

Relativity and Three Four-Dimensionalisms

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 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 second is ‘spacetime unitism’ (as we call it), according to which there is a spacetime manifold, and if there are such things *points of space* or *instants of time*, these are just spacetime regions of different sorts: thus space and time are not *separate* manifolds. A third is perdurantism, according to which persisting material objects (rocks, trees, human beings) are made up of different temporal parts located at different times. We sketch routes from relativity to the B-theory and to unitism. We then discuss some routes to perdurantism, via the B-theory and via unitism.

Introduction

Relativity theory¹ 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;² 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.³

1. Separatism vs. Unitism

Here is an attractive, commonsense view about the relationship between space and time; we call it *separatism*.⁴

There is a three-dimensional entity called *space*.⁵ 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

¹ The disjunction of the Special Theory (STR) and the General Theory (GTR) of Relativity.

² 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.

³ 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).

⁴ Skow (2015: 4-10) calls unitism the ‘4D view’ and separatism the ‘3+1 view’.

⁵ 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, thirteen-dimensional. Parallel remarks go for time.

unitism, there is a physics-based argument for preferring unitism to separatism even in a pre-relativistic context.¹⁰ 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.¹¹ 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.¹²) 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.¹³ 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

¹⁰ 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 (ii) a *neo-Newtonian*, a.k.a. *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).

¹¹ 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.

¹² 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, timelike lines. The separatist should take the notion as officially primitive and fundamental.

¹³ The combination of STR with separatism is similar to what Nerlich calls the *relativity interpretation* of STR: "'t 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).

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 intervals are invariant but distances and durations are not, we should take this as providing at least some evidence for unitism over separatism.¹⁴

So much for the link between STR and unitism. 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,¹⁵ 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? E.g., by saying that there is property of presentness that is successively had by different times?¹⁶ 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 views¹⁷:

Eternalism: Past, present and future all equally exist.

Realism about Time and Tenseless Relations. Time is real and mind-independent, and things in time stand in mind-independent temporal relations (e.g., *being simultaneous with*, *being earlier than*)

¹⁴ A very similar argument is developed independently by Hofweber and Lang (MS), who use it against a cousin of separatist STR, Fine’s (2005) fragmentalist interpretation of STR.

¹⁵ See Crisp (2003: 232-235 and 2007).

¹⁶ It is not clear, e.g., 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).

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

Anti-realism about passage. 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.¹⁸ As Smart (2008: 227) put it, the A-theory is a gerrymandered ‘syndrome, rather than having a very tight definition’¹⁹.

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.²⁰

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.²¹

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.²²

Each of these versions of the A-theory entails that the present is *objectively special*.²³ This seems also to be the A-theory’s main virtue: it respects the allegedly commonsense 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.²⁴ (These disputes have often been run together.²⁵) 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:

¹⁸Other A-theories have been defended. There is, e.g., 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.

¹⁹ Bourne (2006: 10-11) writes: ‘there’s only one way to be a tenseless theorist... There are, however, many ways ... to be a tensed theorist’.

²⁰ See Smith (1993). For a sympathetic discussion and critique, see Sider (2011: 257-265) and Skow (2015).

²¹ See Broad (1923) and Tooley (1997).

²² See e.g. Bourne (2006), Craig (2001), Crisp (2003) and (2007), Hinchliff (2000), Markosian (2004), Prior (1959), and Zimmerman (2008, 2011).

²³ 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 of.

²⁴ 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.

²⁵ Quine (1960: 170-172) is one example. Sattig (2006: ch. 2) discusses the separatism v. 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.

The Shape Question What is the spatiotemporal shape of *the present*, i.e., 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 commonsense 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 .²⁶

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_U 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, i.e., 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) interior of e ’s past light-cone, or

²⁶ 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; e.g., 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 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.

(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.²⁷ The points that lie outside both light-cones of e are *spacelike* separated from it. STR_U does not postulate any frame-independent time-order between e and any of these points.

You and some object o are moving with respect to each other; neither accelerates. You coincide at event e . A distant organism, whose birth= b and whose death= d , resides in the absolute elsewhere of e . With respect to your frame, e is simultaneous with some event in the life of the organism. With respect to o 's frame, e is earlier than both b and d .

