

# Relativity and Three Four-dimensionalisms

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## Abstract

Relativity theory is often said to support something called ‘the four-dimensional view of reality’. But there are at least three different views that sometimes go by this name. One is ‘spacetime unitism’ (as we call it), according to which there is a spacetime manifold, and if there are such things as points of space or instants of time, these are just spacetime regions of different sorts: thus space and time are not separate manifolds. A second is the B-theory of time, according to which the past, present, and future are all equally real and there is nothing metaphysically special about the present. A third is perdurantism, according to which persisting material objects (rocks, trees, and human beings) are made up of different temporal parts located at different times. We sketch routes from relativity to unitism and to the B-theory. We then discuss some routes to perdurantism, via the B-theory and via unitism.

## Introduction

Relativity theory<sup>1</sup> is often said to support something called ‘the four-dimensional view’ of reality. But there are three independent views that go by this name: (i) spacetime unitism, as we call it, according to which spacetime is more fundamental than space or time, and points of space and instants of time, if they exist at all, are just spacetime regions of different sorts; (ii) the B-theory of time, according to which the past, present, and future are all equally real and there is nothing objectively special about the present; and (iii) perdurantism, according to which material objects are four-dimensional wholes made up of different temporal parts.

We survey some relativistic arguments for each, but our emphasis is on the fact that the three views need not stand or fall together and that Relativity might not support all three views in the same way or to the same degree. Since we do not have the space here to introduce Relativity from scratch, we presuppose some familiarity with the basics,<sup>2</sup> but we review some highlights, and we hope that novices may be able to pick up some understanding of the theory along the way. Finally, quantum mechanics is relevant to (i)–(iii) too, but our concern here is just with Relativity, not physics as a whole.<sup>3</sup>

### 1. Separatism vs. Unitism

Here is an attractive, common sense view about the relationship between space and time; we call it *separatism*.<sup>4</sup>

There is a three-dimensional entity called *space*.<sup>5</sup> It is made up of unextended spatial points; these points stand in spatial distance relations to each other, and any collection of these points forms a spatial region. Space as a whole is the collection of all the spatial points. There is also a one-dimensional entity called *time*. It is made up of durationless instants; these instants stand in temporal relations to each other (topological relations such as *being earlier than* and metric relations such as *being two seconds apart*), and certain non-scattered collections of these instants form

intervals. Moreover, each point and region of space, including space itself, persists through time. Each point and each region exists at – or, as we will say, *is located at* – each instant. Finally, space and time are *separate* entities in the sense that they do not share parts. Space is entirely made up of spatial points, which are all *simple* (have no *proper parts*, no parts aside from themselves). Time is entirely made up of instants, which are also simple. And no spatial point is an instant. Each spatial point is located at each instant of time, but no spatial point shares parts with any instant.<sup>6</sup>

Separatism contrasts primarily with *unitism*, according to which there is a four-dimensional entity called *spacetime*; it is spatially three-dimensional and temporally one-dimensional.<sup>7</sup> It contains not only present events but also past events, which are located at earlier spacetime regions, and presumably also future events, which are located at later regions. Spacetime is made up of spacetime points, which are spatially unextended and durationless. If two subatomic particles collide twice, they collide at two different spacetime points, no matter how brief the interval between their collisions. Unitism is neutral as to whether there are such entities as instants of time or points of space, but it requires that if there are such things, they are just spacetime regions of different sorts. An instant would be a durationless, universe-wide ‘time-slice’ of spacetime – a collection of spacetime points that are all simultaneous and that include any spacetime point that is simultaneous with each of them. And a point of space would be a ‘succession’ of spacetime points, one after another, that are all at zero spatial distance from one another and that include every spacetime point at zero spatial distance from each of them. According to unitism, spacetime points are simple, and if there are such things as instants of time and points of space, they are complex entities that share parts (spacetime points) with one another (Fig. 1).<sup>8</sup>

The separatism vs. unitism dispute has far-reaching implications. For example, unitism is in tension with the view that there are entities – God, mental events – that are located in time but not in space. If unitism is true, then (provided that time and space exist at all) anything that is located in time is located in spacetime and hence is located in space. (More on this on Section 3.2)

Although separatism may be favored by common sense, unitism is often said to be favored by physics. Unitism was introduced by Minkowski in 1908 (1952) as an interpretation of Special Theory of Relativity (STR), but once on the table, unitism can be combined with pre-relativistic physics: the result is a so-called ‘classical’ spacetime, of which there are many

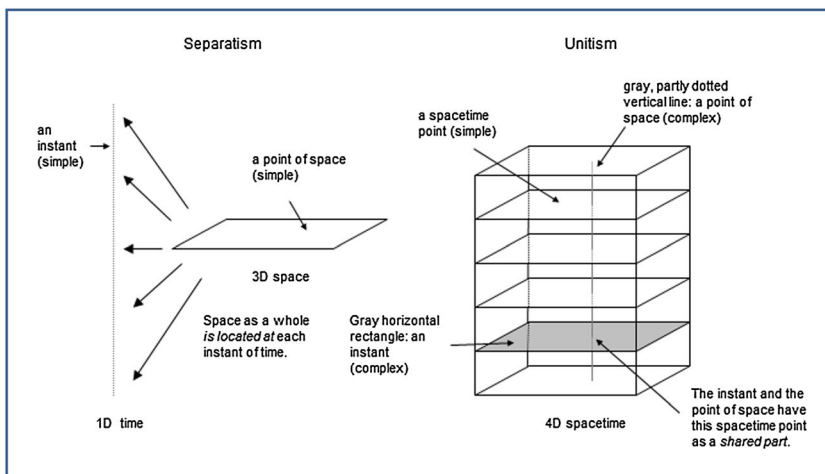


Figure 1. Separatism and Unitism about space and time.

varieties.<sup>9</sup> Moreover, although Relativity may generate an especially forceful argument for unitism, there is a physics-based argument for preferring unitism to separatism even in a pre-relativistic context.<sup>10</sup> Here, however, we focus on the distinctively relativistic case for unitism.

STR entails that inertial (non-accelerating) observers will often disagree about the *spatial distance* and *temporal duration* between two events but will always agree about a kind of mixture of the two, the *spacetime interval* between those events.<sup>11</sup> This fact seems to be logically consistent with separatism. One can hold, presumably, that space is a fundamental, three-dimensional entity, that time is a separate, fundamental, one-dimensional entity, that there is a set of further fundamental entities called (inertial reference) *frames*, and that the relations between these entities conform to the Lorentz transformations of STR. (As a heuristic, think of a frame as a collection of non-accelerating objects that are at rest with respect to each other.<sup>12</sup>) One can then say that for any two instantaneous, point-sized, non-co-located events  $e$  and  $e^*$  and any frame  $F$ , there is a fact about how far apart  $e$  and  $e^*$  are in space *relative to*  $F$ , and there is a fact about how far apart  $e$  and  $e^*$  are in time *relative to*  $F$ , but there are no facts about how far apart they are in space *simpliciter* or how far apart they are in time *simpliciter*. Space and time are thus retained as separate entities, but *frames* are introduced in addition to them, and all facts about the spatial and temporal distances between events *become fundamentally frame-relative*. Although we have not presented a detailed statement of the theory, there is presumably a logically consistent theory in this vicinity that is empirically equivalent to the standard unitist interpretation of STR.<sup>13</sup> Indeed, one might think that Einstein's original presentation of STR in 1905 (1952), in terms of a 'Light Postulate' and 'Relativity Postulate', and without any mention of spacetime, lends itself more naturally to a separatist than to a unitist interpretation. This coheres with the suggestion that Einstein initially dismissed Minkowski's unitist interpretation of STR as 'superfluous learnedness' (Pais 2005: 152).

