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

David Rey

LOGOS - University of Barcelona

dareys@gmail.com

Abstract: In this paper I explore the dialectics underlying the choice between a geometrical and a field interpretation of the metric tensor g_{ab} in general relativity. My aim is to examine the role of a specific type of reasoning process (which I call 'similarity-based reasoning') in interpreting g_{ab}. In recent years, philosophers of physics have claimed that the problem of choosing between the two interpretations in question is somehow insubstantial. This appearance of insubstantiality, I contend, stems from a basic form of underdetermination that affects the concepts of spacetime and physical field in the context of general relativity.

Keywords: general relativity, metric tensor, similarity-based reasoning

1. Two Ways of Interpreting General Relativity

It is often said that the general theory of relativity (henceforth GR) posits a curved four-dimensional spacetime. According to a widespread interpretation of the theory, there is a deep nomological connection between the material contents and the geometrical structure of spacetime. The key insight behind GR is that the curvature of spacetime both determines the gravitational trajectories of material bodies and is partially determined by matter distribution. As Misner, Thorne, and Wheeler put it: "Space[time] acts on matter, telling it how to move. In turn, matter reacts back on space[time], telling it how to curve" (1973, p. 5). Gravity effects do not arise from attraction forces *à la* Newton. Rather, gravitation exists because spacetime interacts with matter in the ways predicted by the theory. Einstein's field equations –the theoretical core of GR– describe the influence of matter on spacetime geometry. Is this the picture of physical reality that GR conveys? GR's formalism consists of certain mathematical objects defined on a four-dimensional differentiable manifold M –roughly, a set

of points endowed with a basic geometrical structure. One of these objects –the stress-energy tensor T_{ab}– serves to represent ordinary matter, which exists in the form of physical fields. Central among the other objects is the metric tensor g_{ab}. The metric specifies the distances between manifold points belonging to the same tangent space. In doing so, it enriches the geometry of M, turning it into a Lorentzian manifold $\langle M, g_{ab} \rangle$ with a fixed curvature and Minkowski light-cone structures assigned to its tangent spaces. If the geometrical machinery employed in the formalism of GR is taken at face value, it is natural to view the manifold points of M as representing spacetime points, and g_{ab} –or perhaps $\langle M, g_{ab} \rangle$– as encoding the geometrical properties of spacetime, while the stress-energy tensor T_{ab} represents the distribution of matter across spacetime. The equations of the theory can thus be viewed as relating matter distribution to the curvature of spacetime.

But GR has also a field-theoretical dimension. Relying on the field-theoretical aspects of GR's formalism, some theorists have challenged the received reading of the theory[1]. On an alternative interpretation of GR, Einstein's field equations describe the interaction between a fundamental physical field –the so-called gravitational field– and the more familiar fields represented by T_{ab}. Such field-to-field interaction is what explains gravitational phenomena, as well as the relativistic behavior of rods and clocks. Thus, the basic ontological picture emerging from GR involves a gravitational field coupling with other physical fields in conformity with Einstein's equations. The formal object encoding the physically relevant properties of the gravitational field is the metric tensor g_{ab}.

In brief, GR poses an interpretational problem. As our preliminary discussion has shown, this problem manifests itself with special clarity when we try to assess the role of the metric tensor in describing physical reality. Must g_{ab} be regarded as representing spacetime? Or, alternatively, must g_{ab} be viewed as representing a gravitational field? Even though the existence of both alternatives has been acknowledged in the philosophical literature, especially in connection with issues revolving around the substantivalism/relationism debate, there have been virtually no attempts of comparing them in a systematic way. A welcome exception is [Lehmkuhl 2008]. Following Lehmkuhl's excellent discussion, I will distinguish between a geometric and a field interpretation of the metric

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[1] Prominent examples are Feynman (see Feymman et al. 1995) and Rovelli (1997, pp. 183-195). See also Earman and Norton 1987, pp. 518-520, and Brown 2005, chapter 9.

tensor g_{ab} –and of GR[2]. The former conceives of g_{ab} as representing spacetime, whereas the latter conceives of it as representing a gravitational field. Do we have grounds to choose between these two interpretations? What kinds of reasons can be offered to adopt one interpretation rather than the other? In this paper I will propose an account of the dialectical situation underlying the choice between the field interpretation and the geometric interpretation of g_{ab}. Lehmkuhl analyzes the dialectics of this theoretical choice in terms of the explanatory power possessed by the different objects of GR's formalism. In contrast to this approach, I want to suggest that our primary source of evidence in deciding between different interpretations of g_{ab} is a form of argumentation that I will call *similarity-based reasoning*.

