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Similarity Assessments, Spacetime, and the Gravitational Field: What Does the Metric Tensor Represent in General Relativity?

Aim and scope of the talk

My topic is the interpretation of the metric tensor of general relativity (GR) in the context of the philosophical literature on substantivalism.

I will be primarily talking about the debate that stemmed from Earman and Norton's (1987) reformulation of the hole argument, where the problem was introduced as the question of how to understand the ontological significance of a standard GR-model $\langle M, g_{ab}, T_{ab}\rangle$ from a substantivalist point of view.

What does g_{ab} represent?

The received view: the metric tensor g_{ab} –or, if you prefer, the pair $\langle M, g_{ab}\rangle$– specifies the fundamental geometrical properties of spacetime. "Space[time] acts on matter, telling it how to move. In turn, matter reacts back on space[time], telling it how to curve" (Misner, Thorne, and Wheeler 1973, p. 5).

The field interpretation: g_{ab} represents a physical field. Einstein's field equations describe the interaction between this special field –the gravitational field– and the more familiar physical fields that T_{ab} serves to represent.
(see Rovelli 1997, Brown 2005, chapter 9)

A shift in the philosophical literature

The question of whether g_{ab} represents a spacetime or a physical field is substantial. What is the most reasonable understanding of substantivalism in the context of GR?

Manifold substantivalism *versus* metric field substantivalism. (Earman and Norton 1987, Maudlin 1988/1989, Hoefer 1996/1998).

Such a question is not substantial. It is ultimately "a matter of whim" (Rynasiewickz 1996, p. 299), "a matter of taste" (Rovelli 1997, p. 193), "irrelevant, and probably a conventional stipulation" (Slowik 2005, p. 154), a "merely verbal question, with no determinate answer […] and also no theoretical importance" (Greaves 2011, p. 197), and "it is hard to resist the suspicion that this corner of the debate is becoming merely terminological" (Pooley 2013, section 7). See also Dorato 2002/2008.

Offensive-move arguments

Do we have grounds to choose between the two interpretations of g_{ab}? What kinds of reasons can be offered to endorse one interpretation rather than the other?

Let us examine Hoefer's reasons for metric field substantivalism (the received view) in his reply to Rynasiewickz:

> Why is it proper to view g_{ab} as the representor of substantival spacetime? The metric's role is exactly to give us the details of the structure of 4-D, curved spacetime. It determines the spacelike-timelike distinction, determines the affine connection or inertial structure of spacetime […] and determines distances between points along all paths connecting them. In all these ways, the metric is perfectly analogous to Newton's absolute space and time.
>
> By contrast, to talk of the metric field as though it were a *physical* field –something of a cousin to the electromagnetic field, say– is awkward and unnatural. It is called the metric 'field' simply because it is represented by a rank-2 symmetric tensor, as is the main field (this time genuinely material) in GTR, the stress-energy field T_{ab}. Whereas the classical concept of a field is that of something *in* space and time, whose properties vary with location in a space and time that could just as well exist without the field, the metric is not *in* spacetime, and spacetime cannot be imagined to exist if it were 'removed'. [Hoefer 1998, p. 459]

Let us call $R(g_{ab})$ the representatum of g_{ab}. Hoefer claims that $R(g_{ab})$:

[1] has a four-dimensional structure that is rich enough to fix the most fundamental spatiotemporal facts of GR (e.g. the past/future distinction or the distiction between spatial and temporal directions)

[2] does not exist *in* spacetime (presumably because M is too impoverished to be reasonably viewed as a spacetime representor)

[3] does not vanish in any GR-physically-possible-world (unlike T_{ab})

In virtue of feature **[1]**, $R(g_{ab})$ looks like a pre-GR space[time] (Newton's space and time, Neo-Newtonian spacetime, Minkowski spacetime). In virtue of features **[2]** and **[3]**, $R(g_{ab})$ looks different from any ordinary matter field.

But the advocate of the field interpretation can counterattack by pointing out other relevant features of $R(g_{ab})$ that speak for her own view.

> In general relativity, the metric/gravitational field has acquired most, if not all, the attributes that have characterized matter (as opposed to spacetime) from Descartes to Feynman: **[4]** it satisfies differential equations, **[5]** it carries energy and momentum, and, in Leibnizian terms, **[6]** it *can act and also be acted upon*, and so on. [Rovelli 1997, p. 193. The numbers are my addition]

[4] - **[6]** are prototypical features of matter that pre-GR space(s)[times] do not have.

Similarity-assessent and categorization

We have a categorization problem. Consider a familiar domain of discourse where a concept C clearly applies to an object O. O has features $F_1,\ldots, F_n$ and $G_1,\ldots, G_n$. Consider now a new domain of discourse where there is an object O^* that has features $F_1,\ldots, F_n$, lacks $G_1,\ldots, G_n$, and has also other features $H_1,\ldots, H_n$ that were associated to another concept C' in the original domain. Does O^* fall under C?

Analogical reasoning has been investigated in cognitive psychology (see e.g. the work of Dedre Gentner). Moreover, similarity-assessment is at the core of two major approaches to human categorization: prototype theories and exemplar theories.

