Identity, Spacetime, and Cosmology

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Abstract

Modern cosmology treats space and time, or rather space-time, as concrete particulars. The General Theory of Relativity combines the distribution of matter and energy with the curvature of space-time. Here space-time appears as a concrete entity which affects matter and energy and is affected by the things in it. I question the idea that space-time is a concrete existing entity which both substantivalism and reductive relationism maintain. Instead I propose an alternative view, which may be called non-reductive relationism, by arguing that space and time are abstract entities based on extension and changes.

Theories about the nature of space and time come traditionally in two versions. Some regard space and time to be substantival in the sense that they consider space-time points fundamental entities in their own right; others take space and time to be relational by somehow constructing points and moments out of objects and events. In spite of their fundamental disagreements, substantivalists and relationists share a common view: they regard space and time as concrete particulars. Hence Quine's famous dictum "no entity without identity" should apply to space and time. Supposing the existence of a concrete particular, we must be able to point to some determinate identity conditions of space and time which would allow us to regard them as concrete particulars. In fact, most philosophers just take for granted that space and time are concrete entities; they tacitly presume that appropriate identity conditions exist and that it is rather unproblematic to specify what these are.

In his seminal work on the debate about absolute and relational theories of space and time, Earman (1989) points to the serious difficulties concerning identity and individuation any theory of space-time points must confront. After having discussed various metaphysical accounts of predication, he makes the following remarks:

> One could try to escape these difficulties by saying of space-time points what has been said of the natural numbers, namely, that they are abstract rather than concrete objects in that they are

> to be identified with an order type. But this escape route robs space-time points of much of their substantiality and thus renders obscure the meaning of physical determinism understood, as the substantivalist would have it, as a doctrine about the uniqueness of the unfolding of events at space-time locations. (p.199)

Earman does not go further into this suggestion because, as he observes, it departures too much from the substantivalist core assumptions. I shall, however, attempt to lay out a view according to which space-time is taken to be an abstract entity. But first I shall review some of the difficulties which Earman mentions in the light of recent discussions on identity and individuality.

Until recently I shared the concreteness view of space and time, or spacetime. But I couldn't find any plausible identity conditions for space and time, or space-time, to be concrete particulars. I have since begun to think that spacetime points should be categorized as abstract particulars.[1] I don't know whether this puts me in a bad company, but I think Leibniz meant something similar in his correspondence with Clarke when he pointed out that space and time are not fully real but are 'ideals'.[2] Space, I submit, refers to the set of all bodies, and time designates the set of all changes with a beginning and an end. I believe that this position has some very important explanatory advantages and that it may even open up for a satisfactory solution to the debate between the relationist and the substantivalist. I shall present some arguments to the effect that space and time, or spacetime, should be considered abstract particulars. By this I mean that locations and moments are existent things – abstract man-made artifacts whose role is to help us represent the world and thereby identify and individuate concrete objects.

My suggestion is that space-time is an abstract object whose structure supervenes on actual things and events. For the sake of terminological clarification, I take an abstract object to be an entity which is existentially dependent on concrete particulars that instantiate it and whose identity does not fulfil the normal determinate identity condition of concrete objects. Similarly, I take particular properties and relations to be tropes that are instances of universals. While I recognize that other philosophers use these terms differently, space prohibits me from discussing those uses here.

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[1] In an earlier paper (Faye 2006b), I argued that time is an abstract entity but kept a door open for the concreteness of space. Also I counted Leibniz as a proponent of space and time as concretes because I took him for being a reductionist by heart. Now, having reconsidered, I must admit that this remark may be too hasty.

[2] Indeed, 'ideal' have several meanings. By using 'ideal' in contrast to 'real', Leibniz seems to think of space and time as something whose existence (partly) depends on the mind.

The Existence of Space

Whether we think of space as being absolute or relational, space is considered to be physically real. Either view takes for granted that spatial locations exist. The absolutist, in being a substantivalist, believes that space points exist over and above what is located in them, and that these points have intrinsic relations to one another. The relationist, in contrast, argues that spatial locations are nothing by themselves, since they are reducible to things that are said to occupy them, and which can be directly related by physical processes among these things.

Historically these characterizations may not be true of the two arch contestants of substantivalism and relationism respectively. Newton denied that space and time are real substances, nor are they accidents. He seems to have taken over Pierre Gassendi's view that space and time are of a third kind, claiming that space and time are preconditions of substance. Before Newton, Gassendi argued that time flows uniformly regardless of any motion, and that space is uniformly extended irrespectively of the bodies it may contain.[3] Newton associated space and time with modes of existence because of his assumption of God as the necessary Being who is substantially omnipresent and eternal. Nonetheless, he claimed: "Although space may be empty of body, nevertheless it is not itself a void; and *something* is there because spaces are there, though nothing more than that" (Hall and Hall 1962: 138). He also emphasized that space is distinct from body and that bodies fill the space. So Newton seems to be as close to being a substantivalist as one can be, especially if one brackets his belief in God and consider space to be an immaterial substance which can exist empty of any material substances. Similarly, Leibniz was less of a hard-core relationist than was Descartes. In his correspondence with Clarke, he explicitly said that space and time are 'ideals', having no full reality. Space "being neither a substance, nor an accident, it must be a mere ideal thing, the consideration of which is nevertheless useful" (Alexander 1956: 71). This is interesting because it indicates that Leibniz saw space and time as abstractions rather than an aggregate of spatial and temporal relations between concrete objects.