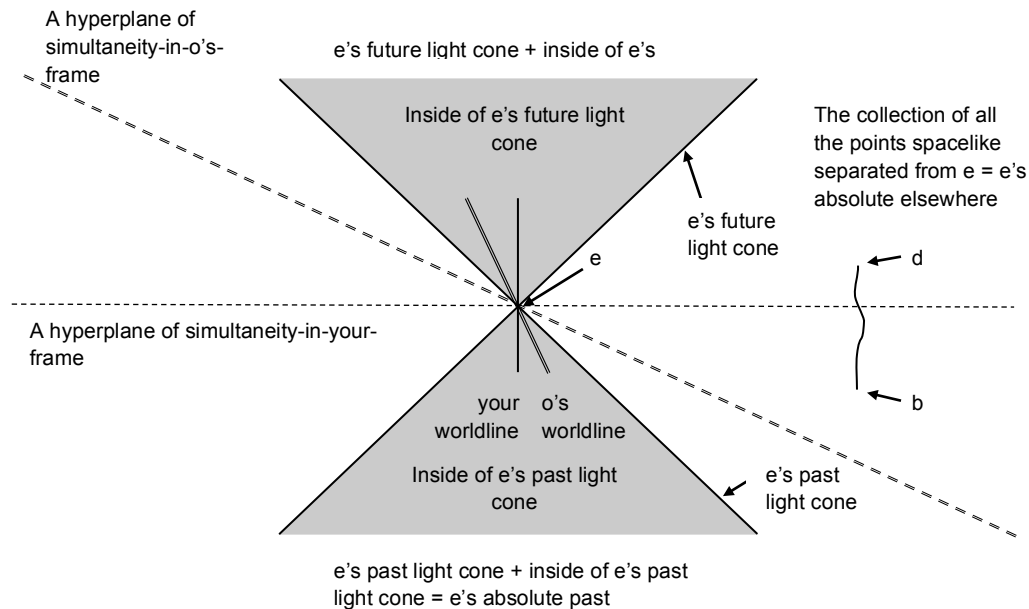


Figure 2

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.²⁸

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.²⁹ The main problem for this view is that it conflicts with the principle that

²⁷ 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.

²⁸ 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, e.g., *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.

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 .³⁰ So, according to Elsewhere-ism, even though d is present and b precedes d , p 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 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, *simpliciter*; 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, e.g., 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.³¹ 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,³² despite the fact that some stages in its history absolutely precede others. (Parallel

²⁹ Weingard 1972.

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

³¹ Godfrey-Smith, 1979; Hinchliff 2000.

³² 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.

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.³³ 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 simpliciter, 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. Point-ism 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 simpliciter 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 simpliciter 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, simpliciter, to their respective owners. Suppose that you are now kissing your beloved, and that your experience of love is available simpliciter to you. Then, according to Pointism, things are different for your beloved. His experience of love is not available to him simpliciter, but at most *at a region*. Thus Pointism, too, might fail to be an A-theory worth having.³⁴

Cauchy-surface-ism: the present is a Cauchy surface, informally, a three-dimensional spacelike region that spans the entire spatial extent of the universe.^{35 36} (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_U . But, on the assumption that STR_U 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.

³³ Skow (2015) argues that that Point-ism is the A-theorist's best option given Relativity. See also Stein (1991) and Hinchliff (2000).

³⁴ Callender 2000 defends this conclusion about Pointism.

³⁵ 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.

³⁶ Zimmerman (2008, 2011) defends Cauchy-surface-ism.

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 foliation³⁷ of spacetime into Cauchy surfaces – call it *f* – such that

PreFol a region was, is, or will be the present³⁸ if and only if it belongs to *f*.

There are many foliations of Minkowski spacetime into Cauchy surfaces. E.g., 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.³⁹ 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.⁴⁰

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*.⁴¹

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, e.g., when physicists speak of the age of the

³⁷ 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.

³⁸ I.e., had, has, or will have the property *being 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*.

³⁹ 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 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.

⁴⁰ 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.

⁴¹ 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**.

universe as a whole⁴². 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 which 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 simultaneity⁴³.

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.⁴⁴

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, e.g., 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 Relativity mandates both the B-theory and unitism. If either of these views entail 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.⁴⁵

The perdurantism vs. endurantism dispute concerns the metaphysics of persistence⁴⁶. Both the perdurantists and the endurantists maintain that material objects persist, i.e. exist at more than one time, but

⁴² The view that the metaphysically privileged foliation is the one corresponding to cosmic time is defended by, e.g., Jeans (1936), Lucas and Hodgson (1990: 118-19), and Craig (2001: ch. 10).

⁴³ See Lockwood (2005: 115-121).

⁴⁴ For discussion of Gödel’s arguments see Yourgrau (1999), Belot (2005), and Bourne (2006: 204-224).

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

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 parts⁴⁷.

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 subregion⁴⁸ 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, 1990; 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.⁴⁹

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 e.g. 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, 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.

⁴⁶ 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).

⁴⁷ 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 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.

