# The Metaphysics of Super-Substantivalism

Dennis Lehmkuhl
Einstein Papers Project and Division of the Humanities and Social Sciences
California Institute of Technology
*lehmkuhl@caltech.edu*

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**Abstract**

Recent decades have seen a revived interest in super-substantivalism, the idea that spacetime is the only fundamental substance and matter some kind of aspect, property or consequence of spacetime structure. However, the metaphysical debate so far has misidentified a particular variant of super-substantivalism with the position per se. I distinguish between a super-substantival core commitment and different ways of fleshing it out. In particular, I distinguish between two categories of super-substantival positions: modest and radical super-substantivalism. I argue that only the latter engages with physics in an interesting way and offers metaphysics the possibility to motivate new research programmes in physics, rather than defending positions that can be maintained no matter what physics tells us about the nature of spacetime.

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# 1 Introduction

What does the universe consist of? A popular answer, at least among physicists, might be well expressed by the title of a famous book by Hermann Weyl: *Space-Time-Matter*. The shouting and screaming starts when one asks about the *relationship* between space and time (or spacetime), on the one hand, and matter, on the other.

The modern debate normally distinguishes between two positions with regard to the ontological status of spacetime. Either spacetime is fundamental, i.e. a substance in its own right (*substantivalism*), or only material bodies are fundamental, and space and time are just abstractions of or derive from the relationships between material bodies (*relationalism*). The first position is often traced back to Newton, the second to Leibniz.[1] But there is a third possibility, a position about which most remain silent, as if it were a cautiously guarded family secret — and even though it has an equally magnificent set of forefathers as the other two camps, among them Plato, Descartes, Spinoza, Clifford and also Newton.[2]

Sklar (1974) has called this position *super-substantivalism*. The idea is simple. Substantivalists claim that there are two kinds of fundamental substances in the world: spacetime and matter.[3] Relationalists claim that there is only one kind of fundamental substance: matter. Super-substantivalists agree that there is only one (kind of) fundamental substance in the world. But, they hasten to add, this fundamental substance is not matter but spacetime. According to the super-substantivalist, *every-thing in the world is spacetime.*[4]

This position may seem logically possible but slightly non-common-sensical, and so I hastened to refer to its famous ancestors. Yet they are not what matters in the end; the question is which position is the best to adopt. There are different reasons one can have for judging one of the three positions to be better than the other two. One oft quoted criterion is Occam's Razor: the most parsimonious position is regarded as having a clear advantage. However, parsimony has to be balanced with explanatory power: if a position can explain more than its rivals, then we may be willing to accept that it postulates more fundamental entities or kinds of entities.[5]

[1]See Section 2 for a more precise definition of the core commitment of substantivalism.

[2]For details on the predecessors of modern super-substantivalism see Graves (1972) and Skow (2005); for an argument that at least the early Newton was a super-substantivalist see Thomas (2013*b*), chapter 3.

[3]I will argue below that strictly speaking the substantivalist core commitment does not commit one to any assumption about the nature of matter, but just to the claim that *spacetime* is a substance in a sense to be specified. Still, most (spacetime) substantivalists presuppose that matter is a fundamental substance, too. As we will see, if one defines substantivalism as a commitment only to the fundamentality of space or spacetime, super-substantivalism is a (more radical) version of substantivalism.

[4]Of course, one can also be a super-substantivalist with regard to space rather than spacetime, and naturally Descartes and Clifford were super-substantivalists of this stripe (regarding space/matter; of course, Descartes was a dualist with regard to space/mind). However, after the development of the general theory of relativity, super-substantivalism with regard to spacetime seems promising. (Note, though, that the development of a super-substantival version of the 3-dimensional 'shape dynamics', see e.g. Barbour (2012), would be very interesting indeed.) For convenience, I will restrict the discussion to super-substantivalism with respect to spacetime, although much of what I say will also apply to the corresponding position that takes space as the only fundamental substance.

[5]Of course, judgements on how explanatory a given theory is may vary depending on one's account of

We should note that both criteria can be stated without explicit recourse to the theories of space, time and matter provided by physics. One might be tempted to regard this as an advantage. However, one may also defend the view that *good* metaphysics should rest on a conceptual analysis of physics; whether we should adopt substantivalism, relationalism or super-substantivalism depends to a large extent on which position is most compatible with our best physical theories of space, time and matter.

It is exactly this idea that has driven many philosophers of physics since the completion of the General Theory of Relativity (GR for short) in 1915. The question was not so much whether we find substantivalism or relationalism more intuitive or more advantageous for purely philosophical reasons. Rather, the question was whether, *given GR*, which has been accepted as at least approximately true, we should adopt a substantivalist or a relationalist position with regard to the nature of spacetime and matter. Pursuing this question turned out to be enormously fruitful for philosophy, for it facilitated the insight that substantivalism and relationalism were not positions but *families of positions*. This development started with the rediscovery of Einstein's 1913 hole argument by Stachel (1989), a paper first presented at the 1980 conference on General Relativity and Gravitation in Jena. Earman & Norton (1987) used the argument as the basis for the claim that a substantival position in the context of GR would lead to indeterminism — a position that should be avoided if there was a philosophical position available (notably relationalism) that did not commit one to either determinism or indeterminism. The subsequent philosophical discussion brought about an entire family of substantivalist and relationalist positions, and, as it turned out, the hole argument carries the threat of indeterminism only for some of them; positions that many regarded as disadvantageous anyhow.[6]

No such discussion, with GR and other relativistic spacetime theories as background, has yet taken place for super-substantivalism. Instead, in recent years the position has mostly been discussed in the field of pure metaphysics, and has been argued (e.g. by Lewis (1986), Sider (2001) and Schaffer (2009)) to be philosophically advantageous to substantivalism at least.

However, just as in the philosophical discussion prior to the rediscovery of the hole argument, much of the literature does not clearly distinguish between the *core commitment* of any super-substantival position, on the one hand, and the properties, advantages and shortcomings of different concrete variants of super-substantivalism on the other. I shall proceed as follows. In section 2, I will isolate the core commitment of super-substantivalism. Section 3 will deal with the two most promising arguments in favour of super-substantivalism as compared to the substantivalist and relationalist core commitments. In both cases, I will show that these arguments do not speak as clearly in favour of the super-substantivalist programme as their recent proponents have claimed. Instead, I argue, both arguments can serve merely as a strong *motivation* to work out the landscape of super-substantival positions in

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explanation, and indeed on one's interpretation of the theory in question.