If locations or space points are concrete entities, it must be possible to specify their identity conditions in a way showing that they are concrete entities. Space points are in Space, and being in Space is a criterion of being a concrete entity. However, space points cannot exist independently of Space itself. Particular locations are intrinsically featureless; they lack any internal features for differentiation among themselves. Being parts of Space they have, by necessity, the same nature of identity as Space itself in terms of being concrete or abstract. Space is not just the mereological sum

[3] See Gassendi (1971), s. 383 ff.

of its parts even though spaces may seem to be absolutely the same all the way down because Space, taken to be a substance, contains an absolute metric that cannot emerge from a collection of individual points. Rather the individuality of the points comes from the structure of Space itself. Bearing witness to this claim, Newton said**:**

> The parts of duration and space are only understood to be the same as they really are because of their mutual order and position, nor do they have any hint of individuality apart from that order and position which consequently cannot be altered. (Hall and Hall 1962: 136)

A location depends for its existence upon Space and consequently its identity depends on the identity of Space. Thus, if locations are concrete particulars, then Space itself must be a concrete particular. But Space itself cannot be in space, because that would make Space a part of space; thus its identity would depend on this further space. Therefore space points cannot be concrete entities.

Nor does the causal criterion of concreteness apply to Space. Although it has been held that Newton considered absolute space to be a cause of the inertial forces, there is no textual evidence for such an interpretation, and it seems more accurate to say that Newton believed that absolute space merely acts as a frame of reference and that acceleration by itself gives rise to the inertial forces. The relationist, however, hopes to account for the distinction between relative motion and 'real' accelerated motion not in terms of absolute space, or any other object to which the motion is relative, but in terms of causes of the motion.

A third conception of abstract entities takes them to be incapable of existing independent of other things.[4] We may define a substance as a concrete particular whose existence does not depend for its existence on any other particular. It then follows, by contrast, that a particular whose existence is dependent on other particulars is an abstract entity in the sense under discussion. Indeed, it may be possible in thought to separate two particulars where one existentially depends on the other. An illustration of such a separation would be whenever we think of a particular colour (a trope) as being divided from the object which it is a colour of. Nevertheless, this view seems to exclude events from being concrete particulars since they exist inseparately from those things they involve. The emission of light cannot exist independently of the source which produces it. But events are concrete particulars to the extent that they exist in space and time, they also partake in causal explanations, and sometimes we even identify a concrete object in virtue of a certain event. A sudden flare on the sky, a supernova, may be used to identify the star that once has exploded. So

[4] See, for instance, Lowe (1998), Ch. 10.

an entity can be an abstract one in the sense of being existentially dependent upon other entities but still be pointed to as a concrete object in terms of having a location in space and time.

Also we find that locations of things can be defined in terms of functional expression such as 'The location of Montreal' is the same as 'The location of the largest city of Canada", where the identity conditions of locations is dependent on things occupying them and the spatial relations. At first glance it seems possible to identify locations quite independently of the physical things.

- (x)(y)(($x = y$) if and only if space(x) & space(y) & x coincides with y).

But we have just learned that the individuality of locations depends on the order of Space itself; hence if Space is not a concrete object, neither can locations be. Furthermore, we should notice that the relation 'coincides with" is reflexive, symmetric, and transitive as required by the abstract principle. Locations can therefore be pointed out in relation to concrete particulars and their mutual spatial relations.

The proper identity condition for locations is then expressed by a proposition which grounds the abstract sortal term 'location' in the coincident relation between things or other concrete particulars:

- (x)(y)((loc$x$ = loc$y$) if and only if thing(x) & thing(y) & x coincides with y).

Neat as the statement seems, it is nonetheless obvious that it negates the existence of empty space. Avoiding any animosity of the void (between separated things) we must allow a modal formulation like the following:

- (x)(y)((loc$x$ = loc$y$) if and only if thing(x) & thing(y) & 1) x coincides with y, or 2) in case y and y did not exist, then if they had existed, x would have coincided with y whenever y would have coincided with x, and vice versa).

This illustrates that locations are actually distinct from physically things but still logically incapable of existing separately from physical things as such.

The Existence of Time

Aristotle said that time is not change but the measure of change, or rather “that in respect of which change is numerable” (*Physics*, $219^{b}2$). This suggestion was perhaps not such a bad choice. Motion is something we can perceive. Together with extension in space, change and motion are what we can immediately see by the naked eye, whereas space and time is what we apparently only are able to see indirectly with the help of the celestial motion of objects such as the sun or mechanical clocks. But there is more to Aristotle’s suggestion than epistemological priority. In addition, his remark implies that our understanding of motion is prior to that of time. Also time *is* nothing but a measure of motion. Given this interpretation, motion is not only semantically prior but likewise ontologically prior to time. The existence of motion and change precedes the existence of time. His ontology of time thus comes close to our everyday experience of temporality.