⁴⁸ This definition closely follows Gibson and Pooley (2006: 163). A region $r1$ is a maximal spacelike subregion of $r2$ iff (i) $r1$ is a part of $r2$, (ii) $r1$ is spacelike (any two distinct points in $r1$ are spacelike separated), and $r1$ is not a part of any other spacelike part of $r2$.

⁴⁹ 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.

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 (Haslinger 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.⁵⁰ Can it?

One thing that should be clear immediately is that the unitism v. 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?⁵¹

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).⁵² The identification is unavailable to endurantists. After all, no spacetime region endures,

⁵⁰ 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.

⁵¹ 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.

⁵² 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).

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 transcendentalism, according to which location is primitive and existence-at-a-time is not (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.⁵³ 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.⁵⁴

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.⁵⁵

⁵³ Any counterexamples to this principle will presumably involve some exotic ‘partially foliable’ spacetimes whose possibility would give no comfort to the heterodox endurantist.

⁵⁴ 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).

⁵⁵ Thanks to

References

- Alexander, S. 1920. *Space, Time, and Deity: The Gifford Lectures at Glasgow, 1916-18*, vol. 1 (London: MacMillan).
- Arthur, R. 2006. 'Minkowski Spacetime and the Dimension of the Present,' in D. Dieks (ed.). *The Ontology of Spacetime*. Amsterdam: Elsevier, 129-155.
- Balashov, Y. 2010. *Persistence and Spacetime*. Oxford: Oxford University Press.
- Balashov, Y. 2014. 'Relativistic Parts and Places: a Note on Corner Slices and Shrinking Chairs', in C. Calosi and P. Graziani, eds., *Mereology and the Sciences* (Berlin: Springer), pp. 35-51.
- Balashov, Y. and M. Janssen. 2003. 'Presentism and Relativity', *The British Journal for the Philosophy of Science* 54: 327-346.
- Belot, G. 2005. 'Dust, Time, and Symmetry,' *British Journal for the Philosophy of Science*, 56: 255-91.
- Bittner, T., M. Donnelly, and B. Smith, 2004, "Endurants and Perdurants in Directly Depicting Ontologies", *AI Communications*, 13: 247–258.
- Bourne, C. 2006. *A Future for Presentism* (Oxford: Oxford University Press).
- Broad, C. D. 1923. *Scientific Thought*. (New York: Harcourt, Brace, and Company).
- Callender, C. 2000. 'Shedding Light on Time', *Philosophy of Science* 67 (Proceedings): S587-S599.
- Callender, Craig. 2008. 'On Finding 'Real' Time in Quantum Mechanics', in Craig and Smith, eds., *Einstein, Relativity, and Absolute Simultaneity* (London: Routledge).
- Calosi, C. 2014. 'Metaphysics of Time in Spacetime', *Thought*, 3: 1-8.
- Calosi, C. 2015. 'The Relativistic Invariance of 4D Shapes,' *Studies in the History and Philosophy of Modern Physics* 50, pp. 1-4
- Craig, W. L. 2001. *Time and the Metaphysics of Relativity* (Dordrecht: Kluwer).
- Crisp, T. 2003. 'Presentism', in M. Loux and D. Zimmerman, eds., *The Oxford Handbook of Metaphysics* (Oxford: Oxford University Press).
- Crisp, T. 2008. 'Presentism, Eternalism, and Relativity Physics', in W. L. Craig and Q. Smith, eds., *Einstein, Relativity, and Absolute Simultaneity*, (London: Routledge).
- Dainton, B. 2010. *Time and Space*, 2nd edition, Montreal: McGill-Queen's University Press.
- Earman, J. 1989. *World Enough and Spacetime* (Cambridge, MA: MIT).
- Earman, J. 1995. *Bangs, Crunches, Whimpers, and Shrieks* (Oxford: Oxford University Press).
- Earman, J. and Gordon Belot. 2001. 'Pre-Socratic Quantum Gravity.' In Callender and Huggett eds., *Philosophy Meets Physics at the Planck Scale*, Cambridge University Press, pp. 213-255.
- Eddon, M. 2010. 'Three Arguments from Temporary Intrinsics', *Philosophy and Phenomenological Research* 81, pp. 605-619
- Einstein, A. 1952. 'On the Electrodynamics of Moving Bodies', in Lorentz, Einstein, Minkowski, and Weyl, eds., *The Principle of Relativity* (New York: Dover), pp. 37-65. [Originally published in German in 1905 as 'Zur Elektrodynamik bewegter Körper,' *Annalen der Physik*, 17]
- Einstein, A. 1961. *Relativity: The Special and General Theory* (New York: Three Rivers Press).
- Fine, K. 2005. 'Tense and Reality', in Fine, K. *Modality and Tense. Philosophical Papers* (Oxford: Clarendon Press), pp. 261-320.
- Fine, K. 2006. 'In Defence of Three-Dimensionalism', *Journal of Philosophy* 103/12, 699-714.
- Gibson, I. and Pooley, O. 2006. 'Relativistic Persistence', *Philosophical Perspectives*, 20, *Metaphysics*: 157-198.
- Gilmore, C. 2004. *Material Objects: Metaphysical Issues*. PhD thesis.
- Gilmore, C. 2006, "Where in the Relativistic World Are We?", *Philosophical Perspectives*, 20, *Metaphysics*: 199–236.
- Gilmore, C. 2008. 'Persistence and Location in Relativistic Spacetime.' *Philosophy Compass*, 3/6, 1224-1254.
- Gilmore, C. 2014. 'Building Enduring Objects Out of Spacetime', in C. Calosi and P. Graziani, eds., *Mereology and the Sciences* (Berlin: Springer), pp. 5-34.
- Giordani, A. and Costa, D. 2013. 'From Times to Worlds and Back Again. A Transcendentist Theory of Persistence.' *Thought*, 2/1, 210-220.

