CHAPTER 2

Is Structural Spacetime Realism Relationism in Disguise? The Supererogatory Nature of the Substantivalism/Relationism Debate

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Abstract

In this chapter I position the substantivalism/relationism debate in the wider context of the scientific realism issue, and investigate the place of structural realism in this debate.

This chapter tries to connect the substantivalism/relationism debate to the wider question of scientific realism. Historically, the issue of the reality of spacetime (substantivalism) was certainly fuelled by a more favourable attitude toward scientific realism, which emerged after the crisis of the neopositivistic criterion of meaning during the second half of the 20th century.

However, there are not just historical reasons for exploring the above connection in a more systematic way. On the one hand, within the camp of scientific realism, in the last couple of decades *structural realism* has emerged as a sort of *tertium quid* between a radically sceptical antirealism about science and an allegedly "naïve realism" about the existence of theoretical entities.[1] On the other, difficulties to adjust the substantivalism/relationism dichotomy to the framework of the General Theory of Relativity (GTR) have pushed philosophers of space and time to find alternative formulations of the debate. Among these, various forms of *structural spacetime realism*—more or less explicitly formulated—have been proposed either as a third stance between the two age-old positions (Stachel, 2002; Rickles and French, 2006; Esfeld and Lam, 2006), or as an effective way to overcome or dissolve

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[1] In Worrall's original view (1989), for example, structural realism was meant to give an account of both the predictive success of science and of its continuity across scientific change, while granting Laudan's pessimistic meta-induction against the existence of theoretical entities (Laudan, 1981).

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the substantivalism/relationism debate (Stein, 1967; DiSalle, 1995; Dorato, 2000; Dorato and Pauri, 2006; Slowik, 2006).

The attempt at using structural realism in order to steer a middle course between substantivalism and relationism and to defend a structural form of realism about spacetime, however, raises several questions.[2] One of these is the following: if structural realism claims that "science is about structure", or about physical *relations* that are partially described by our mathematical models of the physical world, in what sense is structural spacetime realism really different from good old relationism?

My main answer to this crucial question will be two-fold:

(1) Viewed from the perspective of the substantivalism/relationism debate, structural spacetime realism (i.e., the claim that spacetime is exemplified structure) is a form of relationism;
(2) However, if we managed to reinforce Rynasiewicz's (1996) point that GTR makes the substantivalism/relationism dispute "outdated", the re-elaboration of Stein's 1967 version of structural spacetime realism to be proposed here proves to be a good, *antimetaphysical* solution to the problem of the ontological status of spacetime.

In short, it is only if we assume that the dispute between substantivalism and relationism is still meaningful also in the context of GTR that structural spacetime realism turns into a form of relationism. But since that dispute will be shown to be unfit for GTR, structural spacetime realism gives a good answer to the problem of the status of spacetime that is neither relationist nor substantivalist, and overcomes both positions.

The chapter is divided into three parts. In the first (Section 1), I briefly review the main positions in the game of scientific realism, with the intent of showing that *if* the substantivalism/relationism is genuine, then structural spacetime realism is a form of relationism (*first claim*). In the second part (Section 2), I reconstruct what I take to be Stein's (1967) position on the ontological status of spacetime and on the related issue of scientific realism. While he in no way was explicitly trying to defend structural spacetime realism as it is now discussed, I will argue that, especially after the onset of GTR, Stein's claim that worrying about the ontological status of the exemplified structure is "supererogatory" (superfluous or otiose) proves quite robust against four foreseeable objections.

Finally, in Section 3, I will show how the duality of the metric field and the difficulties of defending a "container/contained", or a "spacetime/physical field" distinction in classical GTR speak definitely in favour of a dissolution of the substantivalism/relationism debate, and therefore of a structural realist solution to the question of the ontological status of spacetime (*second claim*).

[2] For some of these, see Pooley (2006).

1. THREE FORMS OF SCIENTIFIC REALISM AND THEIR CONCEPTUAL RELATIONSHIPS

Schematically, there are three versions of scientific realism in the current philosophical debate, whose logical and conceptual relationships are the target of ongoing controversies. In this section, I will briefly sketch the three positions, by dedicating somewhat more attention to the tenets of structural realism. This will prove necessary to situate this doctrine in a wider conceptual framework, and thereby gain a deeper understanding of its main implications.

(1) According to *theory realism*, well-confirmed theories are *true*, either *tout court*, or *approximately*, i.e., in the approximation of the model.

The crucial term in this position is obviously "approximately true": if one decides to forgo as being too audacious the claim that theories are true "without qualifications", one encounters various problems in giving a precise account of the notion "approximate truth" (see, for instance, Niiniluoto, 1999, Section 3.5; Smith, 1998, Chapter 5; Psillos, 1999 Chapter 11).[3] Given my purposes, I will simply leave these difficult questions by side, and move on to the second form of scientific realism.

(2) *Entity realism*: "theoretical", *non-directly* observable entities postulated by well-confirmed theories (quarks, muons, electrons, black holes, etc.) have a mind-independent existence.

As is evident, this definition presupposes a distinction between what is observable with the naked eye and what is observable only with the help of instruments. *Entity realists* typically note that electrons *are* observable, albeit indirectly. If the distinction between direct and indirect observability is one of degree and therefore not ontologically significant, in their opinion we should believe in the existence of electrons or quarks for the same reasons that we grant mind-independent existence to tables and chairs: not only do we perceive them (although indirectly), but we measure and manipulate them to obtain our aims. Antirealists about entities typically use evidence from past science to draw our attention to the numerous entities that have been abandoned during its history (flogist, caloric, aether, etc.). They then note that the methodology used by past theories that postulated what we now regard as non-existing entities is the same that we used today. Consequently, according to the entity antirealist, we should abstain from believing in the theoretical components of current physical models, but only accept them as being *empirically adequate* (Van Fraassen, 1980).

(3) Structural realism claims that science is about structures: while structures are real and knowable, entities—*if regarded as endowed only with monadic properties*—are either unknowable or unreal.