If the problem with separatist STR is not that there is a contradiction internal to the view, then what is the problem? Various answers have been given. Craig (2001: 83–104) offers detailed arguments to the effect that separatist STR is 'explanatorily deficient' vis-à-vis unitist STR and that it leads to an implausible 'fragmentation of reality'. (See Balashov and Janssen (2003) for a reply.) Without entering into the debate over Craig's arguments, we suspect that most philosophers would agree that the transition from pre-relativistic physics to STR, while perhaps not rendering belief in separatism outright irrational, at least improves the prospects of unitism. If it is *spacetime* that is fundamental in the sense relevant to unitism, then it is not so surprising that there should be frame-invariant facts about the *spatiotemporal* relations (e.g., the interval) between events but no invariant facts about the *purely spatial* or *purely temporal* relations between them. For a spacetime might easily have a geometrical structure that supports facts about the interval – but no facts about the distance or duration – between any two of its points. (This is precisely the situation in Minkowski spacetime). If, on the other hand, we take space and time to be separate and fundamental, then, other things being equal, this gives us reason to expect the quantities associated with these manifolds and their contents (viz., spatial distance and temporal duration between events) to be invariant. Moreover, a commitment to separatism would give us *no* antecedent reason to expect that some odd mixture of these quantities (the spacetime interval between events) actually *is* invariant. Thus, upon discovering that spacetime intervals are invariant but distances and durations are not, we should take this as providing at least some evidence for unitism over separatism.<sup>14</sup>

So much for the link between STR and unitism. The General Theory of Relativity (GTR) is usually taken to support unitism more directly. GTR explains gravitational effects by postulating a systematic relationship between (i) the presence of mass and energy in a region and (ii) the *curvature* of that region. Crucially, gravitational effects cannot be explained merely by positing curvature in *space*: the explanations are successful in general only if the curved regions in question can be temporally extended spacetime regions (Dainton 2010: 350–351). So, even if

it is possible to formulate a consistent separatist interpretation of GTR,<sup>15</sup> it seems likely that such an interpretation would be parasitic upon the standard unitist interpretation in a way that detracts from the plausibility of the former. Whatever Einstein's initial reaction to Minkowski's unitism might have been, he was a believer by the time he wrote that

these inadequate remarks can give the reader only a vague notion of the important idea contributed by Minkowski. Without it the general theory of relativity ... would perhaps have got no farther than its long clothes (1961: 63).

## 2. *A-theories vs. B-theories*

Recent debates in the metaphysics of time, especially those that trace back to McTaggart (1908), have taken an interest in the following issues:

*The Existence issue:* Do past, present, and future things exist equally? Or is it the case that only, say, *present* things exist?

*The Passage Issue:* Does time pass in some metaphysically robust sense? If so, how is this best articulated? For example, by saying that there is property of presentness that is successively had by different times?<sup>16</sup> By saying that there is change with respect to what exists?

These questions give us two main dimensions along which metaphysical theories of time may vary, and they open up logical space for many specific positions. In practice, only a handful are believed to be serious contenders. We will restrict our attention to four:

(1) B-THEORY. This term is usually reserved for the following package of views<sup>17</sup>:

<i>Eternalism.</i>	Past, present, and future all equally exist.
<i>Realism about time and tenseless relations.</i>	Time is real and mind-independent, and things in time stand in mind-independent temporal relations (e.g., <i>being simultaneous with</i> and <i>being earlier than</i> ).
<i>Anti-realism about passage.</i>	There is no metaphysically robust passage of time. Nothing instantiates presentness, and no such property flows from one time to another.

Next, we will consider three versions of the A-theory of time.<sup>18</sup> As Smart (2008: 227) put it, the A-theory is a gerrymandered 'syndrome, rather than having a very tight definition'.<sup>19</sup>

- (2) MOVING SPOTLIGHT. Eternalism is true, and yet time passes, in that different times successively have the property of presentness, which flows from earlier to later times.<sup>20</sup>
- (3) GROWING BLOCK. Past and present things exist, whereas (wholly) future things do not. The passage of time is robust and should be construed as the coming into existence of new entities.<sup>21</sup>
- (4) PRESENTISM. Only present things exist. The passage of time is robust and consists of new things coming into existence and old things ceasing to exist.<sup>22</sup>

Each of these versions of the A-theory entails that the present is *objectively special*.<sup>23</sup> This seems also to be the A-theory's main virtue: it respects the allegedly common sense belief that the present is, in some not-merely-perspectival way, different from other times.

Before we move on, we should pause to note that the A-theory vs. B-theory dispute cross-cuts the separatism vs. unitism dispute: the A-theory comes in both separatist and unitist forms,

neither obviously false, and likewise for the B-theory.<sup>24</sup> (These disputes have often been run together<sup>25</sup>). So much, then, for the lay of the land.

Relativity poses a challenge for the A-theory. What is the challenge? To be maximally ecumenical, we would need to keep both unitist A-theories and separatist A-theories in play, and we would need to formulate Relativity so that it is logically consistent both with unitism and with separatism. Perhaps we could then argue that Relativity poses problems for both forms of A-theory, separatist and unitist. But that would make for a long and complicated discussion, and it would require an awkward formulation of Relativity.

Fortunately for us, the literature on Relativity and the A-theory typically makes a simplifying assumption: that unitism is true and consistent with the A-theory. It assumes that we inhabit spacetime (either classical or relativistic), hence that the debate between the A- and B-theories boils down the question of whether some part of spacetime is *present*, not merely relative to a frame or a time or an event or a region, but *simpliciter*, absolutely. A-theories say ‘Yes’; the B-theory says ‘No’.

We can then ask: is the A-theory less plausible in the context of a relativistic spacetime than in the context of a classical spacetime? If so, why? Against this backdrop, the challenge that Relativity poses for the A-theory arises from

**The Shape Question**    What is the spatiotemporal shape of *the present*, that is, the largest part of spacetime that is absolutely present?

In a classical context, one answer stands out as by far the most plausible:

**Absolutism**    The present is a durationless, three-dimensional region that cuts across the entire spatial extent of spacetime. Specifically, it is a maximal absolute simultaneity slice – a region  $r$  such that any points  $p$  and  $p^*$  in  $r$  are absolutely simultaneous with each other, and any point that is absolutely simultaneous with any point in  $r$  is itself in  $r$ .

This answer is natural in a classical context because classical spacetime theories all agree that there are distinct spacetime points that are absolutely simultaneous with each other and that absolute simultaneity is an equivalence relation. It exhaustively carves up spacetime into non-overlapping ‘time-slices’ – instants. Absolutism fits with the common sense view that

**PreSim**    If a given event  $e$  – say, a certain pain experience of yours – is absolutely present, then for any other event  $e^*$  – say, a meteorite impact on Mars –  $e^*$  is also absolutely present if and only if  $e^*$  is absolutely simultaneous with  $e$ .<sup>26</sup>

Thus, the image of presentness as a narrow strip of light cutting across the entire spatial extent of the universe, illuminating a collection of events that are all simultaneous, and moving steadily forward in time, to illuminate ever later such collections.