[6]In section 2, I will isolate what I call the 'core commitment' that all versions of substantivalism share; a similar isolation may be possible for relationalist standpoints. Some of the main variants of substantivalism produced by the debate can be found in Maudlin (1989), Butterfield (1989), Hoefer (1996) and Pooley (forthcoming); see in particular Pooley (2013) for a comprehensive overview and analysis of the debate.

detail. Any entirely convincing argument in favour of super-substantivalism, just as in the cases of substantivalism and relationalism, can be had only with respect to concrete variants going beyond the core commitment. For only then does super-sustantivalism have enough substance in order for the question of its compatibility with modern physics to be non-trivial; only then can the position couple to physics productively. Thus, section 4 distinguishes between different ways of extending the core commitment, while section 5 distinguishes between two classes of extensions, two sets of super-substantival positions: *modest* and *radical* super-substantivalism. I conclude with a plea for radical super-substantivalism, arguing for its heuristic potential in inspiring research in physics, as well as for the philosophical fruit it promises us for a future harvest.

## 2 The core commitment of super-substantivalism

In order to characterise the core commitment of super-substantivalism, we first have to isolate the core of substantivalism.

Both Norton (1989) and Maudlin (1989) assume that a substantivalist has to accept that if a piece of matter is translated three feet in some direction, he then faces a new physical situation, even if the relationships between that piece of matter and all other matter in the universe (if there is any) have not changed. The intuition is that for a substantivalist something important has changed: the piece of matter is located in *this* part of spacetime here rather than in *that* over there, where it was before it was moved.

Norton and Maudlin are in substantial agreement with Leibniz and Clarke:[7] they both believe that *if* one is a substantivalist (using the modern term), *then* one is committed to seeing a world where 'everything is translated three feet in some direction' as a different possible world from the actual one.

Pooley (forthcoming) argues that this commitment does *not* follow from the central metaphysical commitment of the substantivalist position. He writes (p.85):[8]

> As I understand the position, substantivalism is simply a commitment to the real existence of space and its parts (the possible places of material bodies) as concrete, basic entities in the world. The emphasis on 'basic' is intended to underline the contrast with the relationalist, who can agree that there is a sense in which places (i.e., the actual and possible locations of bodies) exist, but who will deny that they are elements of the world's ground-floor ontology. For the relationalist only the (ultimate constituents of) material bodies are basic in this sense. The existence of places, and thus of space, is derivative. It is parasitic on the actual and possible spatial relations that can hold between material objects. For the relationalist, space is thus ontologically dependent on bodies. For the substantivalist, space is (at least) ontologically on a par with its material content.

[7] See Leibniz (1956).

[8] Pooley writes about substantivalism with respect to space here, but what he says generalises directly to spacetime.

This *does* seem to be the core commitment of the substantivalist, and it does indeed not imply that parts of space or spacetime possess primitive thisness, i.e., the substantivalist is committed to regard two parts of spacetime as intrinsically different from one another. As a matter of fact, the position does not even commit the substantivalist to the claim that the parts of spacetime are points — they could be atomistic regions, or something else entirely. Nor does the substantivalist as such have to be sure about which mathematical object(s) represent spacetime, how many dimensions it has, or whether the causal structure of spacetime is compatible with its path structure.[9]

Of course, the substantivalist will want answers to all these questions eventually; and especially the discussion originating with the rediscovery of the hole argument and Earman's and Norton's discussion of it produced more than one answer to the question of how a *smart* substantivalist should answer at least some of the questions above. But the point is that the substantivalist core commitment *as such* does not commit to any particular answer to any of these questions.

Thus, we can summarise the commitment in the following way:

> *Substantivalist core commitment*: Spacetime is a (kind of) substance, and a substance is a basic (or fundamental) concrete object that is not derivative of anything else.[10]

This is the commitment shared by all variants of substantivalism. Every characterisation that goes beyond the core commitment is already a particular, more concrete, variant of substantivalism.[11] And we *do* need these variants, for as it stands the core commitment is

[9]Ehlers et al. (1972) have argued that the causal structure of spacetime is identical to its *conformal structure*, i.e. to its being endowed with an equivalence class of metrics $g_{\mu\nu}$ at every spacetime point. They identify the path structure of spacetime with its *projective structure* and define a condition of compatibility between conformal and projective structure. Only if the condition is fullfilled do we have a unique *affine structure*, which distinguishes geodesics from non-geodesics. And only if the *curvature structure* defined by the affine structure fulfils another condition (that of the vanishing of Weylian length curvature) do we have the pseudo-Riemannian spacetime upon which the formulation of GR rests.

[10]Schaffer (2009) traces this notion of substance back to Aristotle, Descartes and Spinoza. For a discussion of the notion of being 'basic' see Schaffer (2008), section 3.1. (Note that Schaffer introduces 'basic' as a "lower bound of ontological priority"; I will use the latter concept in the definition of the super-substantivalist core commitment below.) Thomas (2013*b*) provides the most careful analysis of how the term 'substance' has been used as applied to space and spacetime from the Greeks to modern metaphysics; and argues that it is anachronistic to define 'substance' as a concrete irreducible object. She also isolates two core commitments of substantivalists, which contains the above core commitment as a proper subset. The second core commitment she argues the substantivalist to have is a commitment towards some relationship between space or spacetime and matter, while different substantivalists may differ with regard to the nature of this relationship. I agree that virtually all substantivalists hold such a commitment; but I do not think they have to *because* of their being space or spacetime substantivalists.

[11]Note that the referent of 'spacetime' in this commitment is the spacetime of the *actual* world. It is perfectly possible to believe that spacetime is a substance in the sense defined above without believing that it *has to be* a substance in all possible worlds. Indeed, most substantivalists who have adopted the position because they think it is the best interpretation of GR and other modern spacetime theories would be happy to admit that in a world in which substantially different laws of nature (especially those governing the relations

just the skeleton of a position; it needs flesh and muscles in the form of answers to the above questions in order to wrestle with physics' theories of spacetime. Of course, different reasons will speak for the adoption of different variants.

