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Persistence and Location in Relativistic Spacetime

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Abstract. How is the debate between endurantism and perdurantism affected by the transition from pre-relativistic spacetimes to relativistic ones? After suggesting that the endurance v. perdurance distinction may run together a pair of cross-cutting distinctions (mereological endurance v. mereological perdurance and locational endurance v. locational perdurance), I discuss two recent attempts to show that the transition in question does serious damage to endurantism (at least of the locational variety).

1. Introduction

Contemporary discussions of persistence through time are dominated by a pair of rival theories, endurantism and perdurantism.[1] Philosophers on both sides of the debate agree that ordinary material objects such as rocks and human beings typically *persist*, i.e., exist at multiple times. They disagree about what this involves. In the current terminology, endurantists say that all persisting material objects *endure*, whereas perdurantists say that all such objects *perdure*. There is controversy about the best way to define these terms rigorously, and I say more about this below, but a first pass is this. A thing perdures just in case it is temporally extended and has a different *temporal part*[2] at each different instant at which it exists, whereas a thing endures just in case it lacks temporal extent and persists not by having temporal parts but rather by being multi-located in time – in particular, by being *wholly present* at each instant at which it exists.[3]

The debate cannot be settled empirically in any straightforward way: the world might well look, sound, and feel just as it actually does regardless of which view is correct. Any grounds for preferring one view to the other are likely to be more philosophical than empirical. Unsurprisingly, the philosophical considerations have pulled in different directions, with endurantism receiving support from common sense and perdurantism receiving support from its alleged puzzle-solving ability. A number of these issues are dealt with in another *Philosophy Compass* paper (McGrath 2007), so I will not discuss them here.

Special relativity (STR) and general relativity (GTR) played a minor role in the debate until recently. It had long been assumed that endurantism was less plausible in a relativistic context than in a pre-relativistic one, but very little was said about exactly *why* this should be. In the last ten years, however, metaphysicians have started to pursue this question in more depth and detail. Here I assess some highlights of the recent literature.

2. Many Relativistic Threats to Endurantism

What is it about the shift from classical to relativistic physics that makes trouble for endurantism? The following answers suggest themselves:

(i) Relativity might favor the B-theory of time over *presentism* and other versions of the A-theory of time, upon which endurantism is often said to depend.

(ii) Relativity might undermine the view ('separatism') that space and time are two separate, nonoverlapping manifolds, a view upon which endurantism might be thought to depend.

(iii) Relativity might undermine certain forms of *substantivalism*[4] about time or spacetime[5] upon which endurantism depends.[6]

(iv) Relativity might support the possibility of backward time travel,[7] a possibility that is often said to pose problems for endurantism.[8]

(v) Relativity might undermine the view that there is a preferred way of carving spacetime as a whole, or the spacetime paths of individual persisting objects, into instantaneous, non-overlapping 'time-slices', a view upon which endurantism might be thought to depend.

Each of these routes from relativity theory to the denial of endurantism deserves to be taken seriously, but in keeping with the contemporary literature, I will focus on (v). I discuss routes (i) and (ii) in a separate *Philosophy Compass* paper (author, under review).

Here I will assume that endurantism can be tenably combined with the *B-theory*, according to which the past, present, and future are metaphysically on a par, and with *spacetime unitism* (as I call it), according to which we inhabit just a single manifold (spacetime) rather inhabiting two separate manifolds (space on the one hand and time on the other). My main question will be this: how does the transition from pre-relativistic spacetimes to relativistic spacetimes affect the debate between endurantism and perdurantism? I will consider two recent attempts to show that this transition does serious harm to endurantism (or at least to one form of it).[9]

2. Galilean Spacetime and Minkowski Spacetime

First, a very quick sketch of some important features of *Galilean spacetime* (one prominent type of classical or pre-relativistic spacetime) and *Minkowski spacetime* (the spacetime of special relativity). Both are composed of instantaneous, spatially unextended, mereologically simple spacetime points. They differ with regard to the spatiotemporal relations that hold amongst their constituent points.

Start with Galilean spacetime. Temporal duration is well defined there: for any spacetime points p and q in a Galilean spacetime, there is a fact as to the number n of minutes (e.g.) by which p precedes q: if n is positive p precedes q (by n minutes), if n is negative, q precedes p (by –n minutes) and if n is zero, then p and q are simultaneous (so absolute simultaneity is also well defined in Galilean spacetime). As a

result, there is always exactly one way to divide up a Galilean spacetime into a set of non-overlapping maximal hyperplanes of absolute simultaneity, or 'global time-slices'. For any two points within a given hyperplane, spatial distance is well defined: there is a fact as to the number of feet (e.g.) by which those points are spatially separated. Indeed, simultaneous spacetime points in Galilean are governed by Euclidean geometry. For non-simultaneous points, however, spatial distance is not well defined. So, for any two events occurring at different times, there is no fact as to whether they occurred 'at the same place', nor any fact as to how far apart they were in space. This means that absolute velocity is not well defined.[10] Absolute acceleration, however, is. For any given continuous line, l, that intersects each hyperplane at exactly one point, and for any point p on l, there is a fact as to the *curvature* of l at p. If l is straight at p, this means that l corresponds to the possible trajectory of a particle that is not accelerating at p. The greater the curvature of l at p, the greater the acceleration of the particle taking the corresponding trajectory at p.