The question of whether g_{ab} represents spacetime or a physical field gained prominence during the late eighties and nineties, when philosophers of physics turned their attention to Earman and Norton's reformulation of the hole argument. In more recent years, though, a recurrent theme in the literature has been that the choice between a geometric and a field interpretation of g_{ab} is in some way insubstantial. With varying degrees of conviction, philosophers of physics have claimed that this theoretical choice –or, more generally, the choice between the two associated interpretations of GR– 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 2005b, p. 154), or a "merely verbal question, with no determinate answer […] and also no theoretical importance" (Greaves 2011, p. 197)[3]. The appearance of insubstantiality that motivates these claims, I contend, stems from a basic form of underdetermination that affects the concepts of spacetime and physical field in the context of GR. The two remaining sections of this paper will be devoted characterize and defend such form of underdetermination. In section 2 I will explain what is similarity-based reasoning. My primary aim in introducing this notion will be to show that the problem of interpreting the metric tensor g_{ab} can be fruitfully seen as the problem of assessing the similarities between the

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[2] Lehmkuhl considers a third alternative, which he calls the *egalitarian interpretation* of GR. Only the most radical variant of this view, called *strong egalitarianism*, is incompatible with the geometrical and field interpretations of the theory (see Lehmkuhl 2008, section 5). In section 2 of this paper I will present my own taxonomy of the relevant positions.

[3] See also Dorato 2002, 2008, Slowik 2005a, and Pooley 2012, section 7. Needless to say, the quoted authors defend significantly different positions, despite of their agreement regarding the non-substantial character of the choice in question.

representatum of g_{ab} and the posits of some other theoretical framework where we have a better understanding of the space(time)/matter dicotomy –such as Newtonian mechanics or special relativity, both interpreted under a geometric reading. In section 3 I will examine an episode of the philosophical debate that arose from the revival of the hole argument in the modern literature on spacetime theories. By critically examining the dialectics of this episode I shall argue that the choice between a geometric and a field interpretation of g_{ab} is underdetermined by the relevant similarity facts. In virtue of this form of underdetermination, there is more than one reasonable way of understanding the ontological import of g_{ab}.

2. Similarity-Based Reasoning

Similarity-based reasoning is the process by means of which we infer judgments about the correct application of a concept from similarity facts. Let S be a familiar situation –or domain– in which a concept C clearly applies to an object O. This object has features $F_1,\ldots, F_n$ and $G_1,\ldots, G_n$. Consider now a new situation S^* in which there is an object O^* that has $F_1,\ldots, F_n$, lacks $G_1,\ldots, G_n$, and possibly has other features $H_1,\ldots, H_n$ that O does not possess[4]. Given these stipulations, does O^* fall under C? Let us define a similarity-based inference as a transition from the judgment that an object O^* possesses –or lacks– some features to the judgment that O^* falls –or does not fall– under a concept C. Similarity-based inferences have thus the following structure:

Positive form

O^* has $F_1,\ldots, F_n$

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O^* is a C

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[4] This abstract characterization is inspired by Recanati's discussion of Meaning Eliminativism in Recanati 2004, chapter 9. Rynasiewickz (1996) also sees the substantivalism/relationism debate, in the context of GR, as the problem of projecting certain traditional categories –such as the concepts of space and physical object– onto a new theoretical domain.