This also explains why Aristotle seems to defy the existence of time instants. He says in connection with Zeno’s paradoxes: Zeno’s conclusion “follows from the assumption that time is composed of moments: if this assumption is not granted, the conclusion will not follow” (*Physics* $239^{b}30$-3). What Aristotle probably had in mind was something like this: Since time is continuous, then each period of time must contain an infinite number of instants. But, according to him, nothing is *actually* infinite, but only *potentially* infinite. Numbers are in this way infinite in so far as there is no limit built into the process of counting. Likewise we can divide a length or a period of time in as many points or instants as we want, there is no limit to such divisions, but the divisions do not exist independently of the one who makes them. Hence, the potentially infinite divisibility does not imply the existence of actually infinite divisibility, and therefore spatial points and temporal instants do not exist independently of us. Although Aristotle does not explicitly say so, his view is not so far from saying that points and moments are not concrete entities but abstracted ones being the product of the converging limit of our cognitive ability to divide things up in smaller and smaller regions and intervals.

Following up on Aristotle, we may say that space and time cannot exist as a measure of motion unless things in motion exist prior to the numbering. Time exists only if change and motion exist. It is impossible for time to exist in case there is no change or motion. Thus, we see here an exemplification of the conception of abstractness according to which existential dependence marks what it means to be an abstract entity; time ontologically depends on things in motion or things which undergo change. Moments are abstracted from varying things but do not exist independently of the concrete particulars from which they are abstracted. In contrast, substantivalism – as we find it in Newton's notion of absolute space and time or in a realist interpretation of Einstein's theory of space-time – takes moments to be ontologically prior to those physical events that may occupy them; time, or space-time, exists as an independent entity, whereas reductionism regards moments to be identical to physical events or their existence to be somehow parasitic on things and processes. Both views consider time to be a concrete particular. The first view captures time as a substance, the second view as a non-substance. This means that it must be possible to specify some identity criteria which show that time is a concrete particular. But what are they?

Moments or temporal instants seem to be concrete particulars existing in time because they stand in temporal relations to other times, and we seem to have no problems of specifying identity criteria for moments. We say:

- $(t)(t^*)((t = t^*)$ if and only if time(t) & time(t^*) & t is simultaneous with $t^*)$.

But time instants cannot exist independently of Time itself; they are parts of Time, and as parts of Time they must have the same nature of identity as Time itself in form of being concrete or being abstract. A temporal instant depends for its existence upon Time, which implies that the identity of a temporal instant depends on the identity of Time. Therefore we must expect Time to be a concrete particular because if moments are concrete particulars, then Time itself must be a concrete particular.

Assume that Time is a substance. Time should then, like any other physical substance, exist in space and time. But Time does not exist in time, whereas Space may be said to exist in time; thus space and time cannot determine the identity of Time. Hence Time cannot be an individual substance (Faye 2006). Assume, in contrast, that Time is a non-substance because all talk about moments and temporal relations can be reduced to talks about events and causal relations. This requires that we can set up identity criteria of events which avoid any reference to space and time. Here Davidson's attempt to specify determinate identity criteria of events in terms of causation comes to mind as the only serious suggestion, claiming that:

- $(x)(y)((x = y)$ if and only if event(x) & event(y) & x and y cause and are caused by the same events).

Unfortunately the criterion has rightly and often been charged as being circular (Faye 1989: 153-160). Thus, the conclusion seems to be inescapable. Time cannot be a concrete entity.

In contrast, I propose that time is an abstraction in the sense that we have a constructed temporal language to be able to talk about collections or sets of concrete changes. Time denotes a tenselessly ordered set of all events in the world. This suggestion is supported by the above conceptions of abstractness. Time does not exist in space and time. Again, time does not have any causal influence on concrete substances because, if it had had such an influence, then each and every particular event would be causally overdetermined by causally prior events and by the definite moment at which the event takes place since both the causally prior events and the moment in question would be causally sufficient for it. Time instants are therefore causally superfluous. Moreover, if we think of two events, which are causally connected so that the cause is not only causally sufficient, but also causally necessary for the event, there is no room for causally active moments.

Facing the third criterion of abstractness, we see that Time, like events, is logically incapable of existing separate from particular substances. Events, however, in contrast to Time, do exist in space and time, and thus we shall leave aside that they may be abstracts in some other sense. Time cannot exist without changing things; nevertheless we can, of course, separate time from substances in thought.

Finally, the concept of a temporal instant fulfils the principle of abstraction. We can assign a time instant to an event in terms of a functional expression and thus express the identity of moments in terms of identity of events. We say, for instance, the time of the Big Bang, the time of the supernova, and the time of the solar eclipse. These functional expressions meet the abstraction principles.

- $(x)(y)((\text{inst}x = \text{inst}y)$ if and only if event(x) & event(y) & x coexists with y in a frame S).

It says that the moment of *x* and the moment of *y* are identical if and only if *x* and *y* are events, and *x* and *y* coexist. The relation ‘coexistence’ is indeed reflexive, symmetric, and transitive in any given inertial frame, and it grounds the abstract sortal term ‘instant’ such that the understanding of instants or moments presupposes an understanding of events and changes.

Space-time substantivalism

Up to now we have mainly considered whether space and time are concrete or abstract entities in a metaphysical context. Let us go on to consider the matter in a physical context.