In Minkowski spacetime, neither temporal duration, nor absolute simultaneity, nor spatial distance is well defined; but certain other notions are. First, there is the future light cone of a spacetime point p: this can be thought of as the set of points that could be reached by a light signal (but no slower signal) emitted at p. Second, the past light cone of p: this is the set of those points on whose future light cones p lies. Third, there is the interior of p's future light cone, which consists of those points that could be reached by a slower-than-light signal emitted from p, and the interior of p's past light cone, which can be defined a parallel way. Finally, there is p's absolute elsewhere, which consists of the points that are spacelike separated from p. No light signal emitted from p could reach any of these points (or vice versa). It is widely assumed that causal connections can be mediated by light signals (and slower-than-light signals) but not by anything faster than light, hence that an event occurring at p can cause events occurring on or inside of p's future light cone (together called p's causal future), and can be caused by events occurring on or inside p's past light cone (p's causal past), but can neither cause nor be caused by anything in its absolute elsewhere.

A point p is said to be lightlike (or null) separated from itself and from the points on its past and future light cones, and it is said to be timelike seprated from the points inside its past and future lightcones. The spacetime paths of photons (which have no mass) are 'lightlike lines', consisting of lightlike separated points, whereas the path of a particle with mass is a 'timelike line', which always remains in the interior of the light cones associated with points on that line. Other well defined notions in Minkowski spacetime include: (i) the distinction between a timelike line's being accelerated (curved) at a given point and its being inertial or non-accelerated (straight) at that point, and (ii) the *proper time* elapsed along a given timelike line l linking a point p to a point q. Different lines linking p and q will, however, be associated with different amounts of proper time.

Another notion that is useful in connection with Minkowski spacetime is that of an inertial reference frame. Intuitively, an inertial frame is given by a set of non-accelerating objects that are mutually at rest, but more formally it can be defined as a maximal set of maximal, straight, pair-wise parallel timelike lines. For any points p and q and inertial frame F in Minkowski spacetime, there is a fact as to the number of minutes by which p precedes q relative to F (and hence a fact as to whether p and q are simultaneous relative to F), and there is a fact about the spatial distance between p and q relative to F (even if they are non-simultaneous), and the facts about these distances will be governed by Euclidean geometry. Each inertial frame, therefore, is associated with its own way of dividing up Minkowski spacetime into non-overlapping hyperplanes of 'frame-relative' simultaneity.

Although the distances and durations between points vary between frames, the spacetime interval does not. If F is an inertial frame, p and q are spacetime points, s is the distance in feet between p and q relative to F, t is the duration in minutes between p and q relative to F, and c is the speed of light in feet per minute, the interval I between p and q is given by the following formula:

$$I^2 = (s^2) - (c^2t^2)$$

Points p and q are spacelike separated just in case I^2 is positive, lightlike separated just in case it is zero, and timelike separated just in case it is negative. Its value remains constant across all inertial frames.

3. Disentangling Mereology and Location

At this point it will be helpful to get clearer about the exact formulation of endurantism and perdurantism. Some take 'endures' to mean nothing more than 'persists but does not have temporal parts'. Others take it to mean something like 'persists and exactly occupies each in a series of temporally unextended regions'.[11] As we shall see, this makes a difference. The latter sort of endurance, call it *locational* endurance, faces prima facie problems in relativistic worlds that the former sort, call it *mereological* endurance, avoids. If we assume spacetime substantivalism, we can formulate the relevant doctrines as follows.

We start with a binary locational predicate, 'is weakly located at', whose intelligibility has not, to my knowledge, been questioned. (I take the predicate from Parsons (2007).) Intuitively, to be weakly located at a spacetime region is to *spatiotemporally overlap* that region: a thing is weakly located at any region that is "not completely free of" the thing (Parsons 2007: 203). We then say that a region R is an object's *path* (my term) just in case R has a subregion in common with all and only those regions at which the object is weakly located. This captures the thought that a thing's path is the region that exactly corresponds to the thing's complete history or career. Our next step is to define 'achronal', a relativistically acceptable variant of 'instantaneous': a region is achronal just in case for any distinct points p and q in that region, p is spacelike separated from q. An achronal region need not be *flat*; it need

not be a subregion of some hyper*plane* of frame-relative simultaneity. Thus there can be achronal regions even in the curved spacetimes of GTR, some of which contain no such hyperplanes. (Note, though, that GTR does not rule out the possibility of flat regions or global hyperplanes of frame-relative simultaneity.)

With these notions in hand, we can say that a thing *persists* just in case it has a path that is not achronal. An *instantaneous* (or achronal) *temporal part* of a thing O can then be defined as a thing P such that: (i) P's path is an achronal slice of O's path[12], (ii) P and O are co-composed[13] at P's path, and (iii) P is a part of O at P's path. A thing can be said to *mereologically perdure* just in case it persists and has a 'sufficiently full distribution' of temporal parts – perhaps one for each achronal slice of its path, perhaps one for each continuous temporal 'chunk' of its path,[14] perhaps even one for each sum of achronal slices of its path; I will leave these matters open. Correspondingly, we can say that a thing *mereologically endures* just in case it persists but does not have such a distribution of temporal parts. Mereological perdurantism can be stated as the view that all persisting material objects mereologically perdure, mereological endurantism as the view that all such objects mereologically endure.[15]

Whereas the dispute between mereological endurantism and perdurantism concerns the existence of temporal parts, the dispute between *locational* endurantism and perdurantism concerns the locations of persisting objects. To get this second dispute off the ground, we need to invoke a different – and more controversial – binary locational predicate: 'exactly occupies'. Intuitively, a thing exactly occupies a region just in case the thing has exactly the same shape and size as the region and stands in all the same spatiotemporal relations to things as does the region. Moreover, on the intended interpretation of the predicate, there should be nothing contradictory or obviously false about the claim that a single thing exactly occupies each of two or more regions without exactly occupying their sum or any of their proper subregions.[16] (This allows that we may ultimately come to believe on the basis of substantive argument that such multi-location, while *intelligible*, is metaphysically impossible.) Friends of 'exactly occupies' typically take it to be the unique primitive locational predicate, with Parsons's 'x is weakly located at R' defined in terms of it, as 'x exactly occupies some region that has a subregion in common with R'.[17]