- Gödel, K. 1949. 'A Remark about the Relationship between Relativity Theory and Idealistic Philosophy', in P. A. Schilpp (ed.), *Albert Einstein: Philosopher-Scientist*, La Salle, IL: Open Court, pp. 557- 562. Reprinted in Yourgrau 1990: 261-265.
- Godfrey-Smith, W. 1979. 'Special Relativity and the Present'. *Philosophical Studies* 36: 233-244.
- Hawley, K. 2001. *How Things Persist*, Oxford: Oxford University Press.
- Hawley, K. 2009. 'Metaphysics and Relativity', *Routledge Companion to Metaphysics*, Robin Le Poidevin, Peter Simons, Ross Cameron, Andrew McGonigal, eds., Routledge, pp. 507-516.
- Hawthorne, J. 2006. *Metaphysical Essays*, Oxford: Oxford University Press.
- Hawthorne, J. 2008, "Three-dimensionalism vs. Four-dimensionalism", in J. Hawthorne, T. Sider, and Dean Zimmerman, eds., *Contemporary Debates in Metaphysics* (Oxford: Blackwell), pp. 263–282.
- Haslanger, S. 2003. 'Persistence Through Time,' in M. Loux and D. Zimmerman, eds., *The Oxford Handbook of Metaphysics*, pp. 315-354.
- Hinchliff, M. 2000. 'A Defense of Presentism in a Relativistic Setting', *Philosophy of Science* 67: S575- S586.
- Hoffman, J. and Gary Rosenkrantz. 2002. *The Divine Attributes* (Oxford: Blackwell).
- Hofweber, T. and Marc Lange. MS. 'Fine's Fragmentalist Interpretation of Special Relativity'.
- Jeans, J. 1936. 'Man and the Universe', in *Progress of Science*, The Sir Halley Stewart Lectures, 1935. (London: Allen & Unwin).
- Lewis, D. 1999, *Papers in Metaphysics and Epistemology* (Cambridge: Cambridge University Press).
- Lewis, D. 2002. 'Tensing the Copula', *Mind* 111: 1-13.
- Lockwood, M. 2005. *The Labyrinth of Time* (Oxford: Oxford University Press).
- Lowe, E. J. 1998. 'Tense and Persistence' in R. Le Poidevin, ed., *Questions of Time and Tense*, pp. 43-60.
- Lucas, J. R. and P. E. Hodgson. 1990. *Spacetime and Electromagnetism* (Oxford: Oxford University Press).
- Markosian, N. 2004. "A Defense of Presentism," in Zimmerman, Dean (ed.), *Oxford Studies in Metaphysics*, vol. 1, pp. 47-82.
- Maudlin, T. 2012. *Philosophy of Physics: Space and Time* (Princeton: Princeton University Press).
- McCall, S. 1994. *A Model of the Universe* (Oxford: Clarendon Press).
- McGrath, M. 2007. 'Temporal Parts', *Philosophy Compass* 2 (5) , 730–748.
- McTaggart, J. 1908. 'The Unreality of Time', *Mind* 17: 457-474.
- Mellor, D. H. 1981. *Real Time* (Cambridge: Cambridge University Press).
- Minkowski, H. 1952. 'Space and Time', in Lorenz, Einstein, Minkowski, and Weyl, eds., *The Principle of Relativity* (New York: Dover), pp. 75-91.
- Monton, B. 2006. 'Presentism and Quantum Gravity', in D. Dieks, ed., *The Ontology of Spacetime* (Elsevier), pp. 263-280.
- Oaklander, L. N. 2004. *The Ontology of Time* (Amherst: Prometheus).
- Nerlich, G. 1994. *What Spacetime Explains* (Cambridge: Cambridge University Press).
- Ney, A. and D. Albert. 2013. *The Wave Function: Essays on the Metaphysics of Quantum Mechanics* (Oxford: Oxford University Press).
- Pais, A. 2005. *Subtle is the Lord: The Science and the Life of Albert Einstein* (Oxford: Oxford University Press).
- Parsons, J. 2007. 'Theories of Location', in D. Zimmerman, ed. *Oxford Studies in Metaphysics*, vol. 3, pp. 201-232.
- Prior, A. 1959. 'Thank Goodness That's Over', *Philosophy* 34: 12-17.
- Putnam, H. 1967. 'Time and Physical Geometry', *Journal of Philosophy* 64: 240-247.
- Quine W. V. 1960. *Word and Object* (Cambridge: MIT).
- Russell, B. 1954. *The Analysis of Matter* (New York: Dover), first edition 1927.
- Russell, B. 1958. *The ABC of Relativity* (London: Allen & Unwin), first edition 1925.
- Sattig, T. 2006. *The Language and Reality of Time* (Oxford: Oxford University Press).
- Saunders, S. 2002. 'How Relativity Contradicts Presentism', in C. Callender, ed., *Time, Reality, and Experience*, Cambridge: Cambridge University Press.
- Savitt, S. 2000. 'There's No Time Like the Present (in Minkowski Spacetime)', *Philosophy of Science* 67 (Proceedings), S563-S574.