Before we can assess the plausibility of something like Absolutism in a relativistic context, we need more groundwork. In particular, we need a more perspicuous formulation STR. We will opt for

**STR<sub>U</sub>**    Spacetime exists and has the ‘positive’ geometrical properties of Minkowski spacetime. Thus, spacetime has at least as much geometrical structure as Minkowski spacetime; it may or may not have more.

It is well known that STR does not entail that there are distinct spacetime points that are absolutely simultaneous. But does it merely *fail to entail* it, or does it positively *entail the negation* of the given proposition, that is, entail that no distinct spacetime points are absolutely simultaneous? Opponents of the A-theory are sometimes evasive here, which can make it seem as

though their anti-A-theory arguments depend on a subtle slide from the weaker to the stronger claim. So we will be explicit: by STR, we mean only  $STR_U$ , which refrains from postulating absolute simultaneity but does not positively ban it.

Now for some basic facts about the geometry of Minkowski spacetime.  $STR_U$  attributes to spacetime a *light-cone structure*. Consider the following picture (Fig. 2), which depicts the light cones of spacetime point  $e$ . Relativity associates such cones with each spacetime point. For each point  $e$  in a Minkowski spacetime, any other point  $e^*$  in the spacetime will belong to exactly one of the following:

- (i) (the surface of)  $e$ 's future light cone;
- (ii) the interior of  $e$ 's future cone;
- (iii) (the surface of)  $e$ 's past light cone;
- (iv) the interior of  $e$ 's past light cone; or
- (v)  $e$ 's absolute elsewhere.

Together, groups (i) and (ii) make up  $e$ 's *absolute future*, and groups (iii) and (iv) make up  $e$ 's *absolute past*. The points that lie *inside* the light cones of  $e$  are said to be *timelike* separated from  $e$ , and those *on* one of  $e$ 's light cones are *lightlike* separated from  $e$ . Each point is lightlike related to itself, too. According to  $STR_U$ , the temporal order between these points is frame-independent, the same in all frames. For any point  $e^*$  inside or on the future light cone of  $e$ ,  $e$  precedes  $e^*$ ; *mutatis mutandis* for  $e$ 's past light cone.<sup>27</sup> The points that lie outside both light cones (in  $e$ 's absolute elsewhere) of  $e$  are *spacelike* separated from it.  $STR_U$  does not postulate any frame-independent time order between  $e$  and any of these points.

If  $STR_U$  is true and spacetime has this light-cone structure, what is the most plausible answer to the Shape Question? What is the spatiotemporal shape of the present? We will discuss four different answers that A-theorists have attempted to combine with  $STR_U$ , and we will mention some potential drawbacks for each.<sup>28</sup>

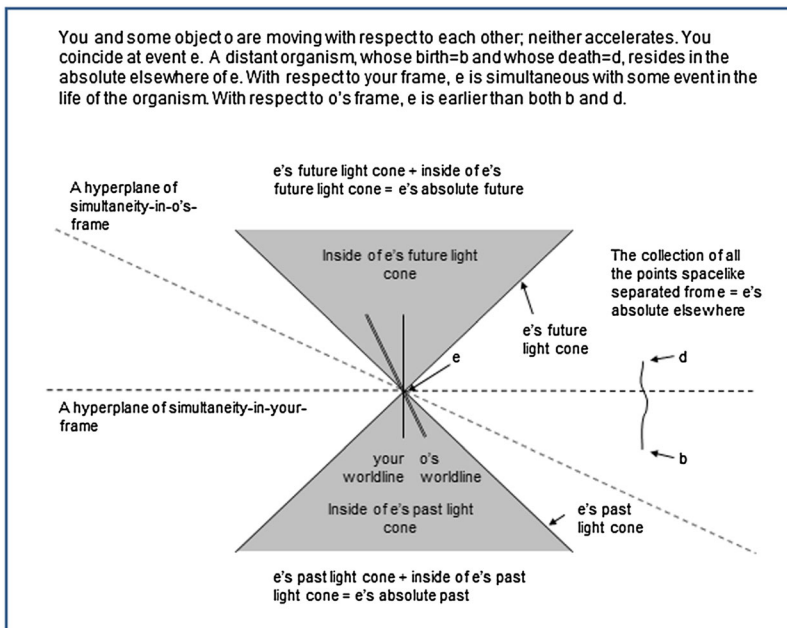


Figure 2. The light cone of an event in Minkowski's spacetime.

*Elsewhere-ism*: the present is a ‘bow-tie-shaped’ region composed of a given point together with all and only those points in its absolute elsewhere.<sup>29</sup>

The main problem for this view is that it conflicts with the principle that

PrePre If an event  $e_2$  is absolutely present, and if an event  $e_1$  absolutely precedes  $e_2$ , then  $e_1$  is past and not absolutely present.

To see this, suppose that the present is  $e$  together with its absolute elsewhere. Note that  $e$ 's absolute elsewhere includes the entire life of a distant organism, from its birth,  $b$ , to its death,  $d$ , and that  $b$  is timelike separated from, and absolutely precedes,  $d$ .<sup>30</sup> So, according to Elsewhere-ism, even though  $d$  is present and  $b$  precedes  $d$ ,  $b$  is present too. This violates PrePre. Elsewhere-ism is also in tension PreSim, though we will leave it to the reader to explain why.

According to Skow (2015), the main motivation for the A-theory is that only it can explain certain facts about the experience of time. Suppose that I am now undergoing a pain experience (only) and that at other times I have various other experiences but am always pain-free. Roughly put, the idea is that only the A-theory can make sense of ‘experientially given’ facts like this: only the pain experience is available to me. Other experiences are available to me at other times, but there is one experience, and one only, that is available to me *simpliciter*, or absolutely: viz., this pain. If one time is absolutely present (as the A-theory says), then it is natural to think that a given experience of mine is available to me absolutely if and only if that experience (or the time at which it occurs) is absolutely present. Certain non-present experiences were or will be available to me, but only present experiences are available to me absolutely. That explains why, of all the experiences I will have had over my life, this pain, and it alone, is available to me absolutely: it, and it alone, is absolutely present.

As Skow notes (2015: 156), Elsewhere-ism does not fit well with this experiential argument. If my worldline runs through  $e$  and my pain occurs there, then Elsewhere-ism explains why only this pain is available to me absolutely. But what about the organism born at  $b$ ? Suppose that it is a person and has experiences. Then, given Elsewhere-ism, the experiential argument will force us to say that all of its experiences over its whole life are present and hence available to it absolutely, which is implausible. So Elsewhere-ism may not yield a version of the A-theory worth having.

Parallel remarks apply in a straightforward way to other possible views, for example, the view that the present is composed of a given point together with all and only those points within its absolute past. So we assume that these views do not require separate discussion.

*Past-Cone-ism*: the present is composed of a given point together with all and only those points on the surface of its past light cone.<sup>31</sup>

This answer is preferable to Elsewhere-ism. It does not yield the result that the present includes four-dimensional, temporally extended chunks of spacetime large enough to contain the entire life of a distant organism. Instead, it gives us a present that ‘slices’ surgically through the worldlines of organisms. If we idealize and pretend that the life of each organism has a one-dimensional timelike worldline, then Past-Cone-ism will tell us that at most one spacetime point in the worldline of any organism is present. This would allow the experiential argument to get back up and running.