Structural realists have not been always very clear about the nature of *physical versus* purely *mathematical* structures. Following Poincaré, in this chapter I will

[3] Supposing with Popper that we don't know whether our current theories are true, how can we estimate their distance from the true theories? Furthermore, does the notion of "being truth" (or "being false") admit of degrees?

understand the former as a class of *physical relations* partially described by the latter, that is, by the equations or laws defining a mathematical model:

> «**The differential equations are always true**, they may be always integrated by the same methods, and the results of this integration still preserve their value. It cannot be said that this is reducing physical theories to simple practical recipes; **these equations express relations, and if the equations remain true, it is because the relations preserve their reality**. **They teach us now, as they did then, that there is such and such a relation between this thing and that**; only, the something which we then called *motion*, we now call *electric current*. But these are merely names of the images we substituted for the real objects which Nature will hide for ever from our eyes. **The true relations between these real objects are the only reality we can attain**, and the sole condition is that the same relations shall exist between these objects as between the images we are forced to put in their place. If the relations are known to us, what does it matter if we think it convenient to replace one image by another?» (Poincaré, 1905, pp. 160–1, the emphasis in bold is mine)

Note that Poincaré does not deny the existence of "real objects" or theoretical entities; rather, he simply declares them to be unknowable ("the real objects which Nature will hide for ever from our eyes"). Consequently, following Ladyman, we can distinguish two forms of structural realism: depending on whether the concrete, physical relations partially referred to by mathematical models are the only things we can know (Poincaré, 1905; Worrall, 1989), or are regarded as the only existing stuff (French and Ladyman, 2003; Esfeld, Esfeld and Lam, 2006), we have *epistemic* or *ontic* structural realism (Ladyman, 1998).

In the former, *epistemic* case, entity realism is not denied, but possibly reached at "the limit of inquiry", as more and more relations between objects are discovered (Cao, 2003). Epistemic structural realism can therefore be either *agnostic* about theoretical entities, or simply presuppose them, with Poincaré, as the indispensable but unknowable *relata* of the relations described by and known *via* scientific theories and laws.

In the *ontic* version of structural realism, instead, entity realism is simply outlawed: entities, *if* regarded as bearers or bundles of, monadic, intrinsic properties, are "crutches" to be thrown away after the construction of the model. Ontic structural realism, as I understand it, is a form of *atheism* about entities, but only if the latter are conceived as endowed with intrinsic, monadic properties in the sense of Langton and Lewis (1998). Roughly speaking, an intrinsic, monadic property is a property that, like boldness, can be attributed to an individual without presupposing the existence of another individual. A property is extrinsic or relational if and only if it is not intrinsic.

This interpretation of ontic structural realism seems to be shared by structural realists like Esfeld (2007), Esfeld and Lam (2006): since *ontic* structural realists cannot be radically instrumentalist about the referential import of models, they must redescribe all ontological claims of moderns science in such a way that theoretical entities simply turn out to be *bundles of relations*. In this version of the theory,

the *relata* of the relations described by science are bundles of relations, and it is therefore accepted that relations cannot exist without their *relata*. In this way, one of the standard objections raised against a more radical view of ontic structural realism (French and Ladyman, 2003) is tackled. However, it seems to me that it is possible to read also French and Ladyman as defending *this* version of ontic structural realism, since even the bundles of relations on which the radical ontic structural realists bets are, after all, *entities* of some kind.[4] I daresay that no ontic structural realist should be falling into the trap of accepting the view that "relations can exist without relata".[5]

Epistemic structural realism has its problems: one may legitimately wonder with Esfeld and Lam (2006) whether it is reasonable to detach epistemology from ontology in such a radical way as to postulate entities that—similar to kantian noumena—are endowed with intrinsic properties that in principle we will never know. But ontic structural realism, even in the moderate form postulated by Esfeld and Lam (2006), is not without troubles, as it is natural to raise doubts about whether an ontology of "entities" possessing purely relational properties is plausible.

For example, one might question whether entities can bear relations to one another without having any intrinsic properties whatsoever: the relation "*a* is heavier than *b*" presumably holds because of a property like "having a certain density of matter", that seems intrinsic to each and every body.

However, independently of conceptual difficulties of this kind, the main point of structural realism in both versions is that their defenders agree that it is natural science that should decide in favour or against the epistemic inaccessibility or the non-existence of intrinsic properties, and not just armchair, *a priori* conceptual analysis.

For instance, if *mass*, *spin* and *charge* could be legitimately regarded as *intrinsic* properties of elementary particles, ontic structural realism as I presented it would be automatically refuted. *Prima facie*, it is hard to see why these should not qualify as *bona fide intrinsic* property of particles, even though, of course, to get to know them, we must have other entities interact with them. Analogously, if we granted that these three properties, treated as causal powers of the entities possessing them, are reliably *known* by current physical theories, also epistemic structural realism would be rejected: we could know at least *some* intrinsic properties of some theoretical entities.

Also the case of entangled particles, considered by ontic structural realism as paramount evidence for their position (Esfeld, 2004), should be discussed in light of a *dispositionalist* interpretation of quantum mechanics. If the quantum properties of entangled particles could be regarded as *dispositional*, then even moderate ontic structural realism should be re-evaluated, since such dispositional properties, belonging to any quantum entity in a superposed, entangled state, should, *pace* Popper, be regarded as *intrinsically* possessed (Dorato, 2006b; Suárez, 2004).

[4] The distinction between radical and moderate ontic structural realism is in Esfeld and Lam (2006).

[5] For this view, a form of which could perhaps be attributed to David Mermin, see Barrett (1999, p. 217).

In a word—except for some inevitable vagueness in the distinction between intrinsic and extrinsic properties, which blurs the distinction between entity realism and ontic structural realism—the requisites of structural realism are sufficiently strict. Unfortunately, a thorough study of structural realism *vis à vis* the properties of particles within the standard model is yet to be written. The same conclusion holds for the consequences of a dispositionalist interpretation of quantum mechanics on the relational ontology of structural realism.