The question of whether 'exactly occupies' is intelligible has recently become the focus of debate in its own right.[18] Much is at stake. For if we help ourselves to this predicate, the dispute between locational endurantism and perdurantism emerges as a genuine issue, entirely orthogonal to the debate about temporal parts, at least from a narrowly logical point of view. (See fig. 1.) Say that a thing *locationally endures* just in case it persists and exactly occupies only achronal regions, and say that a thing *locationally perdures* just in case it persists and exactly occupies one and only one region. (This distinction is far from exhaustive.[19]) Then locational endurantism can be stated as the view that all persisting material objects locationally endure, and locational perdurantism as the view that all persisting material objects locationally perdure. (This dispute is identified and distinguished from the dispute about

temporal parts by Gilmore (2006: 204-208), Hawthorne (2006: 103-104), and Sattig (2006: 47-65), though Hawthorne expresses some skepticism about 'exactly occupies'.)

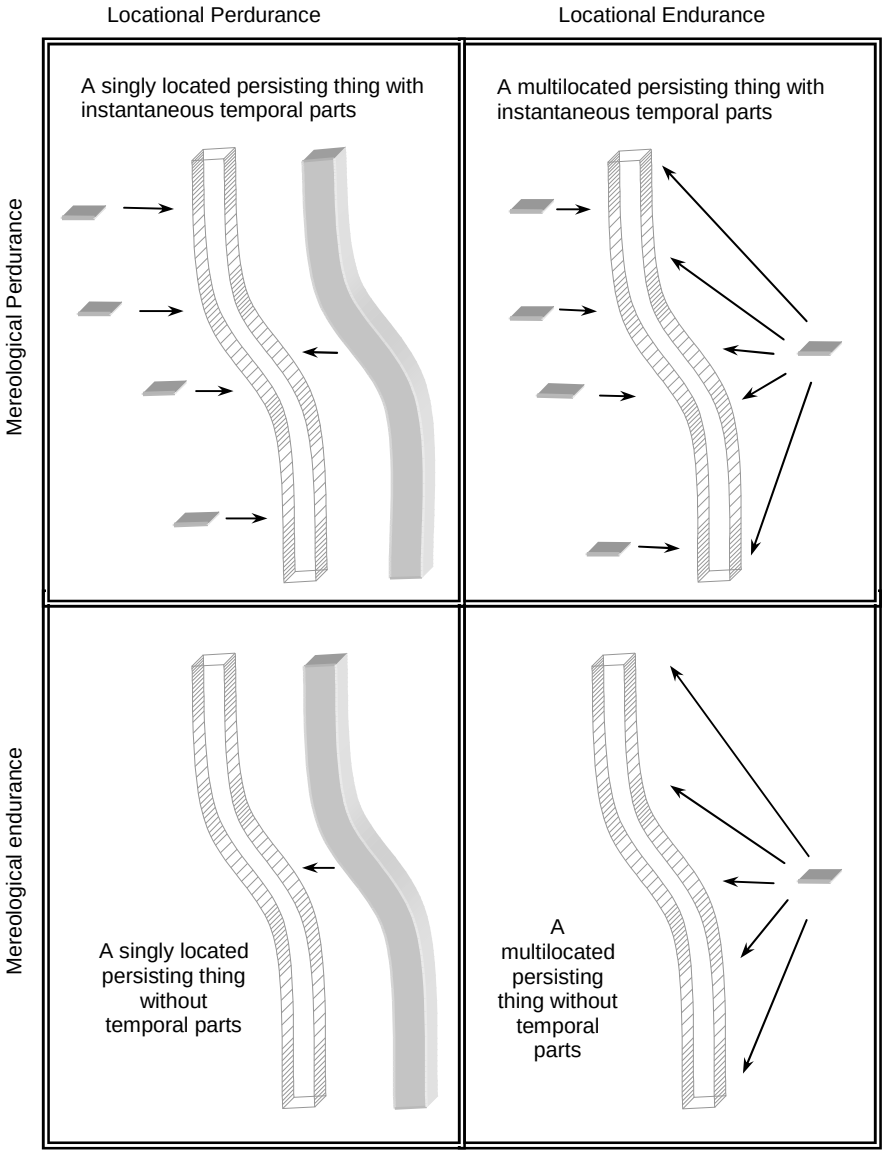


Figure 1

Locationally enduring things are multi-located and temporally unextended (though they have temporally extended paths). Locationally perduring things are singly located and temporally extended. So far as our definitions are concerned, there is nothing to stop a locationally enduring thing from having temporal parts and hence mereologically perduring: think of a multi-located lump of clay that constitutes a different instantaneous statue for each different instant in its career (Sider 2001: 64-65). Nor does anything in our set of definitions stop a locationally perduring thing from lacking temporal parts and

hence mereologically enduring: think of a singly located and temporally extended but mereologically simple electron. Whether there are entailments amongst these views (e.g., from mereological endurantism to locational endurantism) is a substantive question that can be answered only by doing serious metaphysics. This is the case, anyway, so long as 'exactly occupies' can be grasped. If it cannot, then the dispute between locational endurantism and locational perdurantism is a mirage, and those interested in the metaphysics of persistence should turn away from it.