Unfortunately, the main problem for Elsewhere-ism also afflicts Past-Cone-ism. They both conflict with PrePre. Suppose that Past-Cone-ism is true and that  $e$  and the surface of its past light cone are present. Now pick some point  $e^*$  on that surface. Then  $e^*$  absolutely precedes  $e$ . So, given that  $e$  is present and given that  $e^*$  absolutely precedes  $e$ , PrePre tells us that  $e^*$  is past, not present. But the friend of Past-Cone-ism denies this and says that  $e$  and  $e^*$  are both present. Another way to bring out roughly the same problem is to note that, according to Past-Cone-ism, the present can include the entire career of a photon that travels across the universe at light speed,<sup>32</sup>

despite the fact that some stages in its history absolutely precede others. (Parallel remarks apply to Future-Cone-ism, which we will not separately discuss.) Past-Cone-ism is in tension with PreSim, too, though again we leave this to the reader.

*Pointism*: the present is a single spacetime point.<sup>33</sup>

This view harmonizes with PrePre, and it doesn't obviously undermine the experiential argument for the A-theory. Only this experience is available to me absolutely, an A-theorist might say, because (i) only this spacetime point is present and (ii) this point falls within the location of the given experience. Pointism also fits better with PreSim than do Elsewhere-ism and Past-Cone-ism, for reasons we leave to the reader.

But whereas Elsewhere-ism makes the present too big, Pointism makes it too small. According to the common sense picture that motivates the A-theory, the present is spatially extended and so public and shareable. If these experiences are available absolutely to me, then unless I'm the last sentient being in the universe, there ought to be other experiences, occurring elsewhere in space, that are available absolutely to others. Not so according to Pointism, which says that the present is spatially point-sized and so lies within the location of at most one person. Given the presentness-availability link presupposed by the experiential argument, it follows that no two experiences are both available, absolutely, to their respective (different) owners. Suppose that you are now kissing your beloved and that your experience of love is available absolutely to you. Then, according to Pointism, things are different for your beloved. His experience of love is not available to him absolutely, but at most *at a region*. Thus, Pointism, too, might fail to be an A-theory worth having.<sup>34</sup>

*Cauchy surface-ism*: the present is a Cauchy surface, informally, a three-dimensional spacelike region that spans the entire spatial extent of the universe.<sup>35 36</sup>

(Two such regions are depicted in Fig. 2. They are the hyperplanes represented by the dashed lines.)

Cauchy surface-ism is the final answer to the Shape Question that we will discuss. With it, we return to something like Absolutism. Of the four relativistic views on the table, Cauchy surface-ism does by far the best job of accommodating the common sense picture that motivates the A-theory. Cauchy surface-ism harmonizes with PrePre and with the experiential argument, and it makes the present a spatially extended and so shareable region.

The main problem for Cauchy surface-ism is best put in the form of a dilemma. Either (a) the points in the present are all absolutely simultaneous with each other, or (b) not. Each option faces objections. Given (a), there is a relation of absolute simultaneity that holds between distinct points, and there are facts about which points stand in this relation. These facts would go beyond, but not contradict,  $STR_{\cup}$ . But, on the assumption that  $STR_{\cup}$  is empirically adequate, such facts would be unobservable: there would be no test we could perform to find out whether two points are absolutely simultaneous. In this sense, option (a) is guilty of a commitment to surplus geometrical structure (more than the minimum required for an empirically adequate theory), which is standardly taken to be a theoretical vice.

According to (b), the points in the present are not absolutely simultaneous. We will mention two objections. First, (b) conflicts with PreSim. Suppose that your current experience is absolutely present. Then, according to (b), so is some event happening on Mars. And yet, though these events are both present, they are not simultaneous! This contradicts PreSim.

Here is a second objection. Given either version of Cauchy surface-ism, it is natural to go further and hold that there is one particular foliation<sup>37</sup> of spacetime into Cauchy surfaces – call it *f* – such that

PreFol A region was, is, or will be the present<sup>38</sup> if and only if it belongs to *f*.

There are many foliations of Minkowski spacetime into Cauchy surfaces. For example, each inertial reference frame singles out such a foliation, and indeed, these ‘frame foliations’ are all geometrically on a par with one another (assuming that spacetime has no geometrical structure beyond that of Minkowski spacetime). But according to PreFol, exactly one of these foliations, namely  $f$ , is *privileged*: it corresponds to the set of regions that were, are, or will be the present. Finally, if  $f$  is the privileged foliation, presumably this fact is counterfactually stable, so that  $f$  would still be the privileged foliation even if, say, Obama hadn’t been reelected. Indeed, many will find it natural to think that if PreFol is true, then it is metaphysically or at least nomically necessary.<sup>39</sup> But the conjunction of (i) the view that PreFol is at least nomically necessary, with (ii) the view that the geometry of spacetime is just that of Minkowski spacetime, conflicts with a ‘symmetry principle’ that Skow informally glosses as

Sym The laws do not treat differently regions of spacetime that are geometrically the same.<sup>40</sup>

Let  $R$  be the present, and suppose that (i) and (ii) are true. Since  $R$  is the present, it belongs to the privileged foliation,  $f$ . But, given (ii), there are other foliations that are geometrically just like  $f$ , and they contain regions geometrically just like  $R$ . And, given (i), it is at least nomically necessary that, unlike  $R$ , those other regions are not, never were, and never will be the present. Thus, in violation of Sym, the laws treat  $R$  differently from those other regions, despite the fact that they are geometrically just like  $R$ .<sup>41</sup>

Of course, it is open to the friend of Cauchy surface-ism, version (b), to deny PreFol or at least deny that it is nomically necessary. But barring this, she is apparently forced to deny Sym. Is this a cost that outweighs the virtues of her theory? We will not try to answer that here.

So far, we have confined our attention to STR. But STR is false: spacetime does not have the positive geometrical properties of Minkowski spacetime. So we should consider GTR, which allows for a wide range of geometrically different spacetimes. Against that background, there is more hope of finding a foliation of our spacetime into Cauchy surfaces that is geometrically unique. In GTR, spacetime can be curved and, moreover, *variably* curved, so that different regions possess different curvatures. This makes room for spacetimes in which a single foliation stands out geometrically. In particular, many GTR spacetimes admit of a unique foliation associated with the notion of ‘cosmic time’, a notion invoked, for example, when physicists speak of the age of the universe as a whole.<sup>42</sup> When we are told that the Big Bang occurred 13.7 billion years ago, we should remember that duration is not invariant in STR or GTR, and so we should ask: relative to what? The answer is: relative to the so-called *fundamental observers*, the objects

whose state of motion coincides with the average motion of matter in their own local region of the universe, a region sufficiently large for the motion within it to be dominated by the recession of the local galaxies, in accordance with the overall expansion of the universe (Lockwood: 116).

