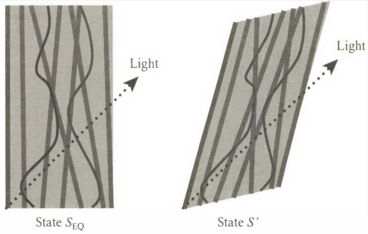


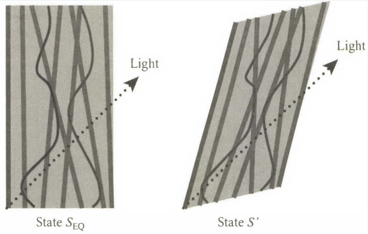
S_{EQ} an equilibrium state of system S.

K an inertial coordinate system adapted to the rest frame of S_{EQ}

K' A coordinate system Lorentz-boosted relative to K

S' The state of S that has the same description relative to K' as S_{EQ} has relative to K.

THE KEY CLAIM: If the fundamental laws are relativistic, S' will also be an equilibrium state. *More specifically, "the behaviour of S' described [wrt K']…will be identical to the behaviour of S_{EQ} described [wrt K]."*



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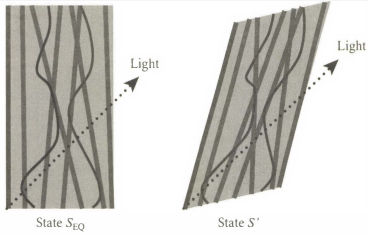

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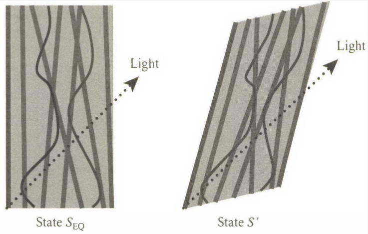

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Maudlin (2012, 116–9)

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  - “Minkowski geometry takes exactly the same form described in either Lorentz coordinate system (by the symmetry of Minkowski space-time)”
  - “the laws can only advert to the Minkowski geometry”
- In other words, Maudlin argues that: the symmetries of spacetime explain the symmetries of the laws.

"Does the Minkowskian nature of spacetime explain why the forces holding a rod together are Lorentz invariant or the other way around?…Our intuition is that the geometrical structure of space(-time) is the *explanans* here and the invariance of the forces the *explanandum*"

(Balashov and Janssen, 2003, 340)

MINKOWSKI SPACETIME: CART OR HORSE?

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- Can we make sense of the claim that the dynamical symmetries are what they are because the symmetries of spacetime structure are what they are?
- "Here we are at the heart of the matter. It is wholly unclear how this geometrical explanation is supposed to work." (Brown, 2005, 134–5)

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- It is simply more natural and economical—better philosophy, in short—to consider absolute space-time structure as a codification of certain key aspects of the behaviour of particles (and/or fields) (Brown, 2005, 25)

THE REAL ROLE OF INERTIAL STRUCTURE

- In pre-GR physics, the primary role of inertial structure is not to encode the behaviour of force-free bodies
- *Prima facie*, it is genuinely explanatory

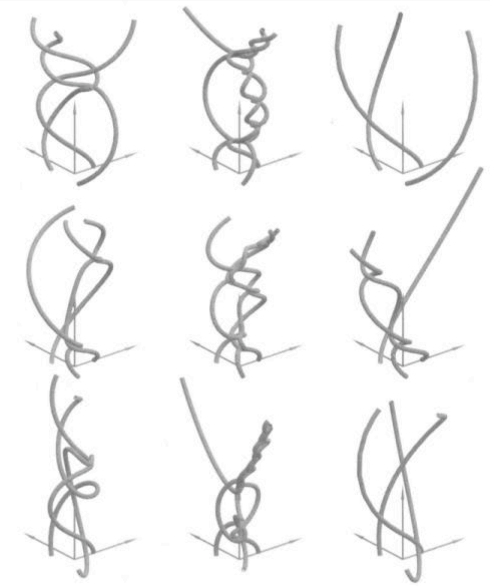

Image from Barbour's *End of Time*

“the consensus view in foundational work on how the coordinate-based approach is to be understood” (Wallace, 2016, 3)

- Identify the spacetime symmetry group as the subgroup of the diffeomorphism group which leaves the (other) absolute spacetime structures invariant
- If the equations defining the theory are expressed with respect to two coordinate systems related by an element of the spacetime symmetry group, then the numerical values of the components of the absolute objects will be the same in each
- In particular, if there are some coordinate system in which those components take a particularly simple form, then we will actually have found a family of such coordinate systems – and the standard coordinate-based way of writing a theory is to be understood simply as the differential-geometric theory described with respect to one of these simplifying coordinate systems.