However, even if the confrontation with field theory were to result in a negative verdict, one could still imagine that *some* version of structural realism could survive if applied to spacetime physics.

This is exactly the issue that I will try to explore in the remainder of this chapter: "local" philosophical analysis may sometimes be more interesting than sweeping and vague attempts at encapsulating the whole of science or of physics in one scheme. Structural realism may fail as metaphysics for quantum field theory and yet be successful for spacetime physics: if this were the case, we would simply have another piece of evidence in favour of the metaphysical disunity of science. After all, it would be strange to find out that a single metaphysical claim squared with both quantum theory and spacetime physics, given that these two theories have not yet been reconciled in a single frame.

Before passing to the definitions of substantivalism, let me briefly note the logical relationships of these various forms of scientific realism. Quite naturally, a theory cannot even be approximately true if the entities and the structure it postulates don't exist at all. This shows that theory realism implies both entity realism and structural realism, so that 1) implies 2) and 3). Since, by contraposition, ¬2) implies ¬1), if 3) implied ¬2), 3) should also deny 1). Now, since ontic structural realism ought to be regarded as a denial of the existence of entities endowed with intrinsic properties (entity antirealism), it also entails theory antirealism, given that we just showed that ¬(2) implies ¬(1).

However, if the only existing *entities* were bundles of relations, ontic structural realism would trivially degenerate into entity realism and would be trivially compatible with it. Epistemic structural realism, on the other hand, is definitely not against the reality of the *relata*, but simply insists on their epistemic accessibility. As a consequence, structural realism in its various forms is compatible with entity realism, but not committed to theory realism, at least to the extent that entity realism, as some philosophers have it, is compatible with instrumentalism about theories and laws.

1.1 Substantivalism and structural spacetime realism

In order to understand the implications of the two forms of structural realism for the nature of spacetime, we need precise definitions of both "substantivalism" and "substance". In the literature on GTR, we find two main types of substantivalism, "manifold substantivalism" and "metric field substantivalism", depending on whether spacetime is identified with the differentiable manifold or with the metric field (plus the manifold):

> MANIFOLD SUBSTANTIVALISM «Space-time is a substance in that it forms a substratum that underlies physical events and processes, and spatiotemporal relations among such events and processes are parasitic on the spatiotemporal relations inherent in the substratum of spacetime points and regions.» (Earman, 1989, p. 11)
>
> METRIC FIELD SUBSTANTIVALISM «A modern day substantivalist thinks that space-time is a kind of thing which *can*, in consistency with the laws of nature, exist independently of material things (ordinary matter, light and so on) and which is properly described as having its own properties, over and above the properties of any material things that may occupy parts of it.» (Hoefer, 1996, p. 5, my italics)

Relationism is a denial of these two theses, and if both definitions of spacetime substantivalism were legitimate, it would come in two forms. While relationism about the manifold would be consistent with metric field substantivalism, a denial of the latter view would seem to entail also a denial of manifold substantivalism.

Note that, in the first definition, spacetime is a substance in virtue of its being a *substratum* underlying physical events, a position which certainly refers to one of the traditional meanings of "substance".[6] The second definition seems to presuppose a second sense of "substance", as something existing independently of other entities and events.[7]

Manifold substantivalism is based on the presupposition that the very debate between substantivalism and relationism requires a clear-cut *separation between spacetime*—regarded as a *container—and physical systems*, gravitational and non-gravitational ones alike, regarded as whatever is contained in it. As we will stress in Section 3, and as noted already by Rynasiewicz (1996), this definition of substantivalism creates conceptual troubles to the extent that GTR "overcomes"[8] the separation between container and contained for reasons that will become clear in Section 3.

The second definition, capturing *metric field substantivalism*, relies on Einstein's field equation, which allows us to write the gravitational field and ordinary matter on the two different sides of the equation. The italicized "can" of the second quotation refers to the fact that *the metric field can exist without matter*, even though it is typically correlated with it by Einstein's equations. This second definition creates controversies to the extent that it identifies *spacetime* with the manifold and the metric field, the metric field in GTR being a *physical* field, that one might want to regard (erroneously, in my view) as something being "contained" in something else enjoying an independent existence (the manifold).

Equipped with these definitions of scientific realism and substantivalism, we are now ready to try to understand the consequences of structural realism as applied to spacetime (i.e., structural spacetime realism) *vis à vis* the substantivalism/relationism debate, *assuming*, for the time being, *that such a debate is genuine*.

[6] From the Latin *sub stare*, to lie under.

[7] On this second sense of substance, more below.

[8] "Overcome" here corresponds to the technical sense rendered by the German verb *aufheben* in Hegel's philosophy: it is an overcoming that somehow realizes a synthesis of the views that were previously regarded as opposed and irreconcilable.

According to an *epistemic* version of structural spacetime realism, spatiotemporal relations would be all that can be known about spacetime: the nature of the *relata* (points, physical events), together with their first order, intrinsic properties, would be unknowable (as Poincaré had it, they would be "for ever hidden from our eyes"). In the *ontic* version of structural spacetime realism, spatiotemporal relations would instead be *all that there is*: spacetime points or physical events endowed with intrinsic properties would simply not exist, and would have to be re-conceptualised in terms of relations. From this perspective, a point P would just *be* something bearing the spatiotemporal relations $R_1, R_2, \ldots, R_n$ to other n points, and these relations would constitute its identity.

I will now argue that—independently of whether spacetime is represented by the manifold or by the manifold plus the metric field—if we think that the dispute between substantivalists and relationists is genuine also after GTR, *structural spacetime realism is a form of relationism.*

Prima facie, this conclusion seems less justified for epistemic structural spacetime realism (let me use the acronym ESSR). It will be recalled that it claims that spatiotemporal points might, or even should, exist *qua relata* of the spatiotemporal relations, but that we will never get to know their intrinsic properties: it is only their spatiotemporal relations that are epistemically accessible. To the extent that substantivalism implies the existence of spatiotemporal points endowed with *intrinsic* properties, ESSR could coherently defend it, but would have to consider it as a metaphysical doctrine which could be never confirmed or disconfirmed by empirical science.