Different precise procedures for singling out the foliation associated with cosmic time can yield slightly different results, a fact that may seem to introduce worries about arbitrariness. Some believe, however, that there is one procedure that has a special status: choose the *constant mean curvature* (CMC) foliation – a foliation in which, for each leaf  $L$  in it, the ‘mean extrinsic curvature’ (a geometrical property whose nature we can ignore) at any point in  $L$  is the same as at any other point in  $L$ . Perhaps CMC foliations give the A-theorist exactly what she needs to respond to worries about the relativity of simultaneity.<sup>43</sup>

In reply to this suggestion, one might concede that there is a single best way of defining a geometrically preferred foliation, but then go on to argue that that we have no reason to think that the facts about such foliations are relevant to facts about the passage of time or about which

events are privileged as present (Callender 2000; Lockwood 2005: 120–121; Wuthrich 2013). Alternatively, one might follow Gödel (1949) and argue that the solution in question is not sufficiently general. After all, some GTR spacetimes are not foliable into Cauchy surfaces at all, while others, though so foliable, admit of no unique, geometrically preferred such foliation. The idea here is that if the A-theory is true and facts about the passage of time are tied in the given way to the geometrically preferred foliation, then this should be at least nomically necessary, but on the assumption that all of the just-mentioned GTR spacetimes are nomically possible (which might be challenged), the current A-theoretic proposal would end up *not* being nomically necessary and, therefore, not even actually true.<sup>44</sup>

Now, some A-theorists (e.g., Crisp 2003: 232–235) are not wedded to the claim that the A-theory is nomically necessary. They will be undaunted by Gödel's objection. They do, however, need it to turn out that spacetime is at least *actually* foliable into Cauchy surfaces. Thus, we have an empirical question: Is it? Many have thought so. Whitrow, for example, writes that

we have strong evidence that the universe as a whole is predominantly homogeneous [such that no position is physically special] and isotropic [such that no direction is physically special], and this conclusion, as we have seen, is a strong argument for the existence of cosmic time [and, a fortiori, foliability] (1980: 307).

Lockwood (2005: 152), however, has raised an interesting objection to this view, which, in a nutshell, goes as follows. Hawking famously discovered that black holes can eventually evaporate. The problem is that if the universe outlives even just one single evaporating black hole, then spacetime cannot be globally foliated into Cauchy surfaces, via the CMC foliation or via any other foliation for that matter. And the astronomical evidence in favor of a forever expanding universe points exactly in that direction. If Lockwood is right, then the prospects of the A-theory hinge on questions about the longevity of black holes: if a black hole evaporates before the universe ends, this will block an attractive strategy for reconciling Relativity with the A-theory of time.

### 3. *Endurantism vs. Perdurantism*

Let's assume that Relativity mandates both the B-theory and unitism. If either of these views entails perdurantism, Relativity mandates the latter as well. In this section, we take a brief look at such arguments. Other arguments from Relativity to perdurantism are explored elsewhere.<sup>45</sup>

The perdurantism vs. endurantism dispute concerns the metaphysics of persistence.<sup>46</sup> Both perdurantists and endurantists maintain that material objects persist, that is, exist at more than one time, but they disagree on how they do so. To put it roughly, according to the perdurantist, material objects are four-dimensional wholes that persist by having a different temporal part at each instant of their existence, whereas according to the endurantist, material objects are three-dimensional wholes that are wholly present at each instant of their existence and thus do not divide into temporal parts.<sup>47</sup>

What is a temporal part? For simplicity, we will focus on instantaneous temporal parts. Informally, an instantaneous temporal part of you would be something that has exactly the same shape, size, and spatial location as you do, and that is made up of exactly the same matter as you are, but that exists for just a single instant. In relativistic terms, we can say that  $x$  is an instantaneous temporal part of  $y$  if and only if  $x$  is a part of  $y$  and  $x$ 's path is a maximal spacelike subregion<sup>48</sup> of  $y$ 's path. We can think of an object's path (worldline, worldtube, etc.) as the region at which the object's entire career is exactly located. Persisting objects have temporally extended paths.

A number of philosophers are happy to grant both the B-theory and unitism but favor endurantism over perdurantism (Mellor 1981; van Inwagen 1990a; Sattig 2006). Is this a tenable combination of views?

### 3.1. THE B-THEORY AND CHANGE

Not according to the *argument from change* against B-theoretic endurantism. As Lewis (2002: 1) writes:

Things somehow persist through time. When they do, they have some of their intrinsic properties temporarily. For instance shape: sometimes you sit, and then you are bent; sometimes you stand or lie, and then you are straight. How can one and the same thing have two contrary intrinsic properties?

If the A-theory is true, it is natural to say that the only properties that a thing *has* (simpliciter) are those that it *presently* has. In that case, you have only straightness; you do not have bentness, though you did or will. If perdurantism is true, it is natural to say that a *temporal part* of you has straightness, another one has bentness, and you have neither.<sup>49</sup>

What about B-theoretic endurantists? The most popular response for them is to adopt a relativizing approach to shapes or the having of them. Relativity just makes this relativization strategy more interesting – and some would say more controversial. Relativity offers two ways of implementing this overall strategy. According to the first variant, endorsed, for example, by Gibson and Pooley, fundamental shapes are *two-place relations* that things can bear to spacetime regions. This is particularly well suited to unitism. According to this view, you are exactly located at many different regions, and you bear the *bent-at* relation to some of them and the *straight-at* relation to others. Given a separatist version of Relativity – which avoids talk of spacetime regions – a second variant of the relativizing strategy will be preferable. The second variant relativizes shapes or the having of them *both to times and to reference frames*. According to this view, you bear the *bent-at relation* to a time *t* relative to a frame *F*. Canonical shape ascriptions are thus of the form *object o is bent at instant t in frame F*. Likewise for the straight-at relation. See Balashov (2010) and Balashov (2014).

According to both views, shapes really are contraries, and so incompatible. But they are incompatible *n-place relations*, not incompatible *properties*. Insofar as it is not impossible to bear incompatible relations to different entities, the problem of change is solved.

To be sure, not everyone is satisfied with this response to the problem. In particular, Lewis (2002) has mounted a vigorous attack against relativizing approaches to shapes and other apparently intrinsic ‘properties’. Lewis’s arguments, however, have been discussed extensively (Haslanger 2003; McGrath 2007; Eddon 2010), and considerations from Relativity do not add anything distinctive to this debate beyond what we have already mentioned. Suffice it to say that there is room for the B-theorist endurantist to maneuver, perhaps at some cost.

### 3.2. UNITISM AND SUPERSUBSTANTIVALISM

Even if endurantism can survive the transition from the A-theory to the B-theory, this is no guarantee that it can survive the transition from separatism to unitism.<sup>50</sup> Can it?

One thing that should be clear immediately is that the unitism vs. separatism dispute is relevant to the question of how *regions of space* persist (if there are such things). Separatists hold that regions of space *endure* through time: they say that each spatial region is located at each instant of time and that no spatial region has temporal parts. Unitists must hold that spatial regions are just temporally extended spacetime regions of a certain sort and hence perdure. Does unitism also favor the view that *material objects* perdure?<sup>51</sup>

One reason to think so is that once we have accepted spacetime regions as real entities, we have the option of holding that material objects are numerically *identical* to spacetime regions. In particular, we become free to endorse

Supersubstantivalism For each material object  $O$ , there is a spacetime region  $R$  such that  
 $O = R$ .

Supersubstantivalists say that a material object is identical to the region that we would ordinarily refer to as that object's *path*. This identification is unavailable to separatists, who have no locations with which material objects could plausibly be identified. Regions of space are ruled out, since objects often accelerate (e.g.), but no region of space does this. Intervals of time are ruled out for the same reason.

Supersubstantivalism might be motivated by considerations of ontological parsimony: it lets us recognize just one basic category of entity (spacetime regions) where others see two (material objects and spacetime regions).<sup>52</sup> The identification is unavailable to endurantists. After all, no spacetime region endures, so no enduring object is a spacetime region. Unlike the perdurantist, then, the endurantist who accepts unitism is committed to a non-parsimonious dualism of material objects and spacetime regions (Sider 2001: 110).

