Advanced Philosophy of Physics: The Dynamical Approach to Spacetime

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MT20-W4

The plan

W1: The philosophy of symmetries

W2: The hole argument

W3: General covariance and background independence

W4: The dynamical approach to spacetime

Today

Introducing the dynamical approach

Metaphysics of the dynamical approach

Spacetime and explanation

General relativity and relationalism

Chronogeometric significance

Spacetime functionalism

Conclusions

Today

Dynamicists...





...versus geometricians

Cutting to the chase

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2. No piece of spacetime structure, whether fixed or dynamical (in the latter case, as in general relativity (GR)) is necessarily surveyed by physical bodies; rather, in order to ascertain whether this is so, one must attend carefully to the details of the dynamics governing the particular matter fields which constitute physical bodies. (Butterfield 2007: "Brown's moral".)

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- That is, the dynamical laws are (at least relatively) fundamental, and spacetime structure is derivative; in this sense, the view is a modern-day form of relationalism (Pooley 2013, §6).
- Warning: the opposing geometrical approach, according to which spacetime explains the behaviour of matter, isn't straightforwardly to be associated with substantivalism (we'll come back to this).

Today

Metaphysics of the dynamical approach

How, exactly, is the ontological reduction of fixed spacetime structures to dynamical symmetries supposed to work, for proponents of the dynamical view?

We'd like to put more metaphysical meat on the bones here.

Dynamical and spacetime symmetries

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- *Spacetime symmetries* are transformations which preserve a specified piece of geometrical structure.
  - Example 1: The symmetries of Gailean spacetime are (no surprises) the Galilean transformations.
  - Example 2: The symmetries of Minkowksi spacetime are the Poincaré transformations.

Earman's adequacy conditions

Famously, Earman (1989, p. 46) declared that spacetime symmetries should match dynamical symmetries in any given theory $\mathcal{T}$:

SP1: Any dynamical symmetry of $\mathcal{T}$ is a spacetime symmetry of $\mathcal{T}$.

SP2: Any spacetime symmetry of $\mathcal{T}$ is a dynamical symmetry of $\mathcal{T}$.

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- ~~SP1~~ means that there are some dynamical symmetries which are not spacetime symmetries—so there is undetectable spacetime structure. (Violates Occamist norm—cf. (Dasgupta 2016).)
- ~~SP2~~ means that there are measurable nonexistent geometrical quantities. (Belot 2000, p. 571: "arrant knavery").

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- *Geometrical approach*: Spacetime *explains* why the dynamical symmetries are what they are.
- *Dynamical approach*: Dynamical symmetries *explain* why spacetime structure is what it is.

Brown and Pooley on the geometrical approach

As a matter of logic alone, if one postulates spacetime structure as a self-standing, autonomous element in one's theory, it need have no constraining role on the form of the laws governing the rest of the theory's models. So how is its influence supposed to work? Unless this question is answered, spacetime cannot be taken to explain the ... covariance of the dynamical laws.

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>
> *From our perspective ... the direction of explanation goes the other way around. It is the Lorentz covariance of the laws that underwrites the fact that the geometry of spacetime is Minkowskian.* (Brown and Pooley 2006, p. 84)

Legitimate concerns

How, metaphysically, is the dynamical approach supposed to work here? Can one in fact state dynamical laws, or understand them as ‘obtaining’, without presupposing facts about spacetime structure?

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Clear connections with the dynamical/geometrical debate.

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- This seems to be exactly what proponents of the dynamical approach need!

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  1. when the field is described using a member of the class, it turns out that its values at spacetime points satisfy some simple/elegant mathematical equation; and
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  2. the members of the class are related by a certain symmetry group.
- If this is so, then the simple/elegant equation can be taken as expressing a dynamical law for the world of this mosaic, and the symmetry group of the law can be seen as capturing the *derivative*, not intrinsic, spacetime structure of the world.

Regularity relationalism references

For more on regularity relationalism and the dynamical approach, see Huggett (2009), Pooley (2013), Stevens (2020).