As a consequence of the fact that the defenders of ESSR must leave substantivalism beyond the reach of empirical science, they seem to be facing a choice between two alternatives. The first consists in dropping the substantivalist/relationist debate altogether as irrelevant for empirical science, which leads us very close to the second claim to be argued for in the following (Section 3). The second alternative consists in embracing ontic structural spacetime realism, i.e., move toward a position that brings a structuralist epistemology into line with a metaphysics postulating *just* the existence of relations.

In a word, ESSR *per se* is certainly compatible with substantivalism, but looks like a remarkably unstable philosophical position. If one does not drop the dispute (first alternative), or does not opt in favour of ontic structural spacetime realism (second alternative), the compatibility with substantivalism would be purchased at too high a price, as it would amount to buying a metaphysical theory that could not be measured *in principle* against the results of a physical theory.

I will now show how also *ontic* structural spacetime realism (call it OSSR, the second alternative mentioned above), with its denial of the existence of intrinsic properties, is against the existence of a substantival spacetime, and turns into pure relationism. Since my argument crucially hinges on the assumption that by "substance" we should mean an entity endowed with intrinsic properties, *i.e.*, something that exists independently of any other entity, we must ensure that this definition is reasonable also in the context of spacetime physics. In order to do so, two remarks are appropriate.

The first remark is that the philosophical tradition yields a univocal verdict with respect to the meaning of "substance": the main difference between an *accident* like being married and a *substance* like Socrates is that the latter, unlike the former, exists independently of anything else. Descartes—to name just one of the philosophers who played an essential role in transplanting the Aristotelian tradition into the soil of modern philosophy—tells us that "when we conceive a substance, we understand nothing else than an entity which *is* in such a way that it needs no other entity in order to *be*." (Descartes, 1644, I). A very similar definition of substance has been defended also by Spinoza: "By substantiam intelligo id quod in se est et per se concipitur…" (Ethics, I, Prop. 3)[9]. And these are but two examples.

If we accept this definition of substance, we should attribute a substantial spacetime (or a region of it, up to a single point) *intrinsic* properties, i.e., properties that can be attributed without presupposing the existence of other entities. This would be sufficient to show that ontic structural spacetime realism is incompatible with point-substantivalism, and is a form of relationism.[10]

The same result is derivable if we use "substance" to refer to an entity possessing a distinct identity, or an individuality derived by the possession of some intrinsic property. In this second, closely related sense of "substance", spatiotemporal points are substantial if and only if they have a distinct identity *just taken by themselves*.

Relative to this second sense of substance, Stein (1967) has first shown how both Leibniz *and* Newton denied substantiality to points and instants: also according to Newton, points and instants receive their identity from the spatiotemporal order to which they belong, as each is qualitatively identical to any other.[11] It follows that any ontology denying the existence of intrinsically individuating, monadic properties is anti-substantival or relational also in the context of spacetime physics. But according to the ontic structural spacetime realist, a point or an instant has no other individuality than that of being in relation to other points: taken by itself, it has no identity and is therefore not substantial also in this second sense of substance.

The above mentioned second remark conceives the possibility of a different definition of "substance", one that would justify the neutrality of the substantivalism/relationism debate with respect to structural spacetime realism. After all, one could argue, in changing scientific contexts it is unavoidable that even notions with an important historical tradition be readjusted to fit a new conceptual framework. However, words have meanings, and contrary to the opinion expressed by Humpty Dumpty in *Alice in wonderland*, we cannot have them mean what *we* want.

And even if in the present case such a change could be done, the dispute about the substantial or relational nature of spacetime would be transformed into

[9] By substance I mean something which exists by itself and can be conceived by itself…, my translation).

[10] This remark counters an objection raised by Michael Esfeld in his reading of a previous version of this chapter.

[11] In the unpublished manuscript *De Gravitatione et equipondio fluidorum*, Newton writes: "the parts of space derive their character from their positions, so that if any two could change their positions, they would change their character at the same time and each would be converted numerically into the other qua individuals. The parts of duration and space are only understood to be the same as they really are because of their mutual order and positions (*propter solum ordinem et positiones inter se*); nor do they have any other principle of individuation besides this order and position which consequently cannot be altered" (Hall and Hall,

a purely *semantic* question, depending on the meaning of "substance". I think it is fair to add that when a philosophical question turns into an issue pertaining exclusively to the meaning of words, then it tends to be deprived of much of its significance. Since this is the second claim that I want to defend in my chapter, I will postpone its defence in Section 3: for the time being it is sufficient to have illustrated the point that it is difficult to escape from the traditional meaning of "substance" as something that exists independently by possessing intrinsic properties. This fact pushes OSSR in the arms of relationism.

Despite these remarks, my fist claim (that structural spacetime realism is a form of relationism) might have been established too quickly. The well-known independence/autonomy of the metric field from the matter field might seem to speak against my view, since in *empty* solutions to Einstein's field equations, the metric field would seem to enjoy the status of an independently existing *substance* (metric field substantivalism). Could the moderate form of OSSR defended by Esfeld and Lam (2006) be compatible with metric field substantivalism, or even be *neutral* with respect to the substantivalism/relationism dispute?

Let us recall that according to OSSR, the entities exemplifying the spatiotemporal/metric relations do *not* possess intrinsic properties (or a primitive thisness) over and above that of standing in certain spatiotemporal relations. That is, these entities are nothing but that which stands in these relations. Against my view, it could then be argued that OSSR need not take a stand about the question of what these entities are: *they might be spacetime points (substantivalism) or material entities, namely parts of the matter fields (relationism)*.[12]

I already granted that the gravitational field and the non-gravitation field can have a distinct existence, since, in $T = 0$ solutions, the former field *can* exist without the latter. According to the previous approach to the notion of substance, if we consider *the whole* of the metric field, shouldn't we regard it as a *substance*, even if its *parts* (points), as the ontic structural spacetime realist has it, do not possess intrinsic properties, or independent existence?[13]

This question can be tackled in at least four different ways:

(i) OSSR cannot be made compatible with metric field subtantivalism. In fact, if the metric field as a *whole* exists as a substance and has therefore an independent existence, presumably it would have intrinsic properties, as all substances have, namely properties attributable to the metric field as a whole independently of anything else. But such an "intrinsicness" or independence of the metric field from the matter field would be hardly compatible with OSSR's relationalist ontology. An entity without relations to something else can hardly be admitted within the latter ontology. And my first claim would be vindicated.