4. Balashov's Explanatory Argument

If a persisting object (e.g., the earth) is spatially three-dimensional and inhabits a relativistic spacetime, then for any spacetime point p in its path, there will be many different achronal slices through its path that intersect p. These three-dimensional slices will vary in shape, depending upon the angle at which they intersect the path. For example, the slice that intersects the earth's path at a right angle to it will be approximately spherical, whereas those that intersect it at a different angle (those slices associated with observers in motion with respect to the earth) will be oblate (squashed) to different degrees, depending upon the angle. Moreover, if we take *all* of the achronal slices through the earth's path (not just those passing through p), we will find that despite their variations in size and shape, they combine to form a relatively smooth, simple 4D volume – viz., the earth's path.

Yuri Balashov has used facts like these as the basis of an inference-to-the-best-explanation argument for perdurantism (1999, forthcoming a). Why does the apparent 3D shape of the earth vary in the relevant ways? And why do the associated 3D regions, which display such a variety of shapes, come together to form such a smooth and simple 4D volume? According to Balashov, the best explanation of these facts appeals to the hypothesis that the earth is a four-dimensional, perduring object, extended both spatially and temporally, with an invariant 4D shape whose intrinsic geometry mirrors that of the region of relativistic spacetime that the earth exactly occupies. Each of the 3D shapes associated with the earth, relative to a given slice, is the invariant shape of the achronal temporal part of the earth that exactly occupies that slice:

> This explanation is open to the perdurantist, who believes in 4D objects, but not to the endurantist, who denies their existence. Indeed, the endurantist will have a hard time explaining how "separate and loose" 3D shapes come together in a remarkable unity, by lending themselves to an arrangement in a compact and smooth 4D volume. Where the four-dimensionalist has a ready and natural explanation of this fact: different 3D shapes are cross-sections of a single 4D object, the three-dimensionalist must regard it as a mystery. One should not expect to be able to fit an arbitrary collection of 3D shapes into a neat 4D shape, without corrugations, dents and gaps. (Balashov *forthcoming a*)

One might reply by arguing that Balashov's request for an explanation of the 'unity' of the relevant 3D shapes is illegitimate for some reason (Sattig 2006: 183). But most have conceded, at least for the sake of

argument, that there is some explanatory burden in the vicinity, and then have gone on to argue that the endurantist can meet it.

An easy way to meet the burden – some will say a suspiciously easy way – is to explain the relevant facts about 3D shapes by appeal to facts about the mereological structure and intrinsic geometry of the 4D *paths* of persisting objects, while remaining neutral about the nature of the persisting objects themselves. Whether or not persisting objects themselves have four-dimensional extent, and whether or not these objects themselves have achronal temporal parts, everyone can agree that their spacetime paths do. So the endurantist can account for the fact that the earth has different 3D shapes relative to different perspectives by noting that its path has an invariant 4D shape and is composed of different achronal slices, running at different angles, that have the relevant 3D shapes. The endurantist can then hold that all it is for a thing to have a given 3D shape S relative to a given perspective (or maximal achronal region) is for the intersection of the thing's path and the given maximal achronal region to have shape S simpliciter. Given that the earth has a certain region as its path and given that this region possesses the relevant relativistic geometry, there would be no mystery at all surrounding the facts about the earth's 3D shapes relative to different maximal achronal regions. Far from it: the endurantist (if he knows his relativity theory) will see these facts as completely predictable.

By way of rejoinder, Balashov can argue that the endurantist is still at a disadvantage. What the easy reply does is simply to (i) *take for granted* the fact that the earth has a 4D region of spacetime with a certain shape as it path, and to (ii) use this fact to explain the data concerning the 3D shapes associated with the earth. This succeeds as far as it goes, but it does not go very far, for it leaves one crucial fact unexplained – viz., the fact that the earth has the 4D region with the relevant shape as its path. The perdurantist, by contrast, has an attractively simple and straightforward explanation of this: the reason why the earth has a 4D region, shaped thus-and-so, as its path, is that *the Earth itself is 4D and has exactly that shape*.

Can the endurantist explain why the Earth has such a path? The main strategy, pursued in different ways by Sider (2001: 83-87), Miller (2004: 366-368), and especially Gibson and Pooley (2006: 187-191), is to appeal to (i) facts about which simple particles[20] the earth is composed of at which stages in its history, (ii) facts about the fields acting on those particles, and (iii) facts about the geometry of spacetime in the neighborhoods of the particles. If one knows everything there is to know about the paths of the relevant particles and about which segments of those paths correspond to the stages of the particles' histories during which those particles are parts of the earth, then (the proponents of this strategy claim) one should be in a position to say why the earth's path is 4D and shaped as it is: after all, its path will be the sum of the relevant segments of the particles' paths. One could then go on to explain the facts about

the variety of 3D shapes associated with the earth in terms of the facts about its 4D path – and all without ever asserting that the earth itself is temporally extended or composed of temporal parts.

Balashov (1999, forthcoming a) argues that such 'micro-reductive' explanations are deficient by comparison with his favored perdurantist explanation. He draws an analogy with Hilary Putnam's example involving a peg and a board with two holes in it (1980: 137-139). The peg, which is cross-sectionally square, can pass through the square hole but not through the round hole with the same cross-sectional area. Why? Putnam discusses two explanations. One appeals to a complex collection of microphysical facts concerning, among other things, details about the relations amongst the pegs' constituent particles and those of the board, together with the fundamental physical laws governing the interactions between these particles. The other explanation just points out that the peg is square and so can fit through the square hole (whose cross-sectional area is slightly larger than that of the peg) but not through the round one, since both the peg and the board are rigid. Putnam argues that the second explanation is better than the first: it is easier to understand, and it cites just those structural features of the situation that are relevant and common to many other systems, while ignoring the irrelevant facts about precise atomic microstructure, which are unlikely to be shared by any other systems.