(Adapted from Wallace. Cf Pooley, 2013, 84–85; Pooley, 2017, §10) "the consensus view in foundational work on how the coordinate-based approach is to be understood" (Wallace, 2016, 3)

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ASSESSING THE EXPLANATION

- If one grants the non-derivative existence of spacetime structure, and grants the advocate of the geometric approach's understanding of the laws as (in part) intrinsically characterisable constraints on how the dynamical content of the world must be adapted to that structure, then it is hard not to concede that one has a genuine (non-causal) explanation.
- It allows that the dynamical symmetry group might be a proper supergroup of the symmetries of the postulated structure (e.g., massless Klein–Gordon theory in Minkowski spacetime). This motivates seeking a formulation of the theory with less postulated structure (in order to satisfy Earman's symmetry principle SP1).
- The explanation does not rule out that more specialised (or other) coordinate systems might be preferred for other reasons.
  - Jacobson–Mattingley theory (timelike A^μ)
  - TeVeS and other bimetric theories.
  - A system of equations not all of which exploit all the structure

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GEOMETRY AS DERIVATIVE ON SPACETIME SYMMETRIES

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For this to provide us with the basis of a reductive account of spacetime geometry in terms of symmetries, we need an independent handle on those symmetries.

ON THE PROPRIETY OF COORDINATE-BASED PRESENTATIONS

Wallace's characterisation of the "coordinate-based" approach:

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- Identifying structure as whatever is invariantly definable in the preferred coordinate systems erases distinctions one might like to draw within that structure (e.g., causal connectability versus timelike inertial lines versus Minkowski distance ratios)
- As a fundamental description of a non-Humean lawlike constraint on how the field must be, it looks nasty ("heavy duty Plantonism")

ARNTZENIUS ON THE GENERAL STRATEGY PLOY

> [S]uppose I were to claim that the world is pretty much as you think it is, except that [chairs] do not exist. I then go on to claim that the true theory of the world is that there are no [chairs], and that the true theory of the world merely says that the things and properties and relations that there are (namely, everything other than [chairs] and their properties) are embeddable in a non-existing make-belief world which includes [chairs] and in which your favourite make-belief laws hold. It seems obvious to me that such a theory is not simple in the sense relevant to evaluation how good such a theory is, and that one should not believe that it is true. Theft is theft. Honest toil is honest toil.
>
> (Arntzenius, 2012, 170)

HOW TO MAKE IT MORE PALETABLE

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Superhumeanism

From the totality of natural phenomena it is possible…to derive…a system of reference x, y, z, t…by means of which these phenomena then present themselves in agreement with definite laws. But when this is done, this system of reference is by no means unequivocally determined by the phenomena. *It is still possible to make any change in the system of reference that is in conformity with the transformations of the group G_c, and leave the expression of the laws of nature unaltered.* (Minkowski, 1908, 79)

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THE DYNAMICAL APPROACH AS REGULARITY RELATIONALISM

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Hmmmm…

OUTLINE

1. Common Ground
2. The Spacetime Explanation of Dynamical Symmetries
3. The Dynamical Explanation of Spacetime Geometry
4. Dynamical Geometry and the Status of $g_{\mu\nu}$

One could pursue a similar programme in GR. Local lorentz charts would be underpinned via patterns in the distribution of fields other than $g_{\mu\nu}$. These would in turn underpin the existence of $g_{\mu\nu}$. A further global pattern involve this defined entity would then provide a Humean underpinning of Einstein's field equation.

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The advocate of the geometrical approach agrees…for the most part.

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