(ii) Suppose the metric field as a whole is substantial while its parts aren't. How can the whole of the metric field be a substance if its parts (regions and points) cannot have intrinsic properties in virtue of the requirements of a structuralist ontology? Typically, the parts of compound substances are themselves

[12] This way of putting the issue was suggested by Michael Esfeld in his comments.

[13] For this holism of the metric field, see Lusanna and Pauri (2006).

substances: the pages of a book (a composite substance) are themselves substances, whether they are detached from the book or not; but if spacetime substantivalism required the existence of spacetime points or region as individual substances, it would go against ontic structural spacetime realism! The dilemma in which the defender of OSSR inclined toward substantivalism is caught is not easily solvable: if the whole metric field *is* a substance, then it must have intrinsic properties. But then the compatibility with OSSR is lost. On the other hand, if the whole metric field is *not* a substance, OSSR has a living chance, but its compatibility with substantivalism is lost, because (contrary to what is actually the case), the metric field would not be independent of the matter field. In either horns of the dilemma, my first claim is vindicated.

(iii) If the substantivalist/relationist debate were simply a matter of deciding whether the gravitational field is distinct and independent from the matter field or not, relationalism couldn't win, and GTR would be substantivalist by *fiat*, without even beginning to fight. This way of cashing the debate would trivialize it. Of course, from the fact that it has such an easy solution, we cannot conclude that the debate is outdated. However, since the question whether GTR is substantivalist, relationist or neither will be evaluated in Section 3, we can move to the last reply, which addresses Esfeld's proposed alternative between the relata of the spatiotemporal relations being *spacetime points* (substantivalism) or *parts of the matter fields* (relationism).

(iv) The expression "spacetime points" is not unambiguous, as it has at least two distinct interpretations. If by "spacetime points" one meant points of the manifold endowed with primitive identity or *intrinsic* properties, one would have *manifold substantivalism*. Since this position would contradict ontic structural spacetime realism, it cannot be the intended interpretation. On the other hand, if by "spacetime points" one meant points of the metric field, one would have to decide whether such a field is geometrical/spatiotemporal or physical (i.e., substantival or relational). Since, as we are about to see in Section 3, the main lesson of GTR is that it is *both*, it is hard to make sense of the question whether we have a substantival spacetime (because spatiotemporal points *exist* on their own as individuated by their metric relations) or a relational spacetime (because spatiotemporal relations supervene on the gravitational field, which is a *physical* field).[14]

Since the question of the status of metric field vis à vis spacetime will be discussed below, here I can afford ending my discussion with two quotations, which illustrate the connection between structural spacetime realism and relationism in a particularly clear way: "There is no such thing as an empty space, *i.e.* a space without field. Space-time does not claim existence on its own, but only as a structural quality of the field" (Einstein, 1961, pp. 155–156); "spacetime geometry is nothing but the manifestation of the gravitational field" (Rovelli, 1997, pp. 183–184).

[14] The above ambiguity is not present in making sense of the claim that "metric relations amount to relations among material entities" (relationism, as Esfeld has it), since "material points" should mean "points of the matter-field". In this "leibnizian" interpretation, however, one is forbidding pure gravitational solutions to the Einstein's field equations; in view of the existence of $T = 0$ solutions of such equations, this seems too high a price to pay to have a plausible formulation of the substantivalism/relationism debate also in the context of GTR.

Despite argument from authority have no value even if they come from Einstein, it should be admitted that as expressions of structural spacetime realism, these quotations also look like acts of relationist faith!

In conclusion, structural spacetime realism either pushes toward, or just *is, relationism*, and in any case it cannot it be regarded as a *tertium quid* between substantivalism and relationism.

However, if we were to agree that the substantivalism/relationism dichotomy has no clear-cut application within GTR, we would need an alternative formulation of the problem of the nature of spacetime, more attentive to the *ontological* problem of its existence than to the *metaphysical* question of a substantival *vs.* a relational existence. As we are about to see in the next section, the seeds of such an important but neglected anti-metaphysical formulation are to be found in Stein (1967), and need to be developed and defended against possible criticism.

2. A REFORMULATION OF THE SUBSTANTIVALISM/RELATIONISM DEBATE: STEIN'S VERSION OF "STRUCTURAL SPACETIME REALISM"

> «If the distinction between inertial frames and those that are not inertial is a distinction that has a real application to the world; that is, if the structure I described[15] is in some sense really exhibited by the world of events; and if this structure can legitimately be regarded as an explication of Newton's "absolute space and time"; then the question whether, in addition to characterizing the world in just the indicated sense, this structure of space-time also "really exists", surely seems supererogatory» (Stein, 1967, p. 193)

Let us recall that a supererogatory (*überverdienstlich*) action, according to the *Critique of Practical Reason* for Kant is an action that goes beyond what is required by one's duty, despite its being possibly inspired by noble sentiments. In a word, according to Stein, worrying about the independent existence of the exemplified structure is otiose. This is the position I would like to defend.

By using a later paper of his (Stein, 1989), I read Stein as claiming that the traditional dispute between substantivalism and relationism is analogous to that between scientific realism and antirealism as he viewed it: *neither position is tenable*! If antirealism about spacetime structure amounted to a position denying that the world of events "really exhibits" a certain geometrical or spatio-temporal structure, something that Stein instead explicitly grants, such antirealism about spacetime would *not be* tenable. «The notion of structure of spacetime" is not to be regarded "as a mere conceptual tool to be used from time to time as convenience dictates… there is only one physical world; and if it has the postulated structure, the structure is—by hypothesis—there, once and for all» (Stein, 1967, p. 52).