Balashov agrees and suggests that, for parallel reasons, the perdurantist explanation of the fact that the earth has a 4D path of such-and-such a shape is better than the microreductive explanation:

> The perdurantist has no need to invoke irrelevant microphysical facts about the occupation of spacetime points by the fundamental constituents of material objects. And she has no need to invoke the details of local dynamics (which may, after all, be different for different kinds of objects, vary from material to material, etc.) (forthcoming a).

Rather, the perdurantist simply cites the fact that the Earth itself is 4D and has exactly the shape in question.

In response to this point, one might try to argue either that the perdurantist explanation is not really any better than the microreductive explanation or, alternatively, that while the former is better than the latter *given our cognitive limitations and practical concerns*, it is not better in any way that would give us reason to believe that the hypotheses to which it appeals are literally true.[21] Suppose, however, that one sides with Balashov on both of these issues. One might still doubt that his argument achieves exactly what he intends. Two concerns arise.

First, relativity *per se* no longer plays an essential role in the argument. Originally, the data to be explained concerned the variety of 3D shapes associated with the earth, and the fact that these shapes combine to form a smooth 4D volume. Call this explanandum *3D SHAPES*. The perdurantist explained it in terms of the earth's being 4D and having different achronal temporal parts, running at different angles, with different 3D shapes. The endurantist explained 3D SHAPES in terms of analogous facts about the earth's 4D *path*, while remaining neutral about the earth itself. While this explains the original data, it

leaves a second fact conspicuously unexplained – namely, the fact that the earth has as its path a 4D region with thus-and-such a shape. Call this explanandum *4D PATH*. One can explain it in terms of perdurance or 'microreductively' (which permits, but does not require, endurantism). Balashov can argue that the perdurance hypothesis offers the *better* explanation of the data and is thereby confirmed.

Note, however, that this last argument would still be available even if spacetime were Galilean as opposed to relativistic. Even in that context, one can (i) point out that the earth has a 4D path of thus-and-such a shape (different from the shape of any region of relativistic spacetime, of course), one can (ii) compare the explicitly perdurantist explanation of this fact with the microreductive explanation (which is neutral with regard to endurantism and perdurantism), and one can (iii) argue that the former explanation is superior to the latter for the reasons that Balashov cites. So what is crucial to the case for perdurantism here is not the assumption spacetime is relativistic but rather the assumption, underpinned by spacetime substantivalism and unitism, that ordinary persisting objects have 4D spacetime regions as paths, this being an assumption that can hold true in pre-relativistic as well as relativistic contexts. To be sure, relativity gives us reasons to accept spacetime unitism that are lacking in a pre-relativistic context (see author, under review), so in that sense relativity may have some role to play in the argument. But since only spacetime unitism is directly relevant, and since we *can* have this view in the absence of relativity, relativity is not essential to the argument. (If all of this is right, then strictly speaking Balashov's argument belongs in Gilmore (forthcoming: sect. 4), which discusses reasons for taking unitism to support perdurantism.)

We can turn now to a second concern. Balashov presents his argument as supporting perdurantism, full stop. But having made the distinction between locational and mereological perdurantism, we should ask whether his argument supports both views equally, or whether it supports one more directly (or forcefully) than another. The answer, I think, is that if successful, it supports locational perdurantism directly and mereological perdurantism only indirectly, if at all. To the extent that the perdurantist gets the better of the endurantist, this is because only the perdurantist can give an appropriately simple and relevant explanation of 4D PATH, the fact that the Earth has as its path a 4D region with such-and-such a shape. What gives him this advantage is his belief that the Earth itself is 4D and of exactly that shape. But this belief stems from locational perdurantism, i.e., from the view that each persisting material object exactly occupies just one region (its path) and hence has the same size and shape as its path. The mereological claim that the Earth has temporal parts plays no role in the 'perdurantist' explanation of 4D PATH; indeed, this explanation would work just as well on the hypothesis that the Earth is a spatially and temporally extended simple. (So too would Putnam's second explanation on the assumption that the square peg is a spatially extended simple.)

Of course, if one denies the possibility of temporally extended things that lack temporal parts, then one may go on to conclude that the Earth has temporal parts as well as temporal extent. But clearly it is the temporal extent that is doing the work in the argument, not the temporal parts, so some philosophers will see the argument as posing no threat to mereological endurantism (the mere denial of temporal parts). And if one rejects the intelligibility of 'exactly occupies' and hence rejects the contrast between locational endurantism and locational perdurantism, then one should hold that there is no well-understood perdurantist thesis for Balashov's explanatory argument to support and no well-understood endurantist thesis for that argument to threaten.

In sum, Balashov's argument is best understood not as an argument from relativity theory to temporal parts; at its core, it is an argument from spacetime unitism to temporal extent.

5. The Location Question

A number of philosophers have claimed that locational endurantism remains tenable in the context of relativistic spacetime, Balashov's explanatory argument notwithstanding (e.g., Sattig 2006). It may therefore be useful to consider one more challenge to the view (developed in Gilmore 2006). It arises from what I call the *Location Question*: "Which subregions of its spacetime path does a material object exactly occupy?"[22] Locational perdurantists will endorse:

1. The Path Principle — "A material object exactly occupies just its path (which is its own *improper* subregion)."

Considered on its own, this answer is attractive, mainly because it is so simple and general, working equally well in relativistic and pre-relativistic settings. Of course it is anathema to locational endurantists, who can accept it only if they say that all material objects are instantaneous and hence non-persisting. In a pre-relativistic context, locational endurantists might be tempted by:

2. The Absolute Slice Principle — ". . . just the absolute-simultaneity-slices of its path."

But given relativity, this answer is unacceptable too. No two points in a relativistic spacetime are absolutely simultaneous, and as a result these spacetimes do not contain hyperplanes of absolute simultaneity. A strict application of the Absolute Slice Principle in a relativistic spacetime would deliver the result that no material object exactly occupies any region. This is no good.