Let us now come to super-substantivalism. Super-substantivalists agree with substantivalists that spacetime is a substance in the sense described above. But substantivalists allow that spacetime is *just one* of the (kinds of) substances in the world, whereas they typically accept matter as the second (kind of) substance. This is the step whereby super-substantivalists break ranks with substantivalists; they thus have the following core commitment:

> *Super-Substantivalist core commitment*: Spacetime is *the only* (kind of) substance.

The first sentence of the super-substantivalist core commitment leaves open whether spacetime is the only substance (i.e. the only fundamental entity) or the only kind of substance. In the latter case, one would say that *parts of spacetime* are substances (i.e. basic), rather than (just) spacetime as a whole. If one were to claim that spacetime is *the only* entity, one would link super-substantivalism to priority monism, i.e. the position that the whole (here spacetime) is ontologically prior to its parts. While one may defend this position, it is not part of the super-substantivalist core position: one can believe that spacetime is ontologically prior to everything else without necessarily believing that the whole of spacetime is in turn ontologically prior to its parts.[12]

Note that, just as the substantivalist core commitment, the super-substantivalist one does not say anything about matter. However, every super-substantivalist will agree that they have to say *something* about matter right after uttering the core commitment; what is the relationship between spacetime as the only (kind of) substance, and matter?

Maybe the most well-known answer has been given by what Schaffer (2009) has called 'the identity view'. According to this position, the core commitment is followed by saying that matter is *identical to* spacetime regions. Depending on how this view is cashed out further (I will write more on this in section 4), one may well argue that rather than showing that spacetime is in some way *more* fundamental than matter, the position alleges that there is no real distinction between the two in the first place. After all, spacetime and matter are identified, and one might as well have written 'Matter is the only kind of substance' in the core commitment. Then, this version of super-substantivalism has been extended in such a way that it goes full circle and becomes identical to a version of relationalism. What started out as a project to base ontology on spacetime rather than on matter might then end up abandoning the very distinction of spacetime and matter.[13]

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between spacetime structure of matter) hold spacetime might not be a substance. Either way, believing that spacetime is *essentially* a substance would go beyond the core commitment of substantivalism as defined here. Furthermore, the core commitment of substantivalism does not commit to two regions of spacetime in distinct worlds as being primitively transworld identifiable with one another.

[12] I will discuss different options for extending the core commitment in section 4 and 5. Some of them involve adopting priority monism with respect to spacetime; others pluralism; and others still different options for what the parts of spacetime are.

[13] I do not believe that all versions of the identity view have to face this danger, but the position Schaffer

Thus, instead of extending the super-substantival core commitment to the identity view, we could extend it by adding the sentence 'Thus, spacetime is ontologically prior to matter'. I will call the core commitment ammended thus the 'minimal extension of the super-substantival core commitment which takes spacetime as ontologically prior to matter', or 'MESP' for short. The extension is minimal because it does not yet spell out the notion of 'ontological priority'. What is it supposed to mean that something (in this case spacetime) is ontologically prior to something else (in this case everything)? Different accounts of ontological priority (and, connected to that, ontological dependence) have been put forward. The rough idea is that $A$ is ontologically prior to $B$ iff the existence of $A$ implies or contains the existence of $B$ but not vice versa. Depending on your precise notion of ontological dependence (and any other metaphysical commitments you may have), $B$ supervening on $A$ might be sufficient for $A$ to be ontologically prior to $B$; or supervenience might only be necessary and reducibility sufficient. For our purposes, the missing consensus of what 'ontologically prior' means is actually an advantage, for it allows us to use the term in MESP position, and to have different ways of cashing out 'ontologically prior' correspond to different ways of extending MESP further, different concreter versions of super-substantivalism.[14]

What speaks in favour of the super-substantivalist core position? Not common sense, surely. But if other arguments speak in favour of it compared to its rivals — e.g. its parsimony or its higher compatibility with modern physics — then we may decide not to worry about common sense too much. Either way, just as in the case of substantivalism, isolating the core commitment is just where work begins. The real interest of super-substantivalism lies in its particular variants rather than in the core commitment shared by all of them, and we will look at some such variants in sections 4 and 5. Nonetheless, we need first to review the two main arguments that have been put forward for super-substantivalism in general (i.e., the core commitment).

# 3 The two main arguments for super-substantivalism per se

## 3.1 Parsimony

Even though philosophers of physics have looked at super-substantivalism only in passing in recent decades,[15] metaphysicians have argued with passion on behalf of super-substantivalism,

(2009) calls the unrestricted identity view (discussed further in section 4), his favourite version of the identity view, definitely does. Of course he may well decide to embrace the breakdown of the spacetime/matter distinction; and he could draw on the discussion of substantivalism/relationism in philosophy of physics for support of said embrace (see the end of section 5).

[14]See sections 4 for different variants of super-substantivalism along these lines. For different accounts of ontological priority / ontological dependence see Fine (1995), Bricker (2006) Correia (2008).

[15]This is likely related to a particular super-substantivalist programme in physics, John Wheeler's Geometrodynamics, being abandoned in the early 1970s, to the big disappointment of many philosophers of physics; see Stachel (1972) and Misner (1972) for details of the development of this research programme. Of course, one particular variant of super-substantivalism being unsuccessful does not say much about the

although, in many cases, surprisingly briefly. For example, Lewis (1986), p.76, states:[16]

> There are three different conceptions of what the spatiotemporal relations might be. There is the dualist conception: there are the parts of spacetime itself, and there are the pieces of matter or fields or whatnot that occupy some of the parts of spacetime. [...]
>
> There are two simpler monistic conceptions. One of them does away with the occupants as separate things: we have the parts of spacetime, and their distance relations are the only spatiotemporal relations. The properties that we usually ascribe to occupants of spacetime — for instance, properties of mass, charge, field strength — belong in fact to parts of spacetime itself. When a part of spacetime has a suitable distribution of local properties, then it is a particle, or a piece of a field, or a donkey, or what have you.
>
> The other monistic conception does the opposite: it does away with the parts of spacetime in favour of the occupants (now not properly so called), so that the only spatiotemporal relations are the distance relations between some of these. I tend to oppose the third option, at least as applied to our world... . I tend, more weakly, to oppose the dualist conception as uneconomical.