However, Stein is not "realist" about spacetime either: if spacetime *realism* were equivalent to the supererogatory claim that the spatiotemporal structure "really exist"—where "really exists" presumably refers to the *independent existence*

[15] If N denotes the mathematical model for absolute space and time, $N = <S \times T>$, i.e., N is the Cartesian product between the three-dimensional Euclidean space S and the time T.

of the structure (over and above the physical events instantiating it) required by some forms of substantivalism—such an (hyper-)realism about spacetime structure would not be reasonable either.

Does Stein's position amounts to proposing a *tertium quid* between substantivalism and relationism?[16] I want to push the point that if Stein is right in insisting that the opposition between substantivalism and relationism is *not* a fruitful way to make sense of the Newton–Leibniz debate, and I think he is correct about this, *a fortiori* it is not fruitful within GTR, where there is no empty, container space in the sense presupposed by the ancient atomists. Following Stein's "style" of philosophical analysis as I understand it, I think that the important questions to be raised are:

- What did the "relationist" Leibniz and the "substantivalist" Newton *agree upon?* (according to both, for instance, instants and points have *no* intrinsic identity)
- How do our spatiotemporal models represent the physical world?
- What does it mean to claim that spacetime *exists*?

Since I cannot pursue the first question here, let me expand on the other two, starting from the last. If we agree in stipulating that **"spacetime exists iff the physical world exhibits the corresponding spatiotemporal structure"**, I would like to press the point that the empirical success of our spacetime models do raise an important *ontological* question ("does spacetime exist?"), while the particular manner of existence of spacetime, namely whether it is substance-like or relation-like, after the establishment of GTR has become a less central, *metaphysical, possibly merely verbal* question. I am here relying on a much neglected distinction between ontology and metaphysics: the former addresses question of existence ("what there is"), the latter is involved in the particular manner of existence.[17] A one-sentence way of putting the main point of this ~~or~~ would be the following: spacetime exists as exemplified structure, while the question whether it exists as substance or relation is not well-posed.

2.1 Some foreseeable objections to Stein

Once we accept the view that spacetime structure postulated in mathematical models is exhibited by the physical world, one may legitimately wonder why we can't be justified in attributing *independent* existence to the spacetime structure. There are at least four objections to the deflationary claim that I am attributing to Stein and trying to defend, the first three of which can be raised independently of GTR:

O_1 By playing the deflationary game, aren't we sweeping the philosophical problems under the carpet?

O_2 Stein's thesis depends on a controversial way of understanding the relationship between models and physical world. What does it mean, exactly, to claim that the world of physical events "*exhibits* a certain structure"?

[16] I am not presupposing here that Stein wanted to propose a *tertium quid* between substantivalism and relationism, let alone that he wanted to defend some form of what is now known as structural realism.

[17] This distinction has been pressed, among others, by Varzi (2001).

O_3 It is not at all meaningless or "supererogatory" to ask whether the space-time structure "really exists" in addition to its being exemplified.

O_4 Which entity does the exemplification of the structure, spacetime points or physical events/systems? If the former, Stein is wrong, if the latter Stein's SSR is pure relationism; in either case my reconstruction of his proposal does *not* amount to dissolving the substantivalism/relationism debate in GTR.[18] Let us discuss these four objections in turn.

As a response to O_1, consider the following analogy taken from the philosophy of time. Regarding *becoming as the successive occurring of events* accommodates both block-view theorists and the friends of becoming, depending on whether we insist on the fact that events *are* (static sounding) tenselessly located in spacetime, or on the fact that they *occur* (dynamic sounding) at their spacetime location.[19] In effect, since the *being* of events is identical with their *occurring*, we realize a fusion of Parmenideian and Heracliteian metaphysics.

Analogously, Stein's version of structural spacetime realism sounds *realist* about spacetime (and it is realist), because it claims that the physical world does indeed have a certain spatiotemporal structure (so in *this* restricted sense, spacetime exists), but it also sounds antirealist to those who keep asking the supererogatory question whether, in addition to characterizing the world in the specified manner, the "structure really exists". This solution to the substantivalist/relationist debate does not look like sweeping difficult questions under the carpet, but simply invites philosophers of space and time to deal with different problems.

Going to the second objection O_2, rather than implicitly defending the semantic view of theories, Stein explicitly advocates a "platonic", model-theoretic understanding of the relationship between mathematical models and physical world:

> «what I believe the history of science has shown is that on a certain very deep question, Aristotle was entirely wrong and Plato—at least on one reading, the one I prefer—remarkably right: namely, our science comes closest to comprehending the real, not in its account of "substances" and their kinds, but in its account of the "Forms" which phenomena "imitate" (for "Forms" read "theoretical structures," for "imitate" read "are represented by» (Stein, 1989, p. 52).

Here Stein's bent toward some of the tenets of structural realism is clear. The forms or "theoretical structures" are the mathematical, abstract models, which refer to the physical world by representing the relationships among those parts of physical systems that are described by laws. To the extent that a given physical process, say free fall, can be subsumed under a well-confirmed physical law, say the principle of equivalence, then one can "represent" that process by a *geometric* notion, that of a geodesic of a curved connection, which is part and parcel of the geometric structure of spacetime (for this view, see also DiSalle, 1995, p. 335). This structural realist way of construing the relationship between physics and geometry seems to me plausible and clear, and taking the notion of "the physical world

[18] The attentive reader will recall that this question had been raised in the previous section.

[19] For such a deflationary claim, see Savitt (2001), Dieks (2006), and Dorato (2006a, 2006b).

(free fall) exhibiting a certain geometric structure" as a primitive cannot be *prima facie* attacked for its inconsistency or lack of clarity.

The third objection O_3 affirms that, besides the hypothesis of manifold substantivalism, there are at least *three* different senses in which one could *meaningfully* ask whether spatiotemporal structure "really exists", in addition to being exemplified by the physical world. I will now argue that they are all supererogatory or irrelevant.