A further point is worth a mention here. Some heterodox forms of endurantism have specific problems vis-à-vis unitism. Such heterodox forms of endurantism claim that objects are related to places and times in different ways. In particular, they claim that the relation between objects and instants or intervals of time – call this relation *existence-at-a-time* – should not be identified with the relation between objects and regions of space – *location*. Moreover, they claim, the fact that objects are not located at instants or intervals explains why they do not have temporal parts. Examples of heterodox endurantism are Fine's three-dimensionalism (Fine 2006), according to which existence-at-a-time and location are two primitive relations, and transcendentism, according to which location is primitive and existence-at-a-time is not (Costa forth.; Giordani and Costa 2013).

This heterodox endurantism clashes with unitism. One of the central claims of heterodox endurantism is that material objects are located at places but cannot be located at times. But if unitism is true, and if both places and times exist, then material objects that are located at places are located at times as well. The point can be most vividly made in terms of weak location. Roughly put, an entity is weakly located at region just in case the region is not completely free of it (Parsons 2007: 203). For example, Schrödinger's cat is weakly located at the region of the box, given that that region is not completely free of the cat. Let us now suppose that unitism is true and that a point-sized material object  $o$  is weakly located at a point of space  $p$ . Remember that under unitism, if there are such things as times and places, they are made up of spacetime points. Hence, the claim that  $o$  is weakly located at point of space  $p$  implies that  $o$  is weakly located at some spacetime point, call it  $s$ . (In general, if  $x$  is weakly located at  $r$ , and if  $r$  is composed of simples, then  $x$  is weakly located at one or more of these simples.) But, given unitism, if there are times, then each spacetime point is a part of at least one time.<sup>53</sup> So  $s$  is a part of some time, call it  $t$ . Now, another core truth about weak location is that if an entity  $x$  is weakly located at a point or region  $r$ , then  $x$  is also weakly located at any point or region that has  $r$  as a part. (If the box region is not entirely free of the cat, then neither is the laboratory region that includes the box region.) So, given that  $o$  is weakly located at  $s$  and that  $s$  is a part of  $t$ , it follows that  $o$  is weakly located at  $t$  – in other words, that a material object is located at a time, contrary to heterodox endurantism.<sup>54</sup>

Is endurantism damaged by the problems mentioned in this section? Philosophers will disagree. But we suspect that even those who are impressed by the above arguments will admit

that they could be overridden by a sufficiently strong case for endurantism. This provides an incentive to look for new routes from Relativity to perdurantism.

### Conclusion

It is no straightforward matter to determine how Relativity bears on the A-theory vs. B-theory, the separatism vs. unitism, or the endurantism vs. perdurantism dispute. We suspect that it does raise the price of the A-theory and of separatism (for somewhat different reasons) and that unitism raises the price of endurantism, but we haven't said enough here to justify much confidence even in these watered-down conclusions.

Our main goal has not been to present detailed, knock-down arguments; rather, it has been to disentangle various questions on which Relativity might be thought to bear. What we have tried to do is make it plausible that when it comes to the impact of Relativity on traditional issues in analytic metaphysics, we have at least *three* quite separate questions to ask. We have given the reader just a taste of the arguments that bear on these questions. Given that the questions have been run together so often in the past, better arguments probably await discovery.

### Short Biographies

Cody Gilmore is Associate Professor at the University of California, Davis. He specializes in metaphysics, mainly on questions about mereology, persistence, and location. He also works on questions about properties, relations, propositions, personal identity, and death. He has published on these topics in such venues as the *Australasian Journal of Philosophy*, *Oxford Studies in Metaphysics*, *Philosophical Perspectives*, *Philosophical Studies*, and the *Stanford Encyclopedia of Philosophy*.

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### Notes

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<sup>1</sup> The disjunction of the Special Theory (STR) and the General Theory (GTR) of Relativity.

<sup>2</sup> There are many excellent introductions to relativity. Huggett (2010: 150–178) and Balashov (2010: 41–69) are brief and accessible presentations of the essentials of STR. Dainton (2010: 313–386) introduces STR and GTR informally and surveys a range of related philosophical literature, as does Hawley (2009), more briefly. Geroch (1978) and Maudlin (2012) are books that presuppose almost nothing and manage to present STR and aspects of GTR pretty rigorously.

<sup>3</sup> See Callender (2008) and Wuthrich (2013) for the bearing of quantum mechanics on (ii) and for further references. One prominent view in the metaphysics of quantum mechanics literature is *configuration space realism*, according to which configuration space, rather than ordinary space or spacetime, is fundamental. Configuration space is  $3n$ -dimensional, where  $n$  is the number of particles. See Ney and Albert (2013). Prima facie, configuration space realism bears on (i)–(iii).

<sup>4</sup> Skow (2015: 4–10) calls unitism the '4D view' and separatism the '3 + 1 view'.

<sup>5</sup> We mention the dimensionality of space, of time, and of spacetime, just to make the exposition easier to follow. But nothing here depends on the claim that space is three-dimensional, as opposed to, say, 13-dimensional. Parallel remarks go for time.

<sup>6</sup> We build a commitment to instants and points of space into our statement of separatism, mainly for vividness and ease of comprehension. Even if space and time were gunky (such that each of their parts, themselves included, had proper parts) and not built out of instants or points, they could still be separate, in the sense that no region of space shared a part with any interval of time.

<sup>7</sup> Separatism and unitism both presuppose some form of substantivalism (about space and time or spacetime). Both views are false given the relationist view that (i) events stand in spatial, temporal, or spatiotemporal relations but (ii) there are no 'locations' – no instants, intervals, points, or regions.

<sup>8</sup> We build a commitment to simple spacetime points into unitism, but even if spacetime were gunky, it might turn out that spacetime is fundamental and that every spatial region shares a part with some interval, and vice versa.

<sup>9</sup> Earman (1989: ch. 1, 2).

<sup>10</sup> Roughly, the argument is that separatism forces unobservable structure upon us, in the form of a distinction between objects absolutely at rest and objects in inertial motion. (This distinction makes no observable difference, even according to Newtonian physics.) Given separatism, space exists and persists through time, and so any object that is spatially located at the same region of space throughout an extended interval of time counts as being absolutely at rest. Given unitism, however, the relevant distinction is not forced upon us. On such a view, there are no persisting simple spatial points. Any two simple points located at different times are different spacetime points, and it might turn out that there is no fact as to whether two given points, at different times, are zero spatial distance apart. Given unitism, we can choose between a (i) *Newtonian* spacetime, in which spatial distance relations (including zero distance) do hold between non-simultaneous spacetime points and hence there is a distinction between absolute rest and inertial motion and a (ii) *neo-Newtonian*, also known as *Galilean*, spacetime, in which cross-time spatial distance relations do not hold and so there is no distinction between absolute rest and inertial motion (though there is a distinction between inertial and non-inertial trajectories, i.e., between straight and non-straight timelike lines). So, the argument concludes, unitism permits us to avoid postulating certain bits of unobservable structure that separatism forces upon us. See Dainton (2010: 194–212) and Maudlin (2012: 47–66).

<sup>11</sup> If  $d$  is a number that specifies the spatial separation, as measured in a given frame  $F$ , between the events (in meters),  $t$  is a number that specifies the temporal separation, as measured in  $F$ , between the events (in seconds), and if  $c$  is a number that specifies the speed of light (in meters per second), then the formula for the spacetime interval,  $I$ , can be given as  $I^2 = (ct)^2 - d^2$ . When their temporal separation 'outweighs' their spatial separation and  $I^2$  is positive, the events are timelike separated. When their spatial separation 'outweighs' their temporal separation and  $I^2$  is negative, the events are spacelike separated. When their temporal and spatial separation 'weigh the same' and  $I^2$  is 0, the events are lightlike separated. The spatial and temporal separation between the events will be different relative to different frames, but the interval will be the same in all frames.