In modern physics space and time merge into a single dynamic entity called space-time. It is sometimes assumed that this entity, according to the field equations of the general theory of relativity, is causally efficacious in the sense that space-time causes the distribution of matter and energy in the universe which in return affect the curvature of space-time. This assumption of mutual influence requires, being true, that space-time is a concrete entity which is able to undergo changes that effect or are affected by changes in the matter and energy distribution. However changes take place only in something which exists persistently through these changes. If one accepts this metaphysical principle, it leads to the conclusion that space-time should be treated as an object, or rather a substance, which forms the persistent ground for any change. Therefore the assumption that space-time can be causally influenced, or can causally influence, presupposes substantivalism of some sort. Space-time is a real substance undergoing changes but which exists independently of those processes occurring within space-time.

Indeed, space-time substantivalism constitutes a serious threat to the claim that space and time are abstracts because it considers space-time points as concrete particulars. The proponents point out that the general theory of relativity quantifies over space-time points, and as true followers of Quine they take this as a reason for believing in the existence of space-time points. We therefore need to take a closer look at this view.

In their co-written paper Earman and Norton (1987) define ‘substantivalism’ as the claim that space-time has an identity independent of the fields contained in it. They emphasize that the equations describing these fields “are simply no sufficiently strong to determine uniquely all the spatio-temporal properties to which the substantivalist is committed” (Earman and Norton, 1987: 516). This catches the standard view that a substance is something that is self-subsistent. We may define a substance as a particular whose identity does not depend on any other particular, and whose existence therefore does not depend on it.

Before we proceed an important distinction should be made between *manifold substantivalism* and *metric substantivalism*. The first type forms a sort of minimal view according to which space-time consists of a topological manifold of points, and the metric field is then attached as an externally defined field, whereas the second type includes the metric field as an intrinsic part of the container itself.

Earman and Norton identify space-time with space-time points. As they say: “Thus we look upon the bare manifold – the ‘container’ of these fields – as spacetime” (1987: 518-9.) The bare manifold consists of space-time points, whereas the fields form the metrical structure of space-time which is added to the manifold as a thing in it. Their motivation for separating the bare manifold as the space-time container and the metric fields as the contained is that the metric fields carry energy and momentum which can be converted into other forms of energy and heat.

Manifold substantivalism takes space-time points to be real, but it is entirely unclear what their identity conditions are. It has been noted before that according to Newton the parts of absolute space and time are intrinsically identical to one another and can only be differentiated by their mutual intrinsic order.[5] But this move is foreclosed to the manifold substantivalist. The identity conditions for space-time points cannot involve the metrical structure because of the way manifold substantivalism has been defined. It is assumed that space-time is nothing over and above space-time points in the sense that the identity of the space-time manifold is dependent on the identity of space-time points. The consequence is that space-time is a real concrete particular if and only if space-time points have an independent identity.

Nevertheless, it appears reasonable to say that space-time is not a composite substance because the whole does not distinguish itself from the parts. Space-time is indefinitely divisible into other particulars of the same kind, but how can we distinguish between these parts in such a way that the distinction represents a real difference? Establishing determinate identity conditions, which make space-time a concrete entity, is a serious problem for manifold substantivalism. The points of the manifold are pure abstract individuals, bare mathematical particulars which do not have any structure or properties in virtue of itself. How can we make sure that these mathematical objects represent self-subsistent physical space-time points (or real events)?

The manifold substantivalist seems to have two possibilities for formulating determinate identity conditions of space-time points. He can either follow the mathematical road or take the physical one. After all he may regard geometrical points as names of physical points, or he can insist on some form of metric structure as belonging to space-time (because we are able to talk about a universe free of matter and energy).

Following the first path, the manifold substantivalist does not bump into the concrete structure of the world, but the road is nonetheless not passable. Because it is impossible to see how geometrical points can act as names for physical space-time points, unless we already possess

[5] See also T. Maudlin (1989), p. 86

independent physical criteria of individuating space-time points. A name refers to what it names; but it can only be assigned to the named, in case the name and the named have mutually independent identity conditions. The manifold substantivalist, however, is unable to point to what these are with respect to physical space-time points. Mathematical points are all we have, and they have no intrinsic features that individuate them from each other.

As we have seen, space-time points can only be defined relatively within a relational structure, and their *only* identity is given in virtue of their position in this structure. We may indeed assign coordinates to the manifold. But in a pure differential manifold each and every possible form of coordination is arbitrary and the manifold is invariant with respect to the choice of a particular coordinate system. Only by adding a structure is it possible to change the situation, but then we no longer are confronting a bare manifold.

Choosing the second road, the manifold substantivalist may seek the identity conditions of space-time points in the metric structure of the physical state of the universe (*versus* Earman and Norton). In this way he may attempt to uphold a view of space-time as a concrete entity. If space-time is taken to be represented by a manifold of geometrical points on which we define a metric field, then the set of physical space-time points is individuated by their metric properties as they are defined by our best space-time theories.

In the theory of general relativity the metric field is identified with the gravitational field and it therefore carries momentum and energy. Let me quote John Norton:

> "This energy and momentum is freely interchanged with other matter fields in space-times. It is the source of the huge quantities of energy released as radiation and heat in stellar collapse, for example. To carry energy and momentum is a natural distinguishing characteristic of matter contained within space-time. So the metric field of general relativity seems to defy easy characterization. We would like it to be exclusively part of space-time the container, or exclusively part of matter the contained. Yet is seems to be part of both." (Norton 2004)

Indeed, if the energy and momentum of the gravitational field can be converted into radiation and heat, and vice versa, in connection with the formation of back holes, and this field also characterized the metric properties of space-time, how can space-time exist independently of what is going on in it? Because the identity of space-time points logically depends on their metrical structure, they are incapable of existing without this structure.