- Savitt, S. 2009. The Transient Now. In C. W. Myrvold, J. Christian (eds.) *Quantum Reality, Relativistic Causality, and Closing the Epistemic Circle*. Amsterdam: Springer, 339-352.
- Schaffer, J. 2009. 'Spacetime the one substance', *Philosophical Studies* 145: 131-148.
- Sider, T. 2001. *Four Dimensionalism: An Ontology of Persistence and Time*, Oxford: Oxford University Press.
- Sider, T. 2011. *Writing the Book of the World*, Oxford: Oxford University Press.
- Sklar, L. 1974. *Space, Time, and Spacetime* (Berkeley: University of California Press).
- Sklar, L. 1981. 'Time, Reality, and Relativity' in R. Healy, ed., *Reduction, Time and Reality* (Cambridge: Cambridge University Press), pp. 129-142.
- Skow, B. 2015. *Objective Becoming*. Oxford: Oxford University Press.
- Smith, Q. 1993. *The Language of Time*, New York: Oxford University Press.
- Smart, J. J. C. 2008. 'The Tenseless Theory of Time', in Sider, Hawthorne, and Zimmerman, eds., *Contemporary Debates in Metaphysics* (London: Blackwell), pp. 226-238.
- Stein, H. 1991. 'On Relativity Theory and the Openness of the Future', *Philosophy of Science* 58: 147-167.
- Tooley, M. 1997. *Time, Tense, and Causation*, Oxford: Oxford University Press.
- Weingard, R. 1972. 'Relativity and the Reality of Past and Future Events', *British Journal for the Philosophy of Science* 23 (2): 119-121.
- Whitrow, G. J. 1980. *The Natural Philosophy of Time*, 2nd ed. (Oxford: Oxford University Press).
- Wuthrich, C. 2013. 'The Fate of Presentism in Modern Physics,' in R. Ciuni, K. Miller, and G. Torrenco, eds., *New Papers on the Present*, Philosophia Verlag: 91-132.
- van Inwagen, P. 1990. *Material Beings*. Ithaca: Cornell University Press.
- van Inwagen, P. 1990a. "Four-Dimensional Objects", *Nous*, 24: 245-255.
- Varzi, A. 2003. "Naming the Stages", *Dialectica*, 57:4, 387-412.
- Yourgrau, P. 1999. *Gödel Meets Einstein: Time Travel in the Gödel Universe* (Chicago: Open Court).
- Zimmerman, D. 2008. 'The Privileged Present: Defending an 'A-theory' of Time,' in T. Sider, J. Hawthorne, and D. Zimmerman, eds., *Contemporary Debates in Metaphysics* (Oxford: Blackwell), pp. 211-225.
- Zimmerman, D. 2011. 'Presentism and the Space-Time Manifold,' in C. Callender, ed., *The Oxford Handbook of Philosophy of Time* (Oxford: Oxford University Press), pp. 163-244.