Negative form

O^* lacks $H_1,\ldots, H_n$
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O^* is not a C

The transition from one judgment to the other must not be understood as a deductive inference. A similarity-based inference can be more or less compelling depending on two factors. First, the number of features shared by O and O^* is relevant to determine whether O^* falls under C. The more features the two objects have in common, the more plausible is the claim that O^* is a C. The less features are shared by the two objects, the more plausible is the claim that O^* is not a C. Second, similarity-based inferences are also sensitive to the weight of the relevant features. Not all features of O are equally relevant in judging whether O^* falls under C. Some features are more significant than others. The presence of shared features with high weight increases the acceptability of the claim 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.

Sometimes, what must be evaluated with respect to a new discursive domain is not the application of a single concept C, but the application of a conceptual distinction involving two concepts C_1 and C_2. Consider the following variant of our pattern: S is a familiar situation in which two distinct concepts C_1 and C_2 respectively apply to two different objects O_1 and O_2. O_1 has features $F_1,\ldots, F_n$ and $G_1,\ldots, G_n$, while O_2 has features $H_1,\ldots, H_n$ and $I_1,\ldots, I_n$. In a source situation S^*, there is an object O^* that is similar to O_1 in some respects and similar to O_2 in other respects. Formally, O^* has features $F_1,\ldots, F_n$, and $H_1,\ldots, H_n$, lacks features $G_1,\ldots, G_n$, and $I_1,\ldots, I_n$, and possibly has other features $J_1,\ldots, J_n$ that O_1 and O_2 do not posses. Let us call 'adjustment' any particular decision as to how to apply C_1 and C_2 to O^*. There are four ways to adjust the C_1/C_2 conceptual distinction to S^*:

(I) O^* is a C_1 (and not a C_2)

(II) O^* is a C_2 (and not a C_1)

(III) O^* is both a C_1 and a C_2

(IV) O^* is neither a C_1 nor a C_2

We can now return to the metric tensor g_{ab} and its two interpretations. Let us call '$R(g_{ab})$' the representatum of g_{ab}. Whereas g_{ab} is a mathematical object of GR's formalism, $R(g_{ab})$ is an inhabitant of the physical world. And let us call '$R(M)$' the representatum of the manifold M. The interpretational problem posed by g_{ab} can then be rephrased as the question of whether $R(g_{ab})$ is a gravitational field or spacetime. Stated in these terms, the problem exemplifies the modified pattern described in the last paragraph. The source situation S is some familiar theoretical framework where the space(time)/matter distinction can be drawn. C_1 and C_2 are the concepts of spacetime and matter. The target situation S^* is GR and the object O^* is $R(g_{ab})$. Advocates of the geometrical interpretation of g_{ab} endorse **(I)**, while advocates of the field interpretation endorse **(II)**. Adjustments **(III)** and **(IV)** have also been endorsed in the literature on GR[5].

In order to evaluate adjustments **(I)** - **(IV)**, the similarities between O^* and O_1, on the one hand, and the similarities between O^* and O_2, on the other hand, must be assessed. Can similarity-based reasoning guide us in choosing between these alternative adjustments? I want to highlight two possible answers to this question:

Unilateralism: Given the relevant similarities, there is only one reasonable way to adjust C_1/C_2 to S^*.

Pluralism: Given the relevant similarities, there is more than one reasonable way to adjust C_1/C_2 to S^*.

In the next section I will argue that pluralism is the right position to adopt with respect to the conceptual distinction and the discursive domain that we have been considering in the present paper. I will defend this claim by arguing that the choice between a geometrical and a field interpretation of g_{ab} is underdetermined by the similarities that $R(g_{ab})$ bears to prototypical fields and

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[5] For a defense of adjustment **(III)**, see Dorato 2000, p. 1611, 2008, pp. 27, 32. For a defense of adjustment **(IV)**, see Rynasiewickz 1996. Adjustment **(III)** corresponds to Lehmkuhl's strong egalitarianism (see Lehmkuhl 2008).

prototypical spatiotemporal structures. My strategy to show that there is such an underdetermination will be to consider the reasons that Maudlin and Hoefer provided in favor of the geometric interpretation of g_{ab} as a response to Earman and Norton's seminal paper on the hole argument. I will then argue that parallel and equally persuasive reasons can be invoked to defend the field interpretation of g_{ab}.