The manifold substantivalist may respond by pointing out that Einstein's field equations connect the intrinsic structure of space-time with the distribution of matter and energy such that the metric field, in the form of the gravitational mass-energy field, and the matter field stand in a causal relationship. Thus, if space-time had no momentum and energy, it would be impossible to see how they could interact with matter. Moreover, we can only have a causal relation in case the relata are logically distinct from one another; i.e., in case the relata have mutually independent identity conditions. Thus, if space-time and stars and galaxies were separate entities, then their mutually causal interaction would constitute the proof that they are concrete particulars. But the argument, as it stands, is not without problems.

I sympathize with Lawrence Sklar as he warns us about believing that the field equations should be interpreted as the non-gravitational mass-energy causing modifications of space-time since "the possible distribution of mass-energy throughout a spacetime depends upon the intrinsic geometry of that spacetime." (Sklar 1974: 75) Apparently, what he wants to emphasize is that the matter field is spatially and temporally distributed, and thus it cannot gain the necessary ontological independence of the metric field which is required of it in order to have a separate existence as necessary for causal efficiency. Instead, Sklar maintains that the equation should be interpreted as a law of coexistence:

> The equation tells us that given *both* a certain intrinsic geometry for spacetime and a specification of the distribution of mass-energy throughout this spacetime, the joint description is the description of a general-relativistically possible world only if the two descriptions jointly obey the field equation. (Sklar 1974: 75)

Such a law-like constraint on the two descriptions robs the substantivalist of the causal argument for space-time and the matter field being concrete, independent particulars.

Where does this take us? It seems that manifold substantivalism either is forced into an abstract mathematical entity (since space-time points become abstract particulars) or collapses into a form of relationism where space-time as such is claimed to be identical with the fields of gravitation-cum-matter. In the latter case the metric field is defined in terms of the gravitational fields whereas the space-time points are defined in terms of the mass-energy fields. So manifold substantivalism seems not to be a viable metaphysical possibility if one wants to sustain a claim that space-time is a concrete substance.

In the debate about manifold substantivalism, according to which space-time is represented by a manifold of points and a metric field is added to the manifold, one argument appears to be more prominent than any other: the hole argument. It apparently shows that a substantivalist interpretation of space-time requires that we are willing to ascribe a surplus of properties to space-time which is impossible for observation or the laws of the relevant space-time theories to determine. The substantivalist must concede that matter fields, which after a transformation go through such a hole in the space-time manifold, are not determined by the metric fields and the matter fields outside the hole. Nevertheless the manifold substantivalist, who wants to save determinism, also holds that there has to be physical differences between the possible trajectories which a galaxy may take inside the hole. Earman and Norton take this to be a most unwelcome consequence of space-time substantivalism and are ready to give up manifold substantivalism as such (Earman 1989: Ch. 9). Attempts to avoid such a conclusion by adding further structure to the manifold can, at least in some important cases, be met by alternative versions of the hole argument (Norton 1988). If manifold substantivalism has to give away, Earman sees three ways to uphold substantivalism with respect to space-time points. One may adopt a structural role theory of identity of space-time point (which I shall return to below in the form of *sophisticated substantivalism*), one may argue that metrical properties are essential to space-time points (Maudlin 1989, 1990), or one may introduce counterpart theory to space-time models (Butterfield 1989). But in conclusion he finds that that "our initial survey of the possibilities was not encouraging" (Earman 1989: 207-208).

The central claim of metric substantivalism, according to Maudlin, is that "Physical space-time regions cannot exist without, and maintain no identity apart from, the particular spatio-temporal relations which obtain between them." (Maudlin 1990: 545) Thus, the identity conditions of space-time points are determined by the intrinsic order among them. A few pages later he states that space-time and metric are connected by necessity: "Since space-time has its spatio-temporal features essentially (cf. Newton above), the metric is essential to it and matter fields not" (Maudlin 1990: 547). The proponent of the metric substantivalism, in contrast to manifold substantivalism, welcomes the idea that space-time carries energy in the form of its metrical structure because it makes space-time on a par with other substances.[6]

In the general theory of relativity the metric field is associated with the gravitational field because of the proportionality of the gravitational and inertial mass so that gravitation and accelerated coordinate systems can be considered physically equivalent. Einstein spoke about this association in various terms: The gravitational field is said to either *influence* (or determine) or *define* the metrical properties of space-time.[7] But holding that the gravitational field *defines* the

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[6] For a discussion of this argument, see Hoefer (2000).

[7] In his introduction to the Leibniz-Clare Correspondence, Alexander (1956), p. liv states two quotations of Einstein without any references, one in which Einstein says that the gravitational field 'influences or even determines the metric laws of the space-time continuum', the other in which he maintains that the gravitational fields 'define the metrical

metric structure of space time, it must be an essential feature of the universe and not just accidental that gravitational and inertial mass is proportional. This indicates, of course, that the proportionality is due to the fact that gravitational field is logically identical to the metric field. Another possibility is to think of them as conceptually distinct but empirically identical. However, according to Kripke, if such an identity proposition is true, it is necessarily true.