Lewis effectively claims that the monistic position which takes only spacetime as basic, i.e. super-substantivalism, is preferable to at least classical substantivalism because of the latter's lack of parsimony (it being uneconomical) when postulating two rather than one fundamental kind of substance. Sider (2001), p. 109-110, gives the same argument with more force:

> First, assume that substantivalism is true, that there are such things as points and regions of spacetime. There is then the question of whether there is anything else, whether spatiotemporal objects occupy, but are distinct from, regions of spacetime, or whether they simply are regions of spacetime.
>
> There is considerable pressure to give the latter answer, for otherwise we seem to gratuitously add a category of entities to our ontology. All the properties apparently had by an occupant of spacetime can be understood as being instantiated by the region of spacetime itself. The identification of spatiotemporal objects with the regions is just crying out to be made.

promise of the family of positions as a whole (compare the abandonment of manifold substantivalism as a consequence of the hole argument and the subsequent development of more sophisticated versions of substantivalism).

[16]Note that Lewis' characterisation of super-substantivalism goes beyond what I call the core commitment: he claims the super-substantivalist is committed to taking only distance relations between the parts of spacetime as fundamental. However, it is completely compatible with the super-substantivalist core commitment to take the topological relations or affine structure as equally or even more fundamental than distance structure. (Indeed, differential geometry tells us that we need topological structure to have metric/distance structure but not vice versa. Affine structure can be derived from metric structure in pseudo-Riemannian spacetimes but not in generalisations thereof.)

Here too, the main argument put forward in favour of super-substantivalism is its parsimony. While relationalism can always claim that it is more parsimonious than substantivalism because it postulates only one kind of fundamental object, namely material objects, the super-substantivalist can claim that he does even better: he does not only get by with *one kind* of substance but with only *one instantiation* of that kind of substance: there is only one spacetime.

But things are not so simple.[17] Even in the context of the classic substantivalism/relationalism debate, substantivalists have claimed that, despite first appearances, relationalism may not be more parsimonious than substantivalism after all. For while the substantivalist can refer to one interrelated corpus of properties of relations possessed by spacetime, the relationalist has to postulate them as unconnected primitive relations between material objects.[18]

By contrast, the core commitment of super-substantivalism does not commit one to the belief that there is only one entity, spacetime. One may be a monist on the categorical level but a pluralist with regard to the number of elements in that category. Thus, rather than saying 'there is only one concrete object, spacetime', one could also be of the opinion that 'there is only one *kind* of concrete objects: parts of spacetime'.[19]

A pluralistic super-substantivalist, of course, faces the same challenges as the relationalist, who believes that the only fundamental kind of object in the world is comprised of material objects. The pluralistic super-substantivalist has to explain why and in what sense the parts of spacetime are related so as to give rise to the multitude of phenomena we observe: from extended regions of spacetime, light cones allowing us to distinguish between past and future, to red billiard balls allowing us to smash windows. He may be able to give a far simpler account than the monistic super-substantivalist, or he may not; and indeed it may be that in the end the (normal) substantivalist, who allowed for two rather than one category of fundamental objects (parts of spacetime *and* material objects), can give the simplest account of all.

In the end, this is just speculation, and speculation has to stop at some point. Neither substantivalism, relationalism nor super-substantivalism *as such* can be judged more parsimonious than its competitors; the respective core commitments are just not rich enough. We need to compare a *particular version* of super-substantivalism with particular versions of substantivalism and relationalism, even to hope for a reliable judgement of which position tells the simplest story of how the different parts of the world are related. The core commitments are just the prologue, and knowing the prologue is not enough to judge a story.[20]

But, even if we had a definite answer to the question of which approach is the most parsimonious, what would it tell us? Sure, parsimony is rather attractive philosophically. But, in the end, we don't know if the world is simple, and so we don't know if the simplest

[17]See Thomas (2013*b*) for a complementary discussion of the argument from parsimony.

[18]See Field (1985) and Maudlin (1993), p.194-196.

[19]Schaffer is a monistic super-substantivalist, thinking that the whole of spacetime has priority over its parts, while Sider is a pluralistic super-substantivalist, denying priority of the whole of spacetime. Both take the parts of spacetime to be regions; see Schaffer (2009) and Sider (2001, 2007), respectively.

[20]I will distinguish between different versions of super-substantivalism in sections 4 and 5.

approach gives the best possible fit to the world. Let's be honest and admit that in the end striving for parsimony amounts to not much more than a 'principle of laziness', or 'principle of pragmatism', if you will: we look for the simplest approaches because they are the ones that seem easiest to handle at first sight. Having only one kind of screwdriver has its advantages: you never have to look where you put the other ones. But it may turn out that operating with only one kind of screwdriver limits you in how you can handle *the actual world*.

Thus, in the end, super-substantivalism has to face the same hard tests that substantivalism and relationalism faced in the debate following the rediscovery of the hole argument: its compatibility with modern physics has to be checked. In order to do this, we have to forge different concrete variants of super-substantivalism going beyond the core commitment — concrete enough to be compared to the different variants of substantivalism and relationalism in the light of modern physics. Of course, the relevant part of modern physics is field theory, and general relativity in particular.

## 3.2 Modern field theory

Hartry Field has argued that even though there is a genuine dispute about whether substantivalism or relationalism is the right metaphysical stance with respect to a theory based on a particle ontology, like Newtonian mechanics, this changes when we come to the theories of modern physics. Here, *fields* are fundamental entities, either solely or in addition to particles.

Field argues that a field theory presupposes a substantivalist conception of spacetime. He writes (Field (1989), p.181):

> As I see it, a field theory is simply a theory that assigns causal properties to space-time points or other space-time regions directly (as opposed to indirectly, via matter that occupies those points or regions). (Or to be more accurate, it is the theory that *employs causal predicates* that apply directly to space-time points or regions.) For instance, in electromagnetic field theory we assign to each point in space-time an electromagnetic intensity, irrespective of whether this point is occupied by matter. Obviously this presupposes a substantival view: on a relational view, there are no points or other regions of unoccupied space-time, so the assignment of a property to such a point or region makes no sense. Consequently, it seems to me that for a physical theory to accord with anything reasonably called relationalism, that physical theory cannot be a field theory.

To follow Field's arguments with respect to a *pure* field theory, i.e. a theory in which *only* fields exist — rather than fields alongside material particles — means presupposing a super-substantivalist conception of spacetime.