(1) In a first sense, the '*really* exists' in "the structure really exists" of the first quotation by Stein[20] could be taken as synonymous with 'mind-independently exist'. However, if we grant that spatio-temporal relations are exemplified by *physical* systems, who would want to deny their mind-independence? And even if one wanted to press the Kantian point that phenomena can be linked by spatiotemporal relations only thanks to our transcendental, pure intuitions of space and time, this rendering of the "really exists" would open a wholly different problem, not relevant to the one we started with.

(2) In a second sense, the "really exists" may refer to a kind of platonic realism about the mathematical structure used to model the physical world. This is a meaningful, *abstract* sense of "really exists", but also not relevant to our problem of establishing the *concrete* existence of spacetime.

(3) In a third sense, the question of the independent existence of spatiotemporal structure might call into play the ontic status of the truth makers of the equations defining the mathematical structure and expressing the laws of nature. *Via* the concept of symmetry, the spatiotemporal structure of spacetime is closely related to laws of nature, which in part codify and express such structure: granting the structure an independent existence might involve accepting a realist, possibly "necessitarist" position about laws of nature in the sense of Tooley–Dretske–Armstrong (see Earman, [illegible]t must be admitted that this interpretation of "really exists" would not be meaningless, and that laws of nature, as opposed to laws of science, may indeed be attributed a primitive existence (Maudlin, 2007). However, questions concerning the metaphysical status of laws or the existence of universals *vis à vis* nominalistic interpretations of laws of nature involve *all* laws of nature, and not just those characterizing spacetime physics. As such, they do not seem specific enough for our gaining a deeper understanding of the ontological role of spacetime.[21]

Objection O_4 takes us closer to the interpretive problems of GTR, and seems the most threatening for my main argument. Given that spacetime is exemplified structure, one is naturally brought to ask what kinds of entities are the relata of the relations, so as to actually doing the "exemplificative work". If such an exemplification is realized by points of the manifold, we must assume their existence, as in manifold substantivalism; on the other hand, if it is realized by physical events/systems, we have relationism. Clearly, without additional argu-

[20] The one occurring just after the beginning of Section 2.

[21] Furthermore, in view of the remarks that will be offered in the next section, how do we distinguish laws involving the spatiotemporal structure from the other laws?

ments coming from GTR, structural spacetime realism, even in Stein's version, does *not* dissolve the debate.

This is true, but note that this objection is predicated upon a clear distinction between spacetime and physical fields, a distinction which, as we are about to see in the next section, is definitely overcome by GTR. We will now see how also this fourth objection fails, and structural spacetime realism in the version defended here is vindicated.

3. THE DUAL ROLE OF THE METRIC FIELD IN GTR

As much as we have a particle-wave duality in QM, we have a (different) spacetime/physical field "duality" in GTR, forced upon us by the well-known dual role that the metric field has in the theory. As a matter of fact, *the metric field plays both the traditional roles represented by "space and time" and those typical of a physical entity*.

While, on the one hand, the metric field carries the distinction between spatial and temporal directions, allows measures of spatiotemporal distances, and specifies the inertial motions (as *geometric* entities typically do), on the other it also carries energy and momentum, satisfies differential equations, and acts upon matter, as *physical* fields do. The former roles leads us to claim that the metric field g_{ab} should be spacetime; the latter roles push us in the opposite direction, namely are conducive to maintain that it is the bare manifold that should represent spacetime, since the metric field is also, and indisputably, a physical entity. In reality, the tensor field g_{ab} has both roles, and I take it that this is the main, essential message of GTR. Since the metric field is both spacetime and a real, concrete physical field, *we should conclude that GTR is either both substantivalist and relationist, or neither substantivalist nor relationist*.

The question "which entity of the mathematical model should we regard as the representor of spacetime?" has, not surprisingly, generated *two* answers also in the literature, as it is illustrated also by the two available definitions of substantivalism provided in Section 1. Those who worried that g_{ab} is a physical field preferred to identify spacetime with whatever is denoted by the differentiable manifold, and thought that substantivalists are committed to *manifold substantivalism* (Earman and Norton, 1987; Earman, 1989; Belot and Earman, 2001; Saunders, 2003). Others, who correctly lamented that the manifold of events is deprived of any metric property, identified spacetime with the metric field plus the manifold (Maudlin, Stachel, 1993; Hoefer, 1996; Lusanna and Pauri 2006, 2007).

The fact that the candidate for representing "spacetime" has been oscillating between the manifold and the metric field is a first but important piece of evidence that in GR the debate lacks a clear formulation. This ambiguity, however, does not mean that our preference for ~~interpreting~~ the metric rather than the manifold as representing spacetime is unmotivated. Even though I cannot rehearse the arguments in favor of this choice here, I will touch on three essential points, because they provide additional motivations to drop the substantivalism/relationism[22]

[22] For additional arguments, I refer to the literature mentioned above. The invitation to drop the debate presupposes the context of our best, empirically confirmed spacetime theory so far, GTR.

The first is that we cannot even *talk* about "spacetime" without the resources provided by the metric, because in order to have spacetime, we need at least to be able to distinguish spatial from temporal intervals. Dimensionality alone, provided by the topological structure of the manifold, does not suffice.

In order to introduce the second argument, recall that it has been argued that if the metric field, rather than the manifold, becomes the "container", i.e., spacetime, then in those unified field theories *à la* Einstein, in which *any* kind of matter is represented by a generalized metric field, substantivalism would be trivialized. In such theories, in fact, there would be "nothing contained in spacetime", and substantivalism would amount to claiming the independent existence of the entire universe (Earman and Norton, 1987, p. 519). However, such an undesirable consequence can also be eliminated by dropping the substantivalism/relationism dichotomy altogether, at least to the extent that it implies a container/contained distinction. Why should we leave room for the meaningfulness of the latter distinction if the main point of GTR is to make spacetime a dynamic entity, capable of acting and reacting with the other matter fields? The dynamical character of spacetime, nevertheless, could seem to lend credibility to metric field substantivalism, and therefore to a form of *spacetime substantivalism* (Hoefer, 1996). If spacetime is the metric field and it is dynamical, why isn't it a substance?