3. The Dialectics behind the Geometric and Field Interpretations

Lawrence Sklar coined the term 'substantivalism' to designate the view that space –or spacetime– is a substance that serves as the container of material objects and that exists independently of them (see Sklar 1976, pp. 161-167). Four our present purposes, substantivalism can be defined as the claim that GR is most plausibly interpreted as positing such a substance. Anti-substantivalism is the denial of this claim. Relationism, which is the most popular form of anti-substantivalism, asserts that all we need in order to make sense of GR are the physical objects and their spatiotemporal relations.

Earman and Norton (1987, pp. 518-520) famously argued for a conception of substativalism on which the manifold M of a GR-model $\langle M, g_{ab}, T_{ab} \rangle$ is what represents substantival spacetime. The metric tensor g_{ab}, they claimed, must be conceived of as standing for a physical field. Critical reactions to this proposal did not take long to come out. During a symposium exchange devoted to Earman and Norton's renewed version of the hole argument, Maudlin (1988) objected that a more credible version of substantivalism conceives of g_{ab} as the representor of spacetime[6]. Some years later Hoefer (1996) joined the discussion by presenting additional arguments in favor of Maudlin's counterproposal[7]. The two proposals in question have been respectively labeled *manifold substantivalism* and *metric field substantivalism.*

Manifold substantivalism: the manifold M of a GR-model $\langle M, g_{ab}, T_{ab} \rangle$ is what represents spacetime. The tensors g_{ab} and T_{ab} stand for the material contents of the universe. They represent physical fields existing in spacetime.

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[6] The other contributions to the 1988 symposium were Norton 1988 and Butterfield 1988.
[7] See Maudlin 1988, 1989, and Hoefer 1996. These three papers were reactions to Earman and Norton 1987. See also Hoefer 1998, which is a reply to Rynasiewicz 1996.

Metric field substantivalism: the metric tensor g_{ab} of a GR-model $\langle M, g_{ab}, T_{ab}\rangle$ is what represents spacetime. Only T_{ab} represents the material contents of spacetime.

Each substantivalist position is associated with one of the two interpretations of the metric tensor g_{ab}. Endorsing metric field substantivalism amounts to adopting the geometric interpretation of g_{ab}. Manifold substantivalism leads us directly to the field interpretation of g_{ab}. But a defender of this interpretation does not need to endorse manifold substantivalism. The reason is that manifold substantivalism is not simply the thesis that g_{ab} represents a physical field. It also says that spacetime is represented by *M*. An advocate of anti-substantivalism might accept the former thesis and reject the latter. Thus, it is worth keeping in mind that, in addition to manifold substantivalism, there is another philosophical position that endorses the field interpretation of g_{ab}.

Metric field anti-substantivalism: the metric tensor g_{ab} represents a physical field and there is no substantivalist spacetime in the ontology of GR.

In what follows I shall discuss Maudlin and Hoefer's main arguments for metric field substantivalism. I will classify these arguments into two categories: *offensive* and *defensive* moves. The former are arguments to the effect that $R(g_{ab})$ is the object that exhibits the most significant features intuitively associated with the concept of space(time). The latter seek to dispel the worry that $R(g_{ab})$ also has some of the features intuitively associated with the concept of physical object.

3. 1. Offensive moves

Let us start with the offensive moves. Maudlin (1988, p. 87) criticized manifold substantivalism by arguing that **[A]** the manifold *M* is too impoverished to specify the most paradigmatic spatiotemporal distinctions and relations; and **[B]** matter-free universes are physically possible according to GR, but the theory does not speak for the possibility of worlds in which there is ordinary matter but $R(g_{ab})$ is absent. Hoefer (1996, pp. 11-13) argued against manifold substantivalism along similar lines. He offered some additional reasons to reject this view and opt for metric field substantivalism: **[C]** while GR allows for

physically possible worlds endowed only with manifold-plus-metrical structure, the physical possibility of worlds endowed only with manifold structure is not guaranteed by GR; **[D]** a basic motivation to endorse substantivalism is the desire to account for physical phenomena such as gravitation and rods-and-clocks behavior, but the formal object of GR that plays a decisive role in explaining these phenomena is g_{ab}; and **[E]** if $R(g_{ab})$ was a physical field, as manifold substantivalism asserts, we would end up with a position that is dangerously close to relationism, since the aforementioned physical phenomena would be explained by resort to the relations between the gravitational field and other material fields.