But is this true? Does field theory (be it pure or not) commit us to interpreting the fields as properties of spacetime points? Earman (1989), p.115, sides with Field to some extent by admitting that super-substantivalism is a *natural* interpretation of a pure field theory:[21]

> The second embellishment comes into its own under what can be called *super-substantivalism*, the view that space is the only first-order substance in the sense that space points or regions are the only elements of the domains of the intended models of the physical worlds.
>
> [...]
>
> To realize super-substantivalism, one doesn't have to revert to the view that space is stuff that forms the corpus of bodies, nor does one have to resort to some outlandish theory. Indeed, modern field theory is not implausibly read as saying the physical world is fully described by giving the values of various fields, whether scalar, vector, or tensor, which fields are attributes of the space-time manifold $M$.

The second half of the quotation alludes to the distinction between modest and radical super-substantivalism that we will look at in detail in section 5. Field's view has been criticized, especially since he does not really give an argument for why field theory should be interpreted as asserting that spacetime points (or regions) are substances and fields properties of these substances; Field merely states this to be the case. Malamant (1982), p.531-532, points out that surely an argument is needed here: after all, Malament argues, it is *fields* such as the electromagnetic field that possess mass-energy content, not the points of spacetime.[22]

A similar argument can be found in Teller (1996), who writes (p. 382):

> Hartry Field (1980, p. 35) argued, very simply, that to do field theories we must have the space-time points as the things of which the field quantities are predicated.
>
> But consider the fact that relativity theories drop the distinction between mass and energy, so that the field quantities, themselves carrying energy, can be seen as substantival. Thus we can reverse the role of predicate and subject. Instead of attributing a bit of mass-energy, in the form of a field, to a substantival space-time point, we can, on the present proposal, attribute a relative space-time location to a bit of a field — a bit of mass-energy in the form of an electromagnetic field, a matter density field, or the like. The relative location is just a relational property, that is, a space-relation to some actually exemplified trajectory.

[21] Schaffer (2009), p. 10, misreads Earman (1989) as "suggesting" and endorsing super-substantivalism, yet the latter merely says that modern field theory is "not implausibly read" in a super-substantival fashion. Indeed Earman does not endorse this view, insetad he ends up defending a view that he locates between substantivalism and relationalism, a view that gets rid of points and regions entirely and endorses the use of 'Einstein Algebras' as introduced by Geroch (1972), renamed by Earman as 'Leibniz Algebras'.

[22] French & Ladyman (2003), p.46 acknowledge both options when they write: "[A] form of metaphysical underdetermination arises here with the physics supporting both the view of fields as substances whose properties are instantiated at space-time points (or regions) and the view of fields as nothing but properties of those space-time points (or regions)".

Field could now answer that mass-energy is represented by the mass-energy-momentum tensor field $T_{\mu\nu}$, and hence should also be considered as a property of spacetime points, albeit one that is associated with the spacetime point also possessing the property of an electromagnetic field (say) being present. In any case, Malament and Teller effectively show that Schaffer (2009), p.8, is surely too quick when he claims that "everyone in the debate understands [$T_{\mu\nu}$] as a feature of spacetime" — many understand it as a property of material systems, described by a field.[23]

What remains is that it seems *plausible* (Earman) rather than *necessary* (Field) to interpret (pure) field theories in super-substantivalist terms, to regard fields as properties of spacetime points or regions.

But if we were to leave it at that, we would overlook an important distinction: that between *geometric* and *non-geometric* properties of spacetime. The metric field $g_{\mu\nu}$ allows us to define spatial distances, temporal durations and a distinction between past and future. If you believe there is spacetime, then you almost can't help taking the metric field as encoding at least some of its paradigmatic properties.[24] But the same is not true for the electromagnetic field: we *can* interpret an electromagnetic field strength as a property of the spacetime region it occurs in, but we do not *have* to.

Thus, there are some fields which *can* be interpreted as properties of spacetime, and yet others that *have to* be interpreted as properties of spacetime;[25] if one believes in the substantival existence of spacetime at all. The question of whether one does justice to this distinction divides the super-substantivalist camp into two subsets: modest and radical super-substantivalist positions.

In section 5 we will see that most if not all extensions of the super-substantivalist core commitment fall into one or other category; but, before we go there, let us examine how the core commitment can be extended to different positions with flesh and muscles on the bones.[26]

[23]Of course, taking such a position does not mean that the properties of material systems do not depend on spacetime. In Lehmkuhl (2011), I argue that mass-energy-momentum density $T_{\mu\nu}$ is a property material systems have only in virtue of their relationship to spacetime structure. However, such a *dependence* of important properties of material systems on spacetime structure is not the same as a *reduction* of these properties to spacetime structure.

[24]This is true even for manifold substantivalists, i.e. substantivalists who take only the manifold $M$ as representing physical spacetime (rather than, say, the pair $(M, g_{\mu\nu})$). For, even if one regards the metric field $g_{\mu\nu}$ as analogous in almost every respect to the other fields defined on $M$, it is still the case that $g_{\mu\nu}$ encodes paradigmatically spatiotemporal properties, that it endows the manifold $M$ with a geometry, or — put more neutrally — that it allows for a geometrical interpretation which other fields lack.

[25]Of course, which category a given property should be put in depends on which physical theory of physics one takes as a basis of one's metaphysical deliberations. If the theory in question is GR, then the metric field arguably belongs in the '*has* to be interpreted as a property of spacetime' category, while the electromagnetic field belongs into the '*can* be interpreted as property of spacetime'. If the theory in question is, say, Kaluza's original five-dimensional unified field theory of gravitation and electromagnetism (see Kaluza (1921)), then both the 4-dimensional metric field and the electromagnetic field arise from projection of the metric field of 5-dimensional spacetime, and are thus equally 'spacetimy'.

[26]In this section I have discussed what I regard as the two most promising arguments for super-substantivalism per se, i.e. for the core commitment. Both Schaffer (2009) and Thomas (2013*b*) put a

# 4 Extensions of the super-substantivalist core commitment

Above I have formulated a minimal extension of the super-substantival core commitment (MESP) as follows: spacetime is *the only* substance in the world; spacetime is ontologically prior to matter. If 'ontologically prior to' is identified with 'reducible to', a shorter version would be: *All there is is recucible to spacetime.*

But identifying ontological priority with reducibility already goes beyond MESP. Indeed, it is an advantage of MESP that it leaves plenty of possibilities to make the super-substantivalist position more precise, make it more concrete, bringing into being a veritable *family* of positions, rivaling the different forms of substantivalism and relationalism created in the last few decades.