A categorization judgment based on similarity-assessments can be more or less compelling depending on two factors. **First,** the number of features that are shared by *O* and *O** is relevant to determine whether *O** falls under *C*. **Second,** features have different weights. Some features are more significant than others. The presence of shared high-weight features between *O* and *O** increases the acceptability of the judgment that *O** is a *C*. Similarly, if some high-weight features of *O* are features that *O** lacks, then the acceptability of the claim that *O** is not a *C* increases.

Defensive-move arguments

In brief, features **[4]** - **[6]** pose a challenge for metric field substantivalism. The defensive-move arguments seek to dispel this kind of worry.

First defensive move: the bite-the-bullet reaction

The argument: The metric tensor g_{ab} represents a special kind of spacetime. Unlike pre-GR space(s)[times], it has features such as **[4]** - **[6]**. But these features just make it more substantial.

Hoefer relied on this line of argument:

> Substantivalists should count the manifold *with* metric as representing space-time; and <u>if this means that space-time can have energy content, so much the better –it makes space-time all the more substantial.</u> [Hoefer, 1996, p. 13]

> For classical GTR, the only reasonable interpretation of the metric is to view it as a modern correlate of Newton's absolute space and time. <u>It is different: it not only affects matter but is apparently affected *by* matter in turn; arguably it may even have energy content of its own. These differences only make it *more* substantial.</u> [Hoefer, 1998, p. 459]

> *Objection 1:* The metric is mathematically just like the tensors representing other physical fields. The physical field it represents propagates, carries energy, etc. Therefore the field must not be essential to space-time.

Maudlin also seems to rely on it in arguing against manifold substantivalism.

> I *answer that* this is a *non sequitur*. It only shows that, *pace* Newton, space-time has physical features which make it quite akin to other physical objects. All the more reason to regard it as a substance on a par with tables and chairs.
>
> […]
>
> *Objection 3a:* Gravitational waves suggest that we cannot distinguish between the spatio-temporal and other aspects or properties of the universe.
>
> I *answer that* in ordinary English, we have clear paradigms of spatio-temporal properties: distance, elapsed times, etc. We can easily determine which mathematical structures in a theory represent information about these properties […] If this is an energy-bearing structure, all the better for substantivalism, as per the response to Objection 1. [Maudlin, 1989, p. 546-547]

One problem: this move does not seem to be fair to the dialectycs of the debate. The more $R(g_{ab})$ resembles an ordinary matter field, the more reason we have to reject the received view and opt for the field interpretation of g_{ab}.

Another problem: the advocate of the field interpretation can mimic this maneuver by claiming that g_{ab} stands for a physical field of a special kind.

> The fact that g_{ab} cannot vanish anywhere in spacetime makes it unlike any other physical field, as does the fact that it couples with every other field. Gravity is different from the other interactions, but this doesn't mean that it is *categorically* distict from, say, the electromagnetic field.
> [Brown 2005, p. 159]
>
> This is not to say that the gravitational field is *exactly* the same object as any other field. The very fact that it *admits* an interpretation in geometrical terms witnesses to its peculiarity. But this peculiarity can be understood as a result of the peculiar way it couples with the other fields. [Rovelli 1997, p. 194]

Second defensive move: the denial reaction

An alternative way in which the metric fiel substantivalist can react to the challenge posed by **[4]** - **[6]** is by denying that $R(g_{ab})$ really has all these features.

An argument: Hoefer (2000) has defended the denial reaction with respect to **[5]**. He argues that we have good reasons to abandon the energy-momentum conservation principle of GR. Absent this principle, there is no need to regard $R(g_{ab})$ as a carrier of energy-momentum.

A problem: Hoefer's argument has the form of a dilemma. Either we reject the energy conservation principle of GR or we accept the existence of non-localisable gravitational stress-energy. As with other dilemmas, one can choose which horn one wants to avoid.

The moral of the discussion

The choice between the received and the field interpretations of g_{ab} is undertermined by the relevant similarity facts.

I have argued for this claim by showing that the ofensive-move and defensive-move arguments do not confer a dialectical advantage on metric field substantivalism. The field interpretation of g_{ab} can be defended by using parallel and equally persuasive arguments.

Two conclusions

1.) Similarity-assessments belong to the space of reasons. The question of whether g_{ab} represents a spacetime or a matter field is not merely verbal in the sense of being just a matter of stipulation.

2.) Our discussion vindicates the appearance of insubstantiality of the debate. There is a form of conceptual underdetermination that affects the concepts of spacetime and physical field in the context of GR.

The logical space

Pluralism: There is more than one reasonable way of understanding the ontological import of g_{ab}.

But one can have (external) reasons to prefer one interpretation.

(i) g_{ab} represents a spacetime (but not a physical field)
[Pooley 2013, section 7?]

(ii) g_{ab} represents a physical field (but not a spacetime)
[Rovelli 1997, Brown 2005?]

(iii) g_{ab} represents both a spacetime and a physical field
[Dorato 2000, p. 1611, 2008, pp. 27, 32]

(iv) g_{ab} neither represents a spacetime nor it represents a physical field
[Rynasiewicz 1996]

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