Very few, I believe, would argue that inertia and gravitation are not conceptually distinct. But when the intrinsic geometry of space-time is *identified* with the structure of the gravitation field, it cannot be an empirical discovery similar to the one that Hesperus and Phosphorus are the same. To see this we should realize what it takes to be an empirical discovery. It means that observation brings together evidence that fulfils two different identifying descriptions. Ancient astronomers possessed different, empirically based, criteria of being Hesperus and of being Phosphorus. But when it comes to identifying the metric of space-time with the gravitational field there are within GRT no such empirically based independent criteria of being a definite metric structure apart from the gravitational field itself. We should also remember that the equivalence of the gravitational field and accelerated frames is merely local. This gives us problems with a global assignment of a unique metric structure founded on the gravitational field. Second, what the association of the gravitational field with the metric structure of spacetime itself does is that we physically narrow down which of the possible abstract space-time models can be the model of the actual world. So the association is not an empirical identification but a metaphysical assumption that allows us to ground space-time talks in physical reality.

Indeed, there is a sense in which inertia and gravitation are the same property that is only described in two different ways in different frames. The principle of equivalence ensures an explanation of the proportionality between the gravitational mass and the inertial mass because it tells us that a system in free fall is an inertial system (locally). Therefore, it is a widely spread understanding of GRT that the metric field (or together with some related geometrical objects like connection …) represents both the space-time geometry and the gravitational field. So when it is said that it has been *decided* by the physics community that it is meaningful to identify the gravitational field with the metric field such a decision must be based on some assumption which is not an empirical discovery.[8] Rather the decision is based on a metaphysical assumption of co-

properties of the space measured'. The first is from Einstein (1955), p. 62, whereas the second has not been possible to locate.

[8] A point made by an anonymous referee.

existence according to which it is physical impossible that the metric field can exist independently of the gravitational field.

This brings me to the second part of the argument. Maudlin considers the metric field as an essential part of space-time substantivalism. As we have just seen, the metric structure of space-time is connected by necessity to the gravitational field where the notion of necessity is to be understood in a metaphysical sense and not merely in a physical sense.[9] Thus space-time is an entity whose existence cannot be separated from the existence of the gravitation. Space-time points and the metric structures we assign to these points are geometrical abstracts.

Assuming this is correct, it is metaphysically impossible for space-time to exist separable from gravitation. I therefore think that the four-dimensional representation of the world is an abstraction. Such an abstracted entity as space-time with a metric and a topology is rich in structure and it therefore helps us to grasp a changing reality.

Space-time Relationism

The proponent of the concreteness of space-time is not limited to substantivalism. He could still argue that space-time is a real entity as it reduces to spatiotemporal relations among the galaxies in the universe. But how can space-time points be concrete individuals without being a substance? The argument goes that space-time points are concrete because they owe their identity to concrete objects which occupy space and time. Especially they owe their identity to continuants or rather physical events.

Relationism, however, does not fare any better than substantivalism. I shall not rehearse all the kinematical-dynamical arguments which have been put against it by Sklar, Friedman, Earman, and others. What is important for my purposes is that the relationist believes that space-time does not exist over and above the concrete fields; he sees it merely as ‘a structural quality of the field,’ and therefore claims that all talk about space-time points reduces to talks about a causal-equivalence class of events. By this founding manoeuvre the relationist regards space-time talks as concerned with concrete particulars as much as the substantivalist does. But the relationist’s attempt to specify such an equivalent class of causally connected events suffers from the lack of a consistent criterion of identity which leaves out space-time points.

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[9] When Maudlin (1990) argues that “The substantivalist can regard the field equation as contingent truths, so that it is metaphysically possible for a particularly curved space-time to exist even if all of the matter in it were annihilated” (p. 551), he is talking about something else. Even if all matter is annihilated there still exists a so-called source free gravitational field which constitutes the metric field (See Norton 1985: 243-244).

The claim is that space-time points exist whenever events that occupy them exist. Thus space-time points are concrete because they reduce to concrete events in them. Space and time are identical to the things and events which are supposedly 'in' space-time. Events are then really constitutive parts of space-time analogous to the way our arms and legs are not in our body, but parts of it, i.e. constitutive parts. I think, however, that this escape route is no way out.

I suggest that we can only have ontological reduction in case a certain identity relation exists between the entity, which we want to reduce, and the parts to which we want to reduce it. The parts of a whole must not be exchangeable without the whole losing its identity. Thus, if a particular entity continues to be the same even if parts of it are replaced by different entities because the identity of such an entity is not dependent on the identity of the parts, then this entity is not reducible to the sum of its parts. An example: a human body does not consist of the mereological sum of its parts because the various organs may be transplanted by donor organs or artificial parts without the body discontinuing being the same. In contrast, however, particulars like particular masses or quantities of stuff are numerically the same as the sum of their parts because they depend for their identity upon the identities of objects which are their own proper parts.