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Let's focus on this latter issue in more detail.

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Apparent problem cases for the geometrical view

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1. Newtonian gravity in Newtonian spacetime. (Read 2020a)
2. Ether theories. (Cheng & Read 2020)
3. The Jacobson-Mattingly theory. (Brown 2005)
4. Universally coupled massive scalar gravity. (Pitts 2019)
5. Clocks in Gödel spacetimes. (Menon *et al.* 2019)

Etc. etc. etc.

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- Cases in which spacetime symmetries do not align with dynamical symmetries. (A failure of the designated structure to be *theoretical spacetime*.) [Cases (1)-(3).]
- Cases in which spacetime symmetries *do* align with dynamical symmetries, but nevertheless in which rods and clocks built from matter do not survey (i.e., read off intervals of) the designated structure. (A failure of that designated structure to be *operational spacetime*.) [Cases (4), (5)]

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Let's focus first on failures of the designated structure to be theoretical spacetime.

In defence of the geometrical view

- One might take the geometrical position not to be that a certain piece of geometrical structure (e.g., the Minkowski metric of SR) invariably constrains matter, whenever it is present in a theory, to manifest its symmetries (a claim which seems to be false, in light of the above cases) ...

In defence of the geometrical view

- One might take the geometrical position not to be that a certain piece of geometrical structure (e.g., the Minkowski metric of SR) invariably constrains matter, whenever it is present in a theory, to manifest its symmetries (a claim which seems to be false, in light of the above cases) ...
- ... but rather to be a conditional claim: *if* one has matter which couples to this piece of geometrical structure in such-and-such a way, *then* that geometrical structure can explain why the laws have the such-and-such symmetries.

Maudlin's geometrical view

... the fundamental requirement of a relativistic theory is that the physical laws should be specifiable using only the relativistic spacetime geometry. For Special Relativity, this means in particular Minkowski spacetime. (Maudlin 2012, p. 117)

Qualified and unqualified geometrical approaches

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Claim: the qualified geometrical approach is a perfectly legitimate position to hold.

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- ... but can maintain that this doesn't render illegitimate using that structure to explain (say) the symmetries of the laws.

Varieties of explanation

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Can we say more about the *kind* of explanation at play here?

Constructive explanations

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- This is a sense of explanation in which phenomenological effects are explained by reference to real (but possibly unobservable) physical bodies.

Types of explanation and the geometrical approach

- If a qualified geometrician is a substantivalist, then she can offer constructive explanations of certain physical effects exhibited by matter ("matter couples to this substantial metic field; that explains why its laws have such-and-such symmetries, and so in turn explains why we witness such-and-such effects").

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- Otherwise, she cannot offer constructive explanations of these effects.
- Even if the qualified geometrician does not hypostatise spacetime, and so concedes that spacetime cannot offer constructive explanations of the behaviour of matter, it is not obvious that spacetime cannot still offer other kinds of explanation. (Cf. Acuña 2016; Read 2020b).

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For more on these matters, see (Read 2020b).

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- We've seen how the dynamical approach, *qua* programme of ontological reduction, can be understood as a form of regularity relationalism.
- We've witnessed Brown and Pooley's concerns about the ability of spacetime to explain facts about the behaviour of matter—but have now seen that the qualified geometrical approach is immune from these critiques.
- We've also seen different senses in which spacetime might be explanatory of facts about the dynamics, on the qualified geometrical approach.

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- However, caution is needed here, for this is a very different sense of relationalism to that discussed previously!
- In particular, in the context of GR—and in significant contrast with his approach to theories such as SR—Brown makes no claim that the metric field should be ontologically reduced to properties of (the laws governing) matter fields!

Regularity relationalism and dynamical spacetimes

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- In GR, one does recover *locally* privileged coordinate systems (see below), so one could *locally* apply regularity relationalism—but it's not obvious how to extend this to be a compelling relationalism story of the metric field of GR in its entirety.

The thin line between dynamical and geometrical approaches

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But then, if Brown reneges on (1) in GR, is there really any difference between the dynamical and geometrical approaches in the dynamical spacetime context?