The fact is that precisely because in GTR spacetime is *also* a physical entity, its role in the theory can always be redescribed by claiming that it is the manifestation of the gravitational field (its structural quality), rather than the other way around (the gravitational field being a manifestation of spacetime).[23] And the choice between these two ways of expressing the relationship between spacetime and gravitational field seems to be underdetermined by the facts, and suggests that the dispute between substantivalism and relationism in GTR is a matter of words, or possibly of a conventional choice about two ways of explaining phenomena that are empirically equivalent. If I claim that the gravitational field is a manifestation of spacetime, I start from the latter to "construe" the former, and I do the opposite in the reverse case, but both approaches look viable.

The third argument concerns the fact that all physical fields are assignment of properties to spacetime regions (Earman, 1989, pp. 158–159); so we should at least quantify over the points and regions of the differentiable manifold on which matter fields live. The reply is two-pronged; for non-gravitational matters, it is not clear why the points over which to quantify could not be those of the metric field, rather than the points of the manifold. Matter fields live on the metric field: as Rovelli once put it, "they live on top of each other". On the other hand, the question "where the points of the metric field are", if spacetime is the metric field or its structural quality, is clearly meaningless, as it would be equivalent to ask where is the universe, once we agree that universe (matter fields and gravitational fields) and spacetime are one and the same entity. In a word, also the Field's argument cannot go off the ground.

[23] In his abstract for the conference to be held in Montreal, Lehmkuhl (2006) has referred to these two alternatives as the fieldization of geometry and the geometrization of the field. He opts for a position that is very close to the one presented here.

Aware of these difficulties, Belot and Earman, who are convinced that the dispute between substantivalism and relationism still makes sense, put forward this account, which is equivalent to endorsing a metaphysics which is very close to heacceitism:

> «It is now somewhat more difficult to specify the nature of the disagreement between the two parties. It is no longer possible to cash out the disagreement in terms of the nature of absolute motion (absolute acceleration will be defined in terms of the four-dimensional geometrical structure that substantivalists and relationist *agree* about). We can however, still look at *possibilia* for a way of putting the issue. Some substantivalist, at least, will affirm, while all relationists will deny, that there are distinct possible world in which the same geometries are instantiated, but which are nonetheless distinct in virtue of the fact that different roles are played by different spacetime points (in this world, the maximum curvature occurs at this point, while it occurs at that point in the other world). We will call substantivalists who go along with these sorts of counterfactuals *straightforward substantivalists*. Not all substantivalists are straightforward: recent years have seen a proliferation of *sophisticated* substantivalist who ape relationists' denial of the relevant counterfactuals (Belot and Earman, 2001, p. 228).

If we regard as different two worlds that contain exactly the same individuals and properties, but vary only about which individual instantiate which properties, then we accept *haecceitism* (Lewis, 1986, p. 221). Imagine having two canvases (spacetimes), and to remove the content of the first picture from the first and paste it onto the second, in such a way as to shift it just by three inches to the left. The content of the two pictures is identical, only the second is moved to the left, and so different individuals (points) in the second canvas play different roles. Notice that in our example the frame allows for an independent identification of the points of the canvas, since the points in which, say, the flower is painted, have a different distance from the left, lowest corner.

In the example given by Belot and Earman, however, such an identification is impossible in principle, and not by chance they refer to the points by using an ostensive criterion (*this* point, or *that* point), and therefore presuppose an implicit reference frame, our bodies. The idea of a primitive thisness (heacceity) seems to stem from an identity criterion that is independent from anything pertaining to the causal role played by the individual or its properties. According to heacceitism, an individual is not the bundle of its properties, but, like a peg which can hold different clothes, has something substantial "under them", so that in an heacceitistic world *I* could have all *your* properties and keep my identity and *viceversa*.

This formulation of substantivalism is definitely supererogatory in Stein's sense. No possible *a posteriori* argument could ever be produced in favour of the kind of heacceitism that is required by the definition, since no empirical criterion whatsoever could in fact distinguish two physically possible worlds simply in virtue of the role played by the different points in the two models. And this result would be independent of the particular spacetime structure exemplified by the world of events, and would therefore be insensitive to the various types of

spacetime theories: the supererogatory nature of Belot–Earman approach to substantivalism is given by the fact that no possible a posteriori argument could ever be produced in favour of substantivalism/heacceitism.

Note, however, that this remark does not entail that in the context of GTR we should all become relationists. The metric field is spatiotemporal and physical at the same time, so that there is no clear sense in which we can distinguish physical entities from purely spatiotemporal relations, as relationism requires. The fact that also in the GTR case spacetime *is* exemplified structure does not entail that the metric field does not carry energy and momentum.

4. CONCLUSION

The metric field is spacetime, and it is a real entity, but the additional, metaphysical question whether it is a substance-like or relation-like is much less important than establishing its existence as exemplified structure, in the sense specified by structural spacetime realism. But structural spacetime realism turns into relationism only if we presuppose that the distinction between substantivalism and relationism has some utility in the philosophy of space and time.[24] However, as Newton had already understood, the categories of ordinary language (subject-predicate) as they have been re-elaborated by scholastic philosophy (substance-accident) seem quite inappropriate to understand the ontology of spacetime, or of any physical theory formulated in mathematical terms:

> «About extension, then, it is probably expected that it is being defined either as substance or accidents or nothing at all. But by no means nothing, surely, therefore it has some mode of existence proper to itself, by which it fits neither to substance nor to accident.» (Newton, 1685, p. 136)

If Newton, the alleged champion of substantivalism, argues that the notion of substance is "unintelligible" (see also DiSalle, 2002, p. 46), why using it after the invention of a theory (GTR) in which the distinction between container (spacetime) and contained (field) has evaporated?

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(Maudlin, 1989) (Spinoza, 1662–1675)

[24] For an historical reconstruction of spacetime theories that put on a side the question of substantivalism *vs.* relationism, see (DiSalle, 2006).

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