<sup>12</sup> This is an informal characterization of the notion of an inertial frame. Physicists also speak of non-inertial frames, but we can ignore those here. The unitist can invoke Minkowski spacetime and define a frame as a maximal set of pairwise parallel, maximal, straight, and timelike lines. The separatist should take the notion as officially primitive and fundamental.

<sup>13</sup> The combination of STR with separatism is similar to what Nerlich calls the *relativity interpretation* of STR: it has a familiar, classical ontology of continuant spatial objects persisting in time. It uses the idea of a frame of reference, a relative space and relative time. The frame defines (relatively) the same place at different times and thus the concepts of rest, speed, and velocity. It also defines (relatively) the same time (simultaneity) at different places. Light is marked out as having an invariant speed for every frame of the interpretation. Whereas one can do spacetime [unitist] physics without coordinates, it is meaningless to speak of a frame-free relativity physics. The concepts of the relativity interpretation make sense, in SR, only with respect to some frame' (1994: 63).

<sup>14</sup> A very similar argument is developed independently by Hofweber and Lange (MS), who use it against a cousin of separatist STR, Fine's (2005) fragmentalist interpretation of STR.

<sup>15</sup> See Crisp (2003: 232–235 and 2007).

<sup>16</sup> It is not clear, for example, that those who take passage seriously must embrace the property of presentness. One might, after all, be a nominalist and reject properties altogether and yet think that tense operators and the predicate 'is present' are metaphysically fundamental and that there is change with respect to which time is present. See Lowe (1998) and Sider (2011: 259).

<sup>17</sup> Defenders of the B-theory include Mellor (1981), Oaklander (2004), Quine (1960), Russell (1954), Sattig (2006), Sider (2001), Skow (2015), and Smart (2008).

<sup>18</sup> Other A-theories have been defended. There is, for example, the THINNING TREE (McCall 1994), according to which reality consists of a branching universe with a single past and present (the trunk) but many possible futures (the branches), all equally real, and the passage of time is robust and should be construed as the ceasing to exist of the lower branches.

<sup>19</sup> Boume (2006: 10–11) writes: 'there's only one way to be a tenseless theorist... There are, however, many ways ... to be a tensed theorist'.

<sup>20</sup> See Smith (1993). For a sympathetic discussion and critique, see Sider (2011: 257–265) and Skow (2015).

<sup>21</sup> See Broad (1923) and Tooley (1997).

<sup>22</sup> See, for example, Bourne (2006), Craig (2001), Crisp (2003, 2008), Hinchliff (2000), Markosian (2004), Prior (1959), and Zimmerman (2008, 2011).

<sup>23</sup> Though the way in which it is special varies from theory to theory. For example, in the case of presentism, it is metaphysically privileged in that it exhausts what exists, whereas in the growing block, it is privileged because it represents the later edge of what exists.

<sup>24</sup> The A-theory is most commonly combined with separatism, but it can be with unitism and has been (Tooley 1997; Zimmerman 2011). Similarly, although B-theorists typically endorse unitism, they are obviously free (at least in a pre-relativistic setting, and perhaps in a relativistic setting) to hold that space and time are separate entities.

<sup>25</sup> Quine (1960: 170–172) is one example. Sattig (2006: ch. 2) discusses the separatism vs. unitism dispute, or something very similar to it, though he seems to build the A-theory into the ‘separatist side’ of the dispute he discusses while building the B-theory into the opposing side.

<sup>26</sup> Here and in what follows, we will be a little sloppy in terminology and not distinguish between events and the spacetime points at which they are located; for example, we will sometimes say that event  $e$  is absolutely simultaneous with [precedes, etc.] event  $e^*$ . This should be understood as saying that there are points  $p$  and  $p^*$  such that event  $e$  is located at  $p$ ,  $e^*$  is located at  $p^*$ , and  $p$  is absolutely simultaneous with [precedes, etc.]  $p^*$ . We will also restrict our attention to relatively brief events, and we will pretend that they are durationless and spatially point-sized.

<sup>27</sup> If  $e^*$  is on the surface of  $e$ ’s future (as opposed to past) light cone, this fact goes beyond the facts about the interval between  $e$  and  $e^*$ . The (lightlike) interval between  $e$  and  $e^*$  would be the same either way. Likewise, if  $e$  is inside  $e^*$ ’s future light cone, rather than vice versa, this goes beyond the facts about the (timelike) interval between them, which would be the same either way.

<sup>28</sup> For further criticisms of attempts to combine A-theories with Relativity, see Gödel (1949), Putnam (1967), Sklar (1981), Savitt (2000), Sider (2001), Saunders (2002), Wuthrich (2013), and Calosi (2014). Our survey of answers to the Shape Question is not comprehensive. We ignore, for example, *Alexandroffism*: there are timelike separated points,  $p_1$  and  $p_2$ , such that the present is composed of those points and their Alexandroff region, the intersection of the absolute future of the earlier of the two with the absolute past of the later of the two. (This will be a ‘disc-shaped’ region.) See Arthur (2006) and Savitt (2009).

<sup>29</sup> Weingard 1972.

<sup>30</sup> The proper time elapsed along the worldline of this organism (an invariant quantity) might be quite long, say, 95 years.

<sup>31</sup> Godfrey-Smith 1979; Hinchliff 2000.

<sup>32</sup> Skow (2015: 156) takes the photon example to be a ‘decisive objection’ to Past-Cone-ism, but he does not invoke PrePre. He seems just to take it as data that it never happens that the entire career of a photon is present.

<sup>33</sup> Skow (2015) argues that that Pointism is the A-theorist’s best option given Relativity. See also Stein (1991) and Hinchliff (2000).

<sup>34</sup> Callender (2000) defends this conclusion about Pointism.

<sup>35</sup> To say that a region is spacelike is to say that any two distinct points in it are spacelike separated. A Cauchy surface is a spacelike region that ‘intersects every causal curve [timelike or lightlike line] without endpoint exactly once’ (Earman 1995: 44). A hyperplane is a ‘flat’ Cauchy surface – a Cauchy surface for which there is a frame with respect to which the points in the surface are all simultaneous. Not all Cauchy surfaces are hyperplanes.

<sup>36</sup> Zimmerman (2008, 2011) defends Cauchy surface-ism.

<sup>37</sup> Informally, a foliation is a way of exhaustively carving up spacetime into non-overlapping portions (leaves). More formally, a foliation of spacetime is a partition of the set  $S$  of spacetime points. It is a set  $f$  of subsets (leaves) of  $S$  such that each member of  $S$  (each spacetime point) belongs to exactly one leaf.

<sup>38</sup> That is, had, has, or will have the property *being the largest part of spacetime that is absolutely present*. If one spells out the A-theory in terms of ‘supertime’ or ‘superspacetime’ (Skow 2015), one should take PF to mean that for any spacetime region  $r$ , there is a perspective  $p$  in supertime or superspacetime such that  $r$  is the present relative to  $p$  if and only if  $r$  belongs to  $f$ .