Currently, the most prominent extension of the core commitment in the metaphysical literature is surely what Schaffer (2009) called *the identity view.* The latter forms a sub-family of super-substantival positions separate from the MESP-family, and all of its positions have in common that they *identify* material objects with spacetime regions.[27] Some variants identify *every* spacetime region with a material object (these variants are preferred by Schaffer; he calls them the unrestricted identity view),[28] others only with spacetime regions that fulfil certain conditions.[29] An alternative is the *composition view*, which regards material objects as *composed* of spacetime regions rather than as identical to them.[30]

The question of whether the identity and the composition view are really two distinct views turns on old questions of metaphysics, often discussed using a statue made of clay, and investigated by pondering the question of whether the statue is or is not identical to

lot of weight on a third argument, which they call the argument from materialisation. In short, the argument says that super-substantivalism is the only position that can readily explain the alleged fact that "[m]aterial objects cannot exist without occupying spacetime regions"(Schaffer (2009), p. 141) or, more carefully put, "the fact that matter seems to be *necessarily* spatio-temporally located" (Thomas (2013*b*), p.120). My answer is that it is not at all clear that this really is a fact, that it really is *necessary* for something to occupy parts of spacetime in order to be material. This doubt is strengthened by the fact that there are now various approaches in quantum gravity research which start from certain quantum structures (which are not defined on a space- or spacetime manifold) as fundamental and which aim to derive spacetime as an emergent entity in the macroscopic limit. In these theories, (quantum) matter *does* exist without occupying parts of spacetime, and *gives rise* to spacetime in some domain. The very conceivability of such approaches suggests that matter cannot *necessarily* be bound to a spatio-temporal existence.

[27] I will argue below that one should generalize the category 'spacetime regions' to 'spacetime parts', which contains spacetime regions as a proper subset.

[28] On this view, even what physicists call empty Minkowski spacetime (or indeed any 'vacuum solution' of General Relativity) would count as one giant material object, by fiat.

[29] If I had to choose among only different variants of the identity view rather than also being allowed to choose from (what I think are) far more attractive variants of super-substantivalism, I would choose a variant where only spacetime regions that possess mass-energy are identified with material objects. The reason is that, I think, there are strong reasons to regard mass-energy as an essential (or, if you want, necessary) property of matter, as argued in Lehmkuhl (2011).

[30] Thomas (2013*b*), chapter 3, attributes this version of super-substantivalism to the early Newton, expressed in his *De Gravitatione*.

the clay it is composed of. I will not elaborate on the issue as it is clear that it does not pertain to super-substantivalism as such; whatever position you take with regard to the relationship between identity and composition will transfer from the statue and clay it's made of to material objects and the spacetime regions they are made of according to super-substantivalism.[31] However, I note that the composition view as applied to material objects and spacetime (just as in the case of the statue and clay) has the advantage that one can give a better account of a *process* that amounts to creating a material object from parts of spacetime. Furthermore, the composition view allows for the composed object to have properties different from those possessed by its constituents.[32] Indeed, this is the super-substantivalist position that Thomas (2013*b*), chapter 3, attributes to the early Newton: he denies the Cartesian identification of matter and space, but thinks of matter as created from space, whilst seeing them as belonging to two different categories nonetheless.[33]

We have seen that two ways to extend the super-substantivalist core commitment involve saying that material objects are either identical to or composed of spacetime regions. However, we should note that even just thinking of spacetime as composed of spacetime regions goes beyond the core commitments of both substantivalism and super-substantivalism. We should instead speak of the *parts* whereof spacetime is composed; this leaves open whether those parts are manifold points or regions, discrete grains not representable by a manifold, or structural aspects of spacetime like its affine or metric structure. Indeed, in the context of modern differential geometry it seems much more natural to think of the building blocks of spacetime not as regions but (in that hierarchical order) as the chain of manifold structure, topological structure, projective and conformal structure, affine structure, and, finally, metric structure. Different spacetime theories assume spacetime to be composed of different members of this list, and that they are related to one another in different ways. Speaking of spacetime as composed of spacetime regions does not do justice to this intricate network of ontological dependences; but either way, speaking of spacetime as composed of parts allows for (super-)substantivalists who believe these parts to be regions, and others who believe the parts to be the above structural aspects.

Let us come back to the question of what may be meant by the assertion that spacetime is ontologically prior to matter in MESP extension of the core commitment. A minimal requirement for ontological priority is that the relation is asymmetrical and irreflexive: if $A$ is ontologically prior to $B$ then $B$ is not ontologically prior to $A$; and nothing is ontologically prior to itself.

[31] If the identity and the composition relationship are concluded *not* to be identical, in particular if the composition relationship is taken to imply that that which is composing is ontologically prior to that which is composed, then the composition view is an extension of the MESP (familiy of) positions.

[32] A gas has a temperature even if the particles its made of do not, and a spacetime manifold has the property of being 'connected' (in a technical sense) even if no point by itself has that property; more on this and the connection to the debate between reductionism and emergentism below.

[33] For Newton in *De Grav*, matter, being composed of space, is a substance, whereas space itself is not. This means that Newton is not so easily categorized as a substantivalist as is often done; however, it is clear that Newton (in *De Grav*) thought of space as ontolologically prior to matter. Thus, even though classifying him as a straightforward substantivalist is tricky, it is clear that he believed in the 'super-' of super-substantivalism.

One way of spelling out what it means for $A$ to be ontologically prior to $B$ is to say that $B$ is *reducible* to $A$. The follow-up question is then: what are the necessary and sufficient conditions for something to be reducible? Of course, there is a huge literature on this in metaphysics and philosophy of science. Even the proponent of the identity view can be a reductionist if he sees 'being identical to' as sufficient for reducibility; yet, he faces the problem that identity is a symmetrical relation while reducibility, on all accounts I think, is not.[34]

Another brand of super-substantivalism may think of spacetime as ontologically prior to material objects by virtue of the latter being *emergent* from the former, a position famously attributed to Samuel Alexander.[35] Just as with 'reducibility', the most important question is how 'emergence' is defined. A promising view, offered by Butterfield (2011*a*,*b*) defines emergence "as behaviour that is novel and robust relative to some comparison class". Defined in this way, emergence is in principle compatible with reduction, if one follows Butterfield in defining reduction as deduction with the help of auxiliary conditions. Either way, without going into details of the different definitions of emergence that have been put forward: thinking of matter as emergent from spacetime also allows for it to have properties different from the spacetime parts it emerges from. However, matter being emergent from spacetime can only be a sufficient, not a necessary condition for spacetime to be ontologically prior to matter.