In a relativistic context, two types of answers are available. *Overlap* answers hold that the *locations* of a material object – the spacetime regions that it exactly occupies – typically overlap each other, so that, e.g., each point in an object's path belongs to a great many different locations of that same object. *No-Overlap* answers deny this. Answers 1 and 2 are No-Overlap answers. Here is the simplest Overlap answer:

3. The Every Slice Principle — ". . . just the achronal slices of its path."

Recall an observation we made in section 5 about the path of the earth, or any ordinary, spatially extended, persisting material object that inhabits a relativistic spacetime: for any point p in its path, there will be a great many achronal slices of its path that contain p. According to Every Slice, the earth itself exactly occupies each of these slices. Since each of these slices 'criss-crosses' with many others, Every Slice gives us rampant overlap amongst the earth's locations.

6.1 No-Overlap Answers

Eventually we will return to Overlap answers, which probably represent the locational endurantist's best hope. To motivate this thought, let us consider some No-Overlap answers. In discussing these answers, it will be useful to employ the notion of a *foliation*. A foliation f of a region R is a set of subregions of R such that: (i) each region in the set is achronal, (ii) no region in the set is a proper subregion of any other achronal subregion of R, and (iii) each point in R belongs to exactly one member of the set. Intuitively, a foliation of a region is a particular way of exhaustively slicing that region up into non-overlapping, temporally unextended 'sheets' or 'leaves'.

With this in mind, we can return to question, "Which subregions of its path does a material object exactly occupy?" One explicitly relativistic No-Overlap answer is:

4. The Rest Frame Principle — ". . . just the slices of its path that are given by its *rest frame foliation*, i.e., that foliation of the path that does the best job of getting its members (all slices through the path) to intersect the path at right angles. Call these slices *ortho-slices*. The goal is for the points in each ortho-slice to be simultaneous *from the object's own perspective* at the relevant stage in the object's career."

The Rest Frame Principle faces two main problems. First, the notion of a rest frame foliation of a region is not always well defined: some regions do not admit of unique, non-arbitrary rest frame foliation.[23] To see this, just pick some point in Minkowski spacetime and consider the interior of that point's future light cone. Call the chosen region R_i. Each foliation of R_i into hyperplanes of simultaneity will have as much claim as any other to be the 'rest frame foliation' of that region. (Gibson and Pooley (2006: 194, note 29) describe a different case that raises problems for the attempt to specify a rest frame foliation.) In response, one might suggest that the only regions that are eligible to be paths of material objects are those select few that do have unique, non-arbitrary rest frame foliations. Even if this maneuver is successful, though, a second problem arises.

Consider one of my red blood cells that is in motion relative to me: while I stand, it shoots upward from my foot to my torso. Its spacetime path will fail to be parallel to my path, and its ortho-

slices will fail to be parallel to my ortho-slices. (See fig. 2.) But if its ortho-slices are not parallel to mine, they will not be sub-regions of mine. According to the Rest Frame Principle, then, the cell's locations are not subregions of my locations; in other words, this cell does not lie within me. Since one thing, at a given moment of its career, cannot be part of another, at a given moment of *its* career, unless the location of the first (at the relevant moment) is a subregion of the location of the second (at the relevant moment), the Rest Frame Principle yields the highly implausible result that the given cell is not a part of me, at least during those portions of its career in which it is in motion relative to me. I take this to be sufficient reason to reject that principle.

Some ortho-slices of my path (horizontal lines) and some ortho-slices of my cell's path (diagonal lines)

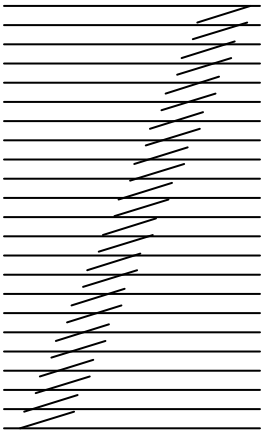


Figure 2

The next answer appeals to the notion of a *physically preferred* foliation of spacetime as a whole. A typical relativistic spacetime admits of many different foliations into spacelike hypersurfaces. It is widely held that in Minkowski spacetime there can be no physical basis for taking any one foliation to be uniquely privileged. The situation is different when it comes to general relativistic spacetimes, which admit of variable curvature and can differ widely from one another. Some such spacetimes have a structure that makes one foliation stand out from the rest. When physicists speak of the age of the universe, they mean something like 'the age of the universe as measured by the *fundamental observers*, the objects whose motion matches the average state of motion in their local part of the universe (where the localities are sufficiently large)'. Time as measured by the fundamental observers is known as 'cosmic time', and corresponding to it is a foliation of spacetime, which by virtue of its geometry and its

association with cosmic time would seem to be physically special. (For more discussion and references, see author, under review).

This suggests the following answer to the Location Question:

5. The Top Down Principle — ". . . just the slices of its path that are given by the physically preferred foliation (e.g., the foliation associated with cosmic time) of spacetime as a whole."

Unlike the Rest Frame Principle, the Top Down Principle has no trouble coordinating my locations with those of my parts. Initially, it looks not to the paths of individual objects, but rather to spacetime as a whole, and tells us that a material object O exactly occupies a region R just in case R is the intersection of O's path and one of the universe-wide slices or leaves in the physically preferred foliation of spacetime. This guarantees that the locations of my blood cell (corresponding to those portions of its career during which the cell is, intuitively, in my body) will be subregions of my locations.