I am inclined to think that Maudlin and Hoefer are right in claiming that, from a substantivalist perspective, it is more reasonable to view g_{ab} as the representor of spacetime. *Prima facie*, **[A]** - **[E]** provide good evidence for this claim. But, as we have seen, the field interpretation of g_{ab} can survive the rejection of manifold substantivalism. Even if M was definitively ruled out as a plausible candidate for representing spacetime, the advocate of metric field anti-substantivalism would insist that neither M nor g_{ab} represent such a spacetime, on the grounds that g_{ab} is better interpreted as describing the properties of a gravitational field. The force of points **[A]** - **[E]** is reduced, though not eliminated, when their target is metric field anti-substantivalism. A direct argument for metric field substantivalism must show that g_{ab} represents spacetime and not a physical field. Only an argument of this kind would allow us to discard metric field anti-substantivalism, and with it the field interpretation of g_{ab}. So, what we need to know at this point is whether such direct argument can be extracted from **[A]** - **[E]**. In his reply to Rynasiewickz, Hoefer argues directly for metric field substantivalism:

> 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]

Here Hoefer is resorting to similarity-based reasoning. He points out that $R(g_{ab})$ **[1]** has a four-dimensional structure rich enough to fix all the fundamental spatiotemporal facts of GR; **[2]** does not vanish in any physical world deemed possible by GR, and **[3]** does not exist *in* spacetime. In virtue of features **[2]** and **[3]**, $R(g_{ab})$ looks different from any ordinary material field. In virtue of feature **[1]**, it looks like a prototypical spacetime structure, such as Minkowski spacetime. The claim that $R(g_{ab})$ has feature **[1]** is a positive version of point **[A]** and it is justified by the central geometrical role that g_{ab} plays in GR[8]. The claim that $R(g_{ab})$ differs from ordinary fields in that it has **[2]** is a natural interpretation of the basic model-theoretic fact underlying **[B]** and **[C]**, namely that there are models of GR where $T_{ab}(p) = 0$, for every manifold point p, but there are no GR-models such that, for every manifold point p, $g_{ab}(p) = 0$. Feature **[3]** is more controversial and I will not discuss it in what follows.

In short, Hoefer's offensive move consists in attributing features **[1]** - **[3]** to $R(g_{ab})$ and then infer metric field substantivalism by similarity-based reasoning. But similarity-based reasoning is a matter of weighing different features that pull in opposite directions. The advocate of the field interpretation can counterattack by pointing out other relevant features of $R(g_{ab})$ that speak for her own view. This is precisely what Earman and Norton did in their 1987 paper on the hole argument. Since then other theorists have echoed Earman and Norton's remarks.

Rovelli summarizes the essential point in a succinct manner:

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

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[8] Some aspects of the geometry of the Lorentzian manifold $\langle M, g_{ab} \rangle$ are characterized by specific objects of the formalism, such as the Ricci tensor R_{ab} and the Riemann curvature scalar R –both of which appear at the left side of Einstein's equations $R_{ab} - \frac{1}{2} g_{ab} R = k T_{ab}$. Any such object, though, can be derived from g_{ab}. For relevant details, see Wald 1984, chapters 2 and 3.

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]

It is widely acknowledged that $R(g_{ab})$ has features **[4]** - **[6]**. As Rovelli stresses, these are features prototypically associated with the concept of matter and not possessed by paradigmatic spatiotemporal structures like Minkowski spacetime or neo-Newtonian spacetime.