Although impossible to perform it seems correct to say that a planet, the sun or a galaxy could be replaced by another object of its kind without space-time changing its identity. Space-time would still have the same curvature everywhere and at every time, it would have the same metrical structure due to the same field of gravitation, and it would still be a four-dimensional continuum. It seems at least that all individual objects can be substituted by other material objects whereas the intrinsic properties of space-time, which ground the identity condition of space-time, stay the same all the way through.

Indeed, there are less radical forms of relationism. One can argue: 1) that space-time points exist only in virtue of those continuants and events which occupy them even though they are ontologically distinct from them; or 2) that space-time points exist only as possible places for continuants and events to exist. The metaphysical basis of the first claim is that an entity can be ontologically distinct from another entity only if they have independent identity conditions (as father and son). By making the identity of space-time points distinct from the identity of their occupants but by claiming them to be existentially dependent on these occupants, we do only make a separation in thought because their acclaimed distinct identity conditions do not have empirical consequences. This view collapses, in my opinion, to a claim that space-time points are abstract entities. The second claim, however, presupposes in contrast that the possible places have some kind of independent existence of their occupants. This view therefore gives a way for a sort of substantivalism. Thus none of the other forms of relationism do better than the radical one and save space-time points as concrete entities.

Space-time as an Abstract Entity

In my opinion, the traditional dichotomy between substantivalism and relationism is false: Either (a) space-time is an ontologically independent entity because it can exit independently of physical things or events, or (b) it is reducible to structural properties of things or events. But substantivalism and relationism are not contradictory terms. (a) implies that things or events are not *necessary* for space and time; whereas (b) implies that events or things are *sufficient* for space and time by presupposing that things and events are definable or identifiable without any reference to space and time. (b) expresses only *reductive relationism,* and one can easily deny (a) without being committed to (b). Things and events can be *necessary* conditions for space and time even though space and time cannot non-circularly be reduced to things and events. I want to argue that space and time can be understood as abstracted from certain structural property of the physical world, and as such space-time is an abstract representation of these things and events. Geometry and pure theories of space and time in general are logical or mathematical abstractions from a physical implementation, but it is a serious mistake, I think, to hypostatize these abstractions. This view I call *non-reductive relationism*.

Non-reductive relationism takes the metric tensor g to represent a gravitational field rather than the space-time structure itself.[10] Field theories seem to change the long-established debate between Newton and Leibniz. The non-reductive relationist does not have to fight the notion of empty space. There is no space where there are no fields, i.e. something physical. The attempt to maintain the classical perspective by defining the physical matter in terms of the matter-impulse-stress tensor T and then claiming that $T = 0$ and $g \neq 0$ represent empty space-time points is not

[10] Carlo Rovelli (1997: 193-94) argues that Einstein's identification between gravitational field and geometry can be understood in opposite ways: 1) "the gravitational field is nothing but a local distortion of spacetime geometry"; or 2) "*spacetime geometry is nothing but a manifestation of a particular physical field*, the gravitational field." He himself defends the second option which I take to be an example of reductive relationism. The metric field is the manifestation of the gravitational field and as such "The metric/gravitational field has acquired most, if not all, the attributes that have characterized matter (as opposed to spacetime) from Descartes to Feynman." In contrast, the non-reductive relationist would say the actual geometry is an exemplification of infinitely many possible geometries and that physical space-time seems to gain individuality by being *instantiated* by the gravitational field.

convincing.[11] In general, *g* represents the gravitational energy and the so-called vacuum solutions exist only in the real world as approximations where the source expressions are ignored. In addition, GTR is not a theory of matter, rather it is an abstraction from matter, and the introduction of a theory of matter via quantum theory gives vacuum solutions different from zero.

If space and time take part in specifying the identity conditions of concrete particulars, then space-time itself cannot be a concrete particular. My suggestion is that it is an abstract particular in the sense that it is existentially dependent on fields and matter. Earman and others reach the substantivalist position by hypostatizing space-time points as objects which are then thought of as the subject for predication of the field properties.[12] Here it seems as if Earman merely hypostatizes the diverse conceptual levels of differential geometry. We begin didactical-mathematically with a differential manifold, then we supply it with diverse affine, metric, and topological structures, and without any further argument it is taken for granted that this pure manifold exists ontologically independently of the structural features which characterize the actual world. What is problematic in the first place is the very idea that we are allowed to hypostatize space-time points as independent entities with their own criteria of identity.

In a recent paper Oliver Pooley (2006) takes issue with Earman and Norton's hole argument. Following Belot and Earman (2001: 228), he defines *sophisticated substantivalism* as any position that denies haecceitistic differences.[13] Such a position regards two diffeomorphic models as representations of the same possible world so they are not injured by the hole argument. In contrast to Belot and Earman, Pooley holds the view that as a sophisticated substantivalist one can argue that space-time points are real substances although their numerical distinctness is grounded by their position in a structure. He believes that such a modest structuralist position does not "go beyond an acceptance of the 'purely structural' properties of the entities in question," while at the same time maintaining that these objects cannot be reduced to the properties and relations themselves. I wonder, however, how space-time points, in terms of their mathematical structure, become physical space-time points. Pooley does not provide us with one single argument according to which the numerical distinctness of the mathematical objects of a manifold (points), whose identity, I agree, depends on their positions in a mathematical structure, corresponds to the numerical distinctness of *real* physical space-time points.