Also, it seems sensible to take reducibility of matter to spacetime to be sufficient for spacetime to be ontologically prior to matter; it is less clear whether the condition is also necessary (in which case 'ontologically secondary to' and 'reducible to' would be synonyms). Still it is clear that a big subset of the super-substantival family of positions will spell out ontological priority via reducibilty.

The above discussion suggests that we have a clear handle on what counts as 'matter' and what as 'spacetime (structure)', and that we can look at the two sides of the divide and wonder whether one is ontologically prior to the other. Of course, one of the most important lessons of modern spacetime theory is that the distinction between matter and spacetime has become more and more blurred. Indeed, most of the debate that resulted in spelling out different forms of (normal) substantivalism starts from the discussion of whether GR's $g_{\mu\nu}$ field should be classified as encoding part of spacetime (structure), or whether it is 'a field like any other', i.e. so close to matter fields like the electromagnetic field $F_{\mu\nu}$ that a categorical distinction is unjustified.[36] However, I take it that both camps in this dispute agree that *if* one takes spacetime to be a substance, then the $g_{\mu\nu}$ field, among other things giving a measure of distance between points of spacetime, can be interpreted as encoding important properties of that substance, or as endowing spacetime with these properties. The question for the super-substantivalist now is which other properties can be taken to describe properties or aspects of spacetime. This brings us to the distinction between modest and

[34]For similar reasons, *supervenience* is unlikely sufficient for ontological priority, if one takes the supervenience relation to be reflexive and not asymmetrical.

[35]See Thomas (2013*a*) for details.

[36]See Anderson (1999), Brown (2009, 2007) and Rovelli (2004) for the latter view, and Maudlin (1993, 1989), Hoefer (1996) and Pooley (2013, forthcoming) for the former view.

radical super-substantivalism.

# 5 Modest and radical super-substantivalism

The family of super-substantivalist positions neatly divides into two camps. Only one camp is willing and capable of engaging with physics; the other is a set of super-substantival positions that can be maintained no matter what physics tells us about the nature of spacetime. I will argue that philosophy should engage primarily with the first camp, even though recent years have seen it concentrate exclusively on the second camp.

The two sets of family members correspond to what Skow (2005), p.66-68, called radical and modest super-substantivalism, respectively. The distinction comes from different answers to the question of which *fundamental* properties spacetime is allowed to instantiate.

For a *modest super-substantivalist*, there is no real difference between saying 'This spatial region has a diameter of 8 inches' and the statement 'This spatial region is red'. The modest super-substantivalist allows spacetime to instantiate (on the fundamental level) not only topological and geometrical properties but also the properties we normally regard as instantiated by matter, such as colour, mass, electric charge or momentum density.

As far as I can see, most if not all metaphysicians advocating super-substantivalism belong to the modest camp. Schaffer (2009), p. 139, makes this particularly clear when he asks

> Once one has pinned the geometrical and mereological properties directly onto the receptacle, why stop there? Why not also pin the masses and charges onto the receptacle as well? In general, is there some principled reason for using spacetime as the pincushion for only some of the fundamental properties?

It is completely clear to Schaffer that one can attribute to spacetime regions properties such as mass or colour just as much as extension or circumference. But, as pointed out in the last section, he thereby does not do justice to the distinction between properties/fields that even the dualistic substantivalist *has to* interpret as aspects of spacetime structure (like the metric field $g_{\mu\nu}$ in GR), and those where he *can* but does not have to do so (like the electromagnetic field $F_{\mu\nu}$ in GR).

The modest super-substantivalist is willing to leave it at that. He just shrugs his shoulders when asked whether attributing the properties 'red' or 'solid' to a spacetime region does not seem to have a different quality from attributing to it the property of being 'extended'.

The *radical super-substantivalist* disagrees. He agrees with the dualistic substantivalist that only geometrical (and topological) properties should be attributed to spacetime and its parts. As a consequence, he has to offer an account of how *apparently* non-geometrical poperties like colour, electric charge or solidity can be *reduced to* (or indeed emerge from) geometrical or topological properties. Sklar (1974), p. 166, is very clear about what he thinks of the two camps of super-substantivalism:

> The identification of all of the material world with the structured world of spacetime is not to be interpreted as the linguistic trick of simply replacing objects by the region of spacetime they occupy and some novel "objectifying feature" — say replacing 'There is a desk in the (X,T) region' by 'The (X,T) region desks.' The *scientific* program of reducing matter to spacetime is rather more on the order of the scientific program of reducing material objects to arrays of their microscopic constituents or identifying light rays with electromagnetic radiation. In the reduction, the assertion of the existence of a material object at some spacetime location is to be shown reducible to the assertion of some spacetime feature holding in the spacetime region, say its having a certain intrinsic curvature over the region.

Even though I sympathise with Sklar, it has to be conceded that he is somewhat unfair towards the modest super-substantivalist. True, modest super-substantivalism is *not* a scientific research programme. It is not a stance that could motivate research in physics, or serve as guiding principle for such research. Modest super-substantivalism is a purely metaphysical standpoint that can be taken quite independently from the physical theory we find to be true, and it is motivated by purely philosophical advantages.

That is not bad in itself. But it cannot be denied that a philosophical standpoint like radical super-substantivalism that *can* be fruitful for physics, motivate it and in turn be questioned by it, is a very desirable thing.

This is what radically super-substantivalist positions offer: they are programmes that pose a real challenge to physics, offering fruitful heuristics for scientific research, and can in turn be challenged by it. One important example of a radically suber-substantival research programme is John Wheeler's 'Geometrodynamics'. His aims are best summarised in the following quotation:[37]

> Is space-time only an arena within which fields and particles move about as 'physical' and 'foreign' entities? Or is the four-dimensional continuum all there is? Is curved empty geometry a kind of magic building material out of which everything in the physical world is made: (1) slow curvature in one region of space describes a gravitational field; (2) a rippled geometry with a different type of curvature somewhere else describes an electromagnetic field; (3) a knotted-up region of high curvature describes a concentration of charge and mass-energy that moves like a particle? Are fields and particles foreign entities immersed *in* geometry, or are they nothing *but* geometry?