Now, do features **[1]** - **[2]** outweigh **[4]** - **[6]**? That is, do **[1]** - **[2]** tip the balance in favor of the geometric interpretation of g_{ab}? Not surprisingly, Maudlin and Hoefer assert that this is the case[9]. However, as we saw in section 1, the problem of choosing between the geometric and the field interpretation of g_{ab} has been regarded by many theorists as an insubstantial issue. Certainly, the spatiotemporal distinctions, properties, and relations that g_{ab} determines are deeply tied to our intuitive notion of spacetime. We think of spacetime as a structure responsible for fundamental facts such as the very distinction between time and space, the past/future distinction, and paradigmatic relations like temporal order and spatial distance, to name just a few. Hence, **[1]** is a high-weight feature associated with the concept of spacetime. As such, it has an important role to play in deciding what counts as spacetime. **[2]** is not a feature associated with the intuitive concept of physical field. Ordinary material fields do not exist in every physically possible world. Arguably, **[2]** has less weight than **[1]**. But it gives additional support to the claim that $R(g_{ab})$ is spacetime. On the other hand, **[5]** and **[6]** are high-weight features associated with the concept of matter. Material fields are the prototypical entities that possess causal powers and carry energy and momentum. This means that **[5]** and **[6]** must have an important role to play in deciding what counts as a physical field. **[4]** is arguably less closely tied to the concept of material object, but it provides an additional consideration in favor of the view that $R(g_{ab})$ is a physical field. In the light of all these facts, no decision as to how to categorize $R(g_{ab})$ is uncontroversially more justified than the other. One can reasonably choose one of the two interpretations of g_{ab}, but similarity-based reasoning does not guarantee that such interpretation is the only reasonable choice.

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[9] See Maudlin 1988, p. 87, and Hoefer 1998, p. 460.

If we do not want to end up with a clash of intuitions between the authors who claim –as Maudlin and Hoefer do– that features **[1]** - **[3]** outweigh **[4]** - **[6]** and those who reject this claim –like Rovelli and Rynasiewickz–, we need to consider other dialectical strategies. What matters for our current purposes is that **[4]** - **[6]** are paradigmatic features of material fields and, therefore, the advocate of the field interpretation of g_{ab} can make an offensive move perfectly analogous to the offensive move of its contender.

3. 2. Defensive moves

To summarize, features **[4]** - **[6]** pose a challenge for metric field substantivalism. If it is the case that $R(g_{ab})$ has all these features, it can be objected that g_{ab} does not represent spacetime, but a gravitational field. I shall distinguish two strategies upon which Maudlin and Hoefer rely in addressing this objection. I will call them *the bite-the-bullet reaction* and *the denial reaction*.

The bite-the-bullet reaction goes as follows: the metric tensor g_{ab} represents a substantivalist spacetime, but this spacetime is of a very special kind, since it differs from more familiar spatiotemporal containers in that it possesses some matter-like features. Far from shedding doubts on metric field substantivalism, such features give further support to it. For they make GR's spacetime even more substantial. Both Maudlin and Hoefer take this line with respect to features **[5]** and **[6]**[10].

But contrary to what Maudlin and Hoefer suggest, attributing **[5]** and **[6]** to $R(g_{ab})$ does not enhance the acceptability of substantivalism. Rather, these features make metric field substantivalism more controversial, because they create dissimilarities between $R(g_{ab})$ and the paradigmatic pre-GR spacetimes. The more $R(g_{ab})$ resembles a matter field, the less compelling is the view that g_{ab} represents spacetime.

Be this as it may, there is a more fundamental reason why the bite-the-bullet reaction is not a helpful dialectical maneuver. Just as Maudlin and Hoefer can rely on this maneuver to face the threat posed by features **[4]** - **[6]**, so too the advocate of the field interpretation can respond to Maudlin and Hoefer's offensive move by arguing that $R(g_{ab})$ is a physical field of a special kind. This

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[10] See Maudlin 1989, pp. 546-548, and Hoefer 1996, p. 13, 1998, p. 460.

peculiar field differs from other material fields in that it has features **[1]** and **[2]**, but its classification as a physical field is justified in virtue of features **[4]** - **[6]**[11]. Since this field has feature **[2]**, its existence is physically necessary –at least according to GR. However, if we look at things from the standpoint of the field interpretation, the idea of a physical field that exists as a matter of physical necessity is no more bizarre than the idea of a spacetime that is causally efficacious. By virtue of **[1]**, $R(g_{ab})$ exhibits a rich metrical structure. But, as Rovelli (1997, p. 194) points out, classifying $R(g_{ab})$ as a spacetime is not the only way to account for the fact that $R(g_{ab})$ possesses **[1]**. The reason why the gravitational field $R(g_{ab})$ is chosen as the primary bearer of metrical structure is that it has privileged explanatory role in GR, accounting for both gravitational effects and the behavior of rods and clocks. In brief, if biting the bullet is a permissible defensive move, advocates of the field intereptation can make use of it to hold that $R(g_{ab})$ has features **[1]** and **[2]** while still rejecting the conclusion that g_{ab} represents spacetime.