This proposal, however, generates several worries. *First*, Michael Lockwood (2003: 152) has suggested that there is some empirical reason for thinking that our own spacetime does not admit of any foliations at all, much less a physically preferred foliation. *Second*, setting aside the structure of spacetime in the actual world, some are troubled by the mere fact that GTR allows spacetimes that admit of no physically preferred foliations, and in some cases, no foliations at all. (See, e.g., Lockwood 2003: 115-154 for discussion of these spacetimes.) On the assumption that the given spacetimes are nomically possible (i.e., that they exist in possible worlds governed by the same laws of nature as our own) and that many of them contain persisting material objects, it would follow that the 'Top Down' version of locational endurantism is not nomically necessary. If one combines this with the traditional view that any such theory of persistence must be true in all nomically possible worlds if actually true, one gets the result that relevant version of endurantism is false. (This parallels a controversial argument due to Gödel (1949) against the claim that existence of a physically preferred foliation makes our universe hospitable to A-theoretic time.)

Third, Top Down risks generating counterintuitive consequences about shapes. According to Top Down, the facts about which slices of its path a given material object exactly occupies depend upon global facts about the distribution of matter and energy across spacetime as a whole. This seems to open the door to an unattractive possibility. Consider a pair of persisting, spatially three-dimensional material objects, O1 and O2, that perdurantists would regard as intrinsic duplicates: their spacetime paths are just alike in their intrinsic geometry, and the contents of these regions are intrinsically just alike as well, at least from a four-dimensional perspective. Insofar as Top Down makes the facts about an object's locations (within its path) depend upon global matters, it gives us no obvious guarantee that O1 and O2 will be located within their paths in the same way. Perhaps O1's path intersects the leaves of the

privileged foliation at one angle, whereas O2's path intersects those leaves at a quite different angle. (This might occur if O1's velocity matched the average velocity of matter in its part of the universe, whereas O2's velocity were very different the average velocity of matter in its part of the universe.) In that case O1's locations will result from dividing up its path in one way, and O2's locations result from dividing up its path in a quite different way, so that O1 and its locations are shaped differently from O2 and its locations.[24] (I assume that the shapes of an object are the shapes of the regions that it exactly occupies.) This would give us the result that whether or not an object has a given shape is not entirely fixed by local matters; it also depends, in a non-causal way, upon how mass and energy are distributed across spacetime as a whole.

Now, merely as a result of accepting the B-theory of time, endurantists face pressure to treat the fundamental shapes as dyadic relations (e.g., <u>being round at</u>) that can hold between things and times or spacetime regions rather than as monadic properties (<u>being round</u>) that can be possessed by things individually. But even those who have come to embrace this relativizing view of shapes will presumably balk at the suggestion that whether a given thing bears the <u>being round at</u> relation to a certain region depends (non-causally) upon the distribution of mass and energy in distant parts of the universe.

In light of these difficulties, let us consider:

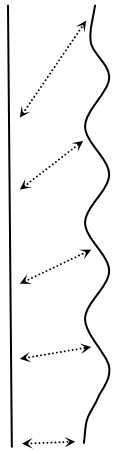
6. The Bottom Up Principle

> ". . . just the *particle synchrony* slices of its path, i.e., just those slices that are given by the following procedure: find the initial slice of the object's path, identify the simple particles that compose the object at that region, and attach to each of these a stop-watch that records the subsequent elapse of that particle's proper time. A particle synchrony slice is, roughly put, a sum of locations of these particles at stages in their careers when their stopwatches are all synchronized, indicating the same number."

Thus, if O's constituent simples are p1, p2, and p3, then one of O's synchrony slices might be the sum of the following regions: the location of p1 at which its stopwatch reads '3 minutes', the location of p2 at which *its* stopwatch reads '3 minutes', and the location of p3 at which *its* stopwatch reads '3 minutes'.

On its face, this principle seems to avoid the problems that afflicted its predecessors, but it confronts new ones. As stated, the principle (i) makes no provision for the gain or loss of parts, (ii) assumes that the path of each object has a *first* slice, and (iii) assumes that each object is composed of simples. Perhaps some of these defects could be avoided by modifying the principle slightly. Even if so, a deeper problem would remain. Let O be an object that throughout its career is composed of two simples,

one of which never accelerates (or, in GTR, lies on a geodesic), while the other accelerates in different directions so that, relative to the first, it oscillates. According to both STR and GTR, eventually the stopwatches on these simples will fall so far out of step that the associated 'synchrony slices' will fail to be achronal and hence will fail to be the sorts of regions that a *locationally enduring* object could exactly occupy.[25] (See fig. 3.) So, unless the locational endurantist is willing to rule out material objects like O, he should reject Bottom Up.



If this process continues indefinitely, there will be a number n such that the 'n-minute location' of the oscillating object is inside the future light cone of the 'n-minute location' of the object at rest. The region R composed of these locations is a synchrony slice of the composite object's path, but R is not achronal and so cannot be exactly occupied by a locationally enduring object.