The programme gives us *one* example of how the super-substantival core commitment may be expanded into a precise position which brings metaphyics and physics closer together. Rather than leaving it at saying that all properties are properties of spacetime (modest super-substantivalism), or even at saying that non-geometrical properties have to

[37] Wheeler (1962*a*), p.361.

be *somehow* reduced to geometrical properties, Wheeler suggests *which* apparently non-geometrical properties might be reducible to *which* geometrical properties. In his approach, the gravitational field is reduced to one kind of spacetime curvature, whereas the electromagnetic field is reduced to another.[38] Particles are reconceptualised as small regions of spacetime in which the curvature is particularly strong and of a certain form; for stable particles, gravitational and electromagnetic curvature have to keep each other in balance. Wheeler called such constructs '*geons*, gravitational-electromagnetic entities'.[39]

Wheeler's research programme was abandoned in the 1970s.[40] For Sklar is right: every version of radical super-substantivalism is a scientific research programme, and as such it can succeed or fail, or be revived after it was judged to have failed.[41] Wheeler wanted to reduce gravity, electromagnetism, and mass-energy to four-dimensional curvature. More recently, other research programmes motivated by radical super-substantivalism have been proposed. Wesson (2007) and collaborators have revisited Theodor Kaluza's and Oskar Klein's idea that spacetime is really five- rather than four-dimensional. Like Klein (1926, 1928), Wesson et al. postulate the vacuum Einstein equations as the field equations of the five-dimensional spacetime. In contrast to the founding fathers of the idea, they get much further in deriving the matter we see in four dimensions from the geometrical properties of the five-dimensional spacetime. In a different, quantum-mechanical, research programme, Bilson-Thompson et al. (2007) start out from the mathematics of Loop Quantum Gravity, introducing a canonical split of spacetime into space and time and assuming that space fundamentally consists of discrete 'grains' of space. The fundamental particles of the standard model of particle physics

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[38] Wheeler solved the Einstein-Maxwell equations for the electromagnetic field tensor $F_{\mu\nu}$, pointing out that Rainich and Misner had shown that this is possible only if the curvature tensor fulfils the two properties

$$R = 0 \tag{1}$$

and

$$R_{\alpha}{}^{\beta} R_{\beta}{}^{\gamma} = \delta_{\alpha}{}^{\gamma}\ (\frac{1}{4} R_{\sigma\tau} R^{\sigma\tau}) \tag{2}$$

The result is then put into Maxwell's equations, and thus the Einstein-Maxwell equations are formulated in terms of $R_{\mu\nu\sigma}^{\ \ \ \ \omega}$ alone rather than $R_{\mu\nu\sigma}^{\ \ \ \ \omega}$ and $F_{\mu\nu}$. With the definition

$$W_{\tau} := (-g)^{\frac{1}{2}} \epsilon_{\tau\lambda\mu\nu} \frac{(\nabla_{\mu} R^{\lambda\beta}) R_{\beta}{}^{\nu}}{R_{\gamma\delta} R^{\gamma\delta}} \tag{3}$$

the Maxwell equations then become

$$\nabla_{\eta} W_{\tau} - \nabla_{\tau} W_{\eta} = 0 \quad , \tag{4}$$

which are equations of fourth order in the metric. See Wheeler (1962*b*), pp.250-253.

[39] Einstein (1919), unbeknownst to Wheeler, had tried out a mathematically similar approach, interestingly without radically super-substantivalist motivations.

[40] See Stachel (1972), Graves (1972), Graves & Earman (1972), Misner (1972) for details of the reasons.

[41] Giulini (forthcoming) discusses the extent to which research in general relativity showed that the ideals of geometrodynamics were fulfilled to a much larger extent by results in canonical GR (a formulation of GR with which geometrodynamics had started out with) than Wheeler and Misner had antipicated when they abandoned the approach.

(and their most important properties rest mass, spin and different kinds of charge) are aimed to be reduced to different states of these grains. Thus, elementary particles would be nothing other than quanta of space.

We see that both in the classical and in the quantum domains there are very different ways in which one could aim to reduce the apparently non-geometrical properties of what we perceive as matter to geometrical or topological properties of spacetime. And each path corresponds to a particular variant of radical super-substantivalism. Many more than those already pursued in physics and described above are possible: e.g., the mass of an electron could be reduced not to the curvature structure of spacetime but to its affine structure, the spin of the electron related to the torsion structure of spacetime and its electric charge to the topological structure of spacetime.[42]

Which aspect of spacetime structure matter is associated with (curvature is only one possibility) will also determine whether an empty (matter-free) spacetime is allowed. If matter is reducible to curvature structure alone, then we can have empty spacetime without losing a grip on its fundamental structure; if it corresponds to certain topological properties, then we cannot have a spacetime without the presence of matter — even though it would still be derivative of spacetime, it would also be necessarily co-existent with it. We see that even within the radical catgory, there are plenty of distinctions to be made, different super-substantival outlooks.

Not much can happen to the modest super-substantivalist, neither good nor bad things: however physics develops, there is a way for him to uphold his position. In contrast, the different versions of radical super-substantivalism have the potential to provide physics with a fruitful heuristic, and take part in actually learning something *about the world*. If we were to find out that, say, electrons are nothing more than excitations of a discrete spacetime, then we would have found out something genuinely new about matter, space and time. The modest super-substantivalist can hope for no such event; his position is too far removed from physics.

As pointed out by Sklar, radical super-substantivalism is more than a metaphysical position. It is a research programme, a challenge and motivator for physics. At the same time, it is philosophically even more attractive than modest super-substantivalism. For the latter has to allow both geometrical and non-geometrical properties as categories, whereas the radical super-substantivalist tries to get by with only geometrical and topological properties and structures. He can even expect *to learn something new* about matter once he has associated it with particular aspects of spacetime structure, for the relationships between different aspects of spacetime structure we know of are likely to direct our attention to as yet unknown relationships between the different kinds of matter and their properties.

The radical super-substantivalist may fail. But, if he succeeds, the reward is great.

[42] Relating electric charge to the topology of a multiply connected four-dimensional spacetime was actually part of Wheeler's programme; the other two options named here have not, to my knowledge, been pursued yet.

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