An alternative way to react to the challenge posed by **[4]** - **[6]** is to deny that $R(g_{ab})$ really has all these features. The denial reaction consists in reinterpreting the formalism of GR in such a way that $R(g_{ab})$ does not possess one or more of the features **[4]** - **[6]**. Hoefer (2000) has defended the denial reaction with respect to feature **[5]**. He argues that $R(g_{ab})$ must not be viewed as carrying energy and momentum. What motivates the view that $R(g_{ab})$ has **[5]**, Hoefer suggests, is the principle of energy conservation. But there is no good reason to think that energy-momentum is conserved in GR. If we abandon this principle, he claims, gravity-waves phenomena can be viewed as involving genuine gains and losses of energy.

The problem with the denial reaction is that it reproduces at a new level the kind of interpretational issues that we have considered throughout this paper. Hoefer's worry regarding feature **[5]** is that the stress-energy allegedly carried by $R(g_{ab})$ is described by a pseudo-tensor that is well-defined only in certain specific circumstances (see Hoefer 2000, section 3). To avoid this result, he denies that $R(g_{ab})$ carries any form of genuine energy. However, the solution

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[11] This line of reasoning has been pursued in the literature. Brown (2005, p. 159) makes the point with respect to **[2]**. Rovelli (1997, p. 194) explains why the gravitational field can be seen as possessing **[1]** even if we endorse the field interpretation of GR. His account is based on a relationist reading of the theory, according to which the Leibnizian intuition that dynamical objects move only in relation to one another, without reference to a substantivalist space(time), is vindicated by GR (see Rovelli 1997, pp. 185-191).

proposed by Hoefer comes at a price, because it forces us to sacrifice energy-momentum conservation. What we are witnessing here, I contend, is a similarity-assessment problem, analogous to the problem posed by $R(g_{ab})$ and its features **[1]** - **[6]**. Armed with our intuitive concept of energy, we are asked to decide between an adjustment of this concept that leads us to the non-conservation of energy-momentum and an alternative adjustment that leads us to posit the existence of non-localizable stress-energy –described by the aforementioned pseudo-tensor. Both horns entail some deviation from our pre-GR understanding of the concept of energy. Different theorists will weigh the costs and benefits of each choice in different ways[12]. Since both horns assign to energy strange features not associated with the intuitive concept, similarity-based reasoning does not decisively favor one of the two adjustments of the concept of energy. Consequently, the advocate of the field interpretation of g_{ab} can legitimately endorse the interpretation of the concept of energy on which $R(g_{ab})$ has **[5]**, on the grounds that sacrificing the conservation of energy-momentum is a price too high to pay.

4. Conclusion

In the previous section I examined the offensive and defensive arguments that Maudlin and Hoefer have offered to vindicate the geometrical interpretation of g_{ab}. I argued that the defensive moves do not confer a dialectical advantage on this interpretation. The field interpretation of g_{ab} can be defended by using parallel argumentative maneuvers. The offensive moves, on the other hand, depend upon how the spacetime-like and field-like features of $R(g_{ab})$ are weighed. I argued that these features can be weighed in different ways. Similarity-based reasoning does not yield a unique correct answer in this case. My conclusion is that the choice between the two interpretations in question is undetermined by similarity facts. Assessments of similarities belong to the space of reasons. For similarity-based reasoning can reveal that some adjustments are more compelling than others. But there are limits on what similarity-based inferences can do. Pluralism is the right position to adopt with respect to the present debate.

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[12] *Cf.* Baker 2005, pp. 1305-1306, and Slowik 2005a, pp. 1320.

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