[11] Friedman (1983), p. 223.
[12] See for instance Earman (1989), p. 155.
[13] See also Belot and Earman (1999)

Let me illustrate why I think Pooley's suggestion that space-time points are real entities in spite of their purely structural properties is problematic. Take a series of identical billiard balls and add an ordering structure: 1, 2, 3, 4, 5 …, from the left, then the identity qua 'number 4 from the left' is given in virtue of the entire structure, namely all the other billiard balls plus the given structure. But it is not a property of that particular ball that if we change it and the 5^{th} ball around, then their identity switches too. They keep their own identity before and after the switching although the order itself is completely unaltered. Space-time points, however, are only defined in relational terms, which mean that they change identity whenever they change their place in the structure. Had they not changed identity, and were they still individuated only by their place in the structure, then the order amongst themselves would not have stayed the same. Analogously, the identity of the number 4 is defined by its place in the entire sequence of numbers, and whatever whole number that may occupy the place between 3 and 5 would be identical with number 4. Here numbers and space-time points seem to be ontologically on par.

Elsewhere I have argued that the structural realism holds an indefensible position on the relationship between mathematically formulated models and the world, namely that there exists an isomorphic coherence between the mathematical structures, which exist independently of the world, and the real structure of the world as it exists independently of mathematics. It does not suffice for the structural realist to point to the ontological commitments of structures given to us by theories (Faye 2006a). The commitment to a certain structure is always internal to the mathematical framework. The structural realist needs to point to some external commitments which guarantee the existence of real physical counterparts. Claiming conversely that the identity of physical space-time points constitutes a primitive fact which does not require any further explanation is to my mind based on an act of fiat.

Seeing space-time points as independently existing entities with their own identity conditions seems to be a problematic extrapolation of common sense ontology according to which physical objects have intrinsic and not only relational properties. Space-time points lack intrinsic features and without these they do not have a physical basis for differentiation amongst themselves. What determines the identity of space-time points as abstract objects is the mathematical structure as a whole in the sense that we define and identify the constituents (points etc.) within the entire structure; that is to say, the identity of any particular constituent is given in virtue of all the other constituents plus a certain order among them. However, we cannot define and identify the entire structure in virtue of the structure itself. There is therefore a categorical difference between the constituents of the structure (points) and the structure as a whole. Their criteria of identity are not the same. We identify and define the constituents (points) within the structure, but such an individuation is not possible with respect to the structure itself.

So far I have argued that space-time points and fields are ontologically distinct entities because they belong to different kinds of existence, but I have also claimed that space-time is ontologically as well as conceptually posterior to changing and extending things. I now want to conclude that space and time, or space-time, is nothing but an ordered *set* of all concrete particulars. We need space and time, or space-time, to assist us in identifying and ordering things and events. We would be unable to identify particular things as such and track them down unless we had the possibility of referring to their continuity through space and time. Space gives us the conceptual tool to describe movement of the same material object, and time gives us the conceptual tool to talk about the persistence of numerically the same object possessing different properties. We may therefore say that *particular* concrete objects are in space and time, meaning that they are parts of the ordered set of all changing things. Thus, a persisting object is one that may undergo changes in time, while it continues to stay the same during its changes. The question then arises: is space-time a mere conceptual tool, an instrument for predication, or does it have some sort of reality?

I am inclined to hold that space-time exists as an abstract particular, i.e., as a non-concrete entity, in the sense that its existence is ontologically, but not causally, dependent on the existence of changing things and extended objects. I agree with Jonathan Lowe that the notion of a set is precisely the notion of a number of things and not a 'collection' of things, where natural numbers are kinds of sets (Lowe 1998: 220-21). Hence space-time is the total number of events and things which exist in the universe from the beginning to the end.

The view I advocate is: space-time exists as an ordered set of all changing things because all its members exist, the set constitutes space-time. Our conception of the set is acquired by acquaintance with a limited number of members of the set and the order is subsequently abstracted from their relations to all possible members. But from this it does not follow that the term used for that abstracted concept refers to an abstract object over and above the entire collection of concrete members in the universe. However, being an ordered set space-time exists as an abstract entity with its own internal identity conditions, and therefore space-time is not reducible to a mere collection. As an abstract entity space-time has no space-bounded or time-bounded properties, it is subject to only tenselessly true predication as far as its relational properties are concerned.

Thus, space-time is not only a set but an ordered set of all concrete particulars in the universe. Any particular event may coexist with some particular events, or precede or succeed some other particular events, and based on these facts we may assign an order of simultaneousness, as well as being earlier or later to all the space-time points which represent the events. In general, events causally (and perceptually) succeed each other and therefore belong to different subsets (hyperplanes) of coexisting events. The actual spatio-temporal order supervenes on structural features of concrete thing and events. What kind of supervenience relation we are talking about has to be dealt with elsewhere due to the lack of space. Grounding the order of space-time points in the causal structure of some actual events we are able to ascribe a unique and unambiguous order to all events in the universe. Every space-time point is ordered with respect to every other space-time point, and we may use this abstracted representation to order any particular event. Indeed, space-time is an abstract entity which has a very privileged relation to the physical reality. There are many mathematical geometries all of which could represent the actual world, but which of the mathematical structures that is instantiated as the actual space-time depends on the distribution of fields and matter in the universe.

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