Figure 3

4-6 are the simplest and most natural No Overlap answers to the Location Question, and they've all been found wanting. One might take this as motivation for giving an Overlap answer, or even for dropping locational endurantism altogether. But there is another option. In response to a version of the Location Question pressed by J.J.C. Smart (1972: 7), Michael Rea writes that

> These are indeed difficult questions. But it is not at all clear that they are questions the endurantist needs to answer. The endurantist is committed to there being some set of axes with respect to which the object counts as being 'all at once', for otherwise there would not be definite regions at which the object counts as being wholly present. But why think she should be able to specify the relevant axes (or regions)? Moreover, it seems that a similar problem will plague the perdurantist. A perdurantist who believes in persisting persons will, I take it, think that there is some "right" way to carve up a person into thought-bearing person-stages. And yet it seems she will have exactly the same difficulty the endurantist has specifying the relevant axes and regions. (1998: 232-233)

Rea's position here appears to consist in three main claims. (i) For each material object O, there must be some inertial reference frame (or at least some foliation of O's path) F such that O exactly occupies all and only the 'F-slices' of O's path; thus an object's locations must never overlap. (ii) The endurantist's inability to formulate some informative, general principle that tells us *which* frame or foliation is privileged for any given object is not a problem for endurantism: we shouldn't expect the endurantist to be able to formulate such a principle. (iii) Even if this *were* a problem for the endurantist, the perdurantist would not benefit from it, because she is confronted with a parallel and equally difficult question

concerning the 'right' way to divide a person into non-overlapping, instantaneous temporal parts. Let me briefly address these claims, in order.

It is not clear to me why Rea endorses (i), if indeed he does. Our discussion of Overlap answers (in section 6.2 below) may provide some motivation for it, but in the end, I think that a committed locational endurantist should give up (i). As for (ii), this *might* be a sensible attitude to take if we had reason to believe that there were many perfectly adequate No-Overlap answers to the Location Question and the problem were merely that we had no basis for deciding amongst them (though arbitrariness concerns would still apply). But having seen the problems for Rest Frame, Top Down, and Bottom Up, this is not our current situation. We now know that the *prima facie* most natural No-Overlap answers have serious flaws. Of course I have not shown that this is true of *all* No-Overlap answers, but it should be easy to see that some of these same flaws (or different, more obvious ones) are present in certain other answers that I have not discussed. Thus, not only do we have reason to doubt that there is a unique, easily formulated, *best* No-Overlap answer, but – more significantly – we also have reason to doubt that *any* No-Overlap answer is tenable.

With regard to (iii), two points are relevant. First, it is not at all clear that Rea's question about temporal parts really is parallel to (or as difficult to answer as) the Location Question. For example, the problem about moving parts that I raised for the Rest Frame Principle does not carry over to the corresponding answer to Rea's question about temporal parts.[26] Likewise for a problem that I will raise for most Overlap Answers to the Location Question (as I will explain). Second, even if Rea's temporal parts question *were* as difficult as the Location Question, this would not entirely neutralize the problem facing locational endurantists. For, in light of the taxonomy presented in section 4, one may be able to reject locational endurantism while at the same time rejecting temporal parts: this is the position held by Parsons (2000). In that case neither question would pose a problem.

6.2 Overlap Answers

The most straightforward Overlap answer is the Every Slice Principle that I mentioned earlier: a material object exactly occupies each achronal slice of its path. One problem for this principle (and for some of the others that I've mentioned) arises from the possibility of backward time travel. Consider a 'cylindrical' spacetime (not necessarily relativistic) in which the temporal dimension is closed, forming a loop. Now suppose that the earth inhabits this spacetime and lasts so long that its path winds all the way around the cylinder, with the result that younger and older versions of the earth co-exist with each other for a period of time, though always with some distance between them.

What are the earth's locations in this situation? Surely the most natural thing for the locational endurantist to say here is that the earth is spatially bilocated throughout the relevant period: for any

maximal achronal slice of spacetime as a whole that intersects the period of co-existence, there are two different subregions of this slice, R and R*, each of which is exactly occupied by the earth, and each of which is planet-sized and shaped like a ball (perhaps a squashed one). But a strict application of Every Slice to this case forbids us from saying that. After all, to count as an achronal slice of a given path, a region must not be a subregion of any other achronal subregion of that same path. So the ball-shaped regions, each of which is a subregion of a larger achronal subregion of the earth's path (a sum of two spatially distant ball-shaped regions), do not count as achronal slices of that path. According to Every Slice, then, the earth does not have ball-shaped locations during the period of co-existence; instead, each of its locations (and hence the planet itself) is shaped like a scattered sum of two balls. This is a troubling result. (See Gilmore 2006: 230, note 29, where this case is raised as a problem for Absolute Slice, and Gibson and Pooley 2006: 185, who note that it constitutes a problem for Every Slice too.)

One response to the problem would be to deny the possibility of backward time travel, or at least those cases in which a thing coexists with its younger self. A second response would be to try to modify Every Slice just enough to avoid the troubling result. The goal here would be (i) to formulate a principle that rules out, as locations of the object, those achronal slices of its path that are exactly occupied, not by the object itself, but by a sum of younger and older versions of the object, if by anything at all, and (ii) to do all of this in a non-circular way. I will leave it to the reader to attempt to formulate such a principle; suffice it to say that the task is difficult.

A third response has been defended by Ian Gibson and Oliver Pooley (2006). Like Rea, they argue that that the locational endurantist is under no burden to offer a fully general, non-circular answer to the Location Question:

> The . . . locations of . . . an object are not determined by the fact that some spacetime region contains its [path] and that certain subregions of this region satisfy certain geometrical constraints. It is, of course, the other way around. Facts about where the object is located determine which region is its [path]. This might be as true for point particles as for composite objects; some facts about where a particle is located, together with causal laws, will determine that the particle is also located in certain other point-sized regions. For composite objects, bedrock is the pattern of (multiple) location of the fundamental entities that, at various spacetime regions, compose them. . . In general, whether a given three-dimensional region contains an object of a given type will not just be a matter of the intrinsic character of the contents