Pooley's concern

What, then, is at stake between the metric reifying relationalist and the traditional substantivalist? Both parties accept the existence of a substantival entity, whose structural properties are characterised mathematically by a pseudo-Riemannian metric field and whose connection to the behaviour of material rods and clocks depends on, inter alia*, [facts about the dynamics of matter]. It is hard to resist the suspicion that this corner of the debate is becoming merely terminological.* (Pooley 2013, p. 63)

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> *chronogeometrical significance of the $g_{\mu\nu}$ field is not an intrinsic feature of gravitational dynamics, but earns its spurs by way of the strong equivalence principle.* (Brown 2005, p. 151)

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- There are *lots* of delicate issues regarding making this precise: see e.g. (Read *et al.* 2018) for discussion.

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1. By the SEP, dynamical laws governing matter fields take locally a Poincaré invariant form.
2. By the existence of Riemann normal coordinates, the metric field of GR takes locally a Minkowskian form.
3. Therefore, dynamical symmetries coincide locally with metric symmetries.
4. Therefore, the metric field (at least locally) comes to acquire its chronogeometric significance.

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- (1) and (2) above are not sufficiently well-defined. (Weatherall 2020)
- The inference to (4) is too fast: it presupposes also the existence of stable rods and clocks—in which case, why bother with the SEP?
- There are other accounts of how the metric field acquires chronogeometric significance—e.g., the appeal to Ehlers-Pirani-Schild constructive axiomatics, which states that, given the trajectories of massive and massless particles, one can recover the metric. (Ehlers *et al.* 1972)

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- There are no *a priori* restrictions on the behaviour of matter in GR—so the SEP is best understood as an additional input assumption in the theory.
- One might then ask whether one can explain the SEP by looking to successor theories to GR: (Read 2019) answers affirmatively by looking to perturbative string theory; (Salimkhani 2020) answers affirmatively by looking to (classical and quantum) theories of spin-2 gravity.

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- How Brown argues that the chronogeometric significance in GR is inherited via the SEP—but that there are concerns about this line of reasoning.

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- How Brown argues that the chronogeometric significance in GR is inherited via the SEP—but that there are concerns about this line of reasoning.
- That *explaining* the SEP in GR might require appeal to some deeper theory.

Finally, let's consider how the dynamical approach relates to the project of *spacetime functionalism*.

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- The idea behind spacetime functionalism is this: ‘spacetime’ is to be defined as whatever plays an antecedently-designated functional *role* of spacetime.
- For Knox, that role is to ‘pick out a structure of local inertial frames’—roughly, it’s for a structure to pick out the symmetries of the dynamical laws governing matter.

Spacetime functionalism

> *I propose that the spacetime role is played by whatever defines a structure of local inertial frames.* (Knox 2019, p. 122)

- The idea behind spacetime functionalism is this: 'spacetime' is to be defined as whatever plays an antecedently-designated functional *role* of spacetime.
- For Knox, that role is to 'pick out a structure of local inertial frames'—roughly, it's for a structure to pick out the symmetries of the dynamical laws governing matter.
- I.e., it's for a structure to qualify as 'theoretical spacetime', in the sense introduced earlier.

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- Though related (especially to (2)), Knox's work is distinct from either of these. (Read & Menon 2019, §7).

Today

Introducing the dynamical approach

Metaphysics of the dynamical approach

Spacetime and explanation

General relativity and relationalism

Chronogeometric significance

Spacetime functionalism

Conclusions

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- Seen the problems for the ontological reduction aspect of the dynamical approach in GR.
- Thought about different ways in which the metric field of GR might be said to acquire its chronogeometric significance.
- Seen something of the differences between the dynamical approach spacetime functionalism.

To-do list

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2. Articulate the SEP with a sufficient level of mathematical rigour to overcome the concerns of e.g. (Weatherall 2020).
3. Explore systematically the different ways in which the metric field of GR might be said to acquire its chronogeometric significance.

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