<sup>39</sup> Something is nomically necessary iff it is entailed by the laws of nature (e.g., the laws of physics). Something is metaphysically necessary iff it is entailed by the ‘laws of metaphysics’. It is uncontroversial that anything that is metaphysically necessary is nomically necessary. Standardly, it is held that some nomically necessary propositions (e.g., that no object with mass goes from a sub-light-speed to a super-light-speed trajectory) are not metaphysically necessary, but this has been denied.

<sup>40</sup> Skow (2015: 148). A more precise formulation, he says, is ‘every symmetry of the spacetime geometry is a symmetry of the laws’ (148, note 8). He traces such principles to Earman (1989: 45–47) and refers the reader to Belot (2013) for critical discussion.

<sup>41</sup> There are versions of this argument that apply to other relativistic answers to the Shape Question, aside from Cauchy surface-ism. Suppose, for example, that one endorses Past-Cone-ism. Then one will say that the region that is the present is a certain point together with the surface of its past light cone. But which regions were or will be the present? One answer, analogous to PreFol, is PreFol\*: there is a certain foliation  $f^*$  of spacetime into cone regions (each of which consists of a certain point plus the surface of its past light cone), where  $f^*$  is associated in the natural way with a certain timelike line, such that it is just those members of  $f^*$  that are, were, or will be the present. If PreFol\* is nomically necessary, a conflict with Sym arises, since then the laws treat the regions in  $f^*$  differently from the members of other ‘cone foliations’ of spacetime, which are geometrically just like the members of  $f^*$ .

<sup>42</sup> The view that the metaphysically privileged foliation is the one corresponding to cosmic time is defended by, for example, Jeans (1936), Lucas and Hodgson (1990: 118–19), and Craig (2001: ch. 10).

<sup>43</sup> See Lockwood (2005: 115–121).

<sup>44</sup> For discussion of Gödel’s arguments, see Yourgrau (1999), Belot (2005), and Bourne (2006: 204–224).

<sup>45</sup> Gilmore (2008) is a *Philosophy Compass* article focusing on these arguments. Other contributions to the recent literature include Balashov (2010) and Calosi (2015).

<sup>46</sup> There is yet another contender, *stage theory*, according to which ordinary objects are instantaneous stages and persist by having temporal counterparts (other stages) at other times. See Sider (2001), Hawley (2001), and Varzi (2003).

<sup>47</sup> This is just one way to phrase perdurantism and endurantism, one that focuses on the mereological structure of persisting objects. Other formulations are possible, most notably those in terms of spatiotemporal location. As an intuitive gloss on the notion of exact location take Gilmore (2014): “a entity  $x$  is exactly located at a region  $y$  if and only if  $x$  has (or has-at- $y$ ) exactly the same shape and size as  $y$  and stands (or stands-at- $y$ ) in all the same spatial or spatiotemporal relations to other entities as does  $y$ ”. Say that a persisting object is a three-dimensional object iff it is exactly (multi)-located at temporally unextended regions, whereas it is a four-dimensional object iff it is (singly) exactly located at a temporally extended one. These definitions are rough but we cannot enter into the details here. Endurantism and perdurantism can then be phrased as the theses according to which all persisting material objects are three-dimensional/four-dimensional respectively. Locational endurantism is endorsed by van Inwagen (1990 and 1990a), Bittner, Donnelly and Smith (2004), Sattig (2006). The view is also discussed sympathetically in Hawthorne (2006; 2008) and Gilmore (2004; 2006). Lewis (1999: 227) claims that there are possible worlds at which things endure via multilocation. There are yet other ways of framing the endurance / perdurance distinction, for example in terms of grounding (see Hawthorne 2008).

<sup>48</sup> This definition closely follows Gibson and Pooley (2006: 163). A region  $r_1$  is a maximal spacelike subregion of  $r_2$  iff (i)  $r_1$  is a part of  $r_2$ , (ii)  $r_1$  is spacelike (any two distinct points in  $r_1$  are spacelike separated), and  $r_1$  is not a part of any other spacelike part of  $r_2$ .

<sup>49</sup> If stage theory is true, you (an instantaneous stage) have straightness; you have future counterparts (other stages) who have bentness; and de re temporal predications have counterpart theoretic truth conditions, so ‘you will have bentness’ is true.

<sup>50</sup> The argument from STR to perdurantism via unitism was discussed sympathetically by Alexander, who offered independent metaphysical reasons for unitism and for the view that spacetime ‘is the stuff of substances’ (1920: 341). Russell was an explicit advocate of the argument: ‘I think that relativity demands the abandonment of the old conception of “matter” ... In the old view, a piece of matter was something which survived through time, while never being at more than one place at a given time. This way of looking at things is obviously connected with the complete separation of space and time in which people formerly believed. When we substitute space-time for space and time, we shall naturally expect to derive the physical world from constituents which are as limited in time as in space. Such constituents are what we call events ... Just as, in the old view, an extended body was composed of a number of particles, so, now, each particle, being extended in time, must be regarded as composed of what we may call “event-particles”’ (1958: 132, first published 1925). See also Russell (1954: 286, first published 1927). Though Russell seems to conflate perdurantism with some thesis to the effect that what we ordinarily think of as material objects are actually events, to his credit he recognizes the difference between unitism (a view about space and time) and perdurantism (a view about particles, rocks, trees, etc.), and so he sees the need to supply an *argument* from one to the other.

<sup>51</sup> Hoffman and Rosenkrantz (2002: 60) write that ‘the main reason for thinking that a persisting substance perdures rather than endures is that it is in space-time’, but they do not elaborate.

<sup>52</sup> See Schaffer (2009) for additional arguments for supersubstantivalism. For further discussion, see Alexander (1920: 341), Sklar (1974: 221–224), and Sider (2001: 110–113). As Sider notes, some will reject the proposed identification on the grounds that there are de re modal differences between a material object and its path. For example, it is plausible that (i) a certain tree,  $T$ , which in fact lasts 100 years, *could* have had a shorter duration but that (ii) the 100-year long spacetime region,  $R$ , that is,  $T$ ’s path could not have had a shorter duration; like all spacetime regions, it has its actual duration

essentially. One response to this argument for the non-identity of *R* and *T* is to appeal to some view according to which all facts about an object's de re modal profile are relative to a counterpart relation or way of being conceived: thus, although *R* and *T* are just one thing, this thing *qua tree* could have had a shorter duration, but the thing *qua spacetime region* couldn't have. A second response concedes that material objects are not identical with their paths but insists that each material object still mereologically coincides with its path – where *x* and *y* mereologically coincide just in case *x* and *y* share parts with exactly the same things (Hawthorne 2006: viii). On this view, although our tree is not a spacetime region, it is 'entirely made up of spacetime'. This has the advantage of letting us take our modal intuitions at face value, while achieving some measure of ontological parsimony. On strategies for reconciling this object–region coincidence theory with endurantism, see Gilmore (2014).

<sup>53</sup> Any counterexamples to this principle will presumably involve some exotic 'partially foliable' spacetimes whose possibility would give no comfort to the heterodox endurantist.

<sup>54</sup> The point may be easily generalized to apply to material objects that are extended in space, but this would require an extensive package of principles about the relation between weak and exact location, which are standard but that we do not have space here to introduce. And after all, the case of a point-sized material object is already enough to show that under unitism, at least some material objects must be located at times in order to be located at places. It is worth noting that, along with his heterodox endurantism, Fine has developed a heterodox interpretation of Special Relativity and a heterodox version of A-theory – fragmentalism – that is supposed to allow him to keep both Special Relativity and spacetime separatism (Fine 2005). See also Hofweber and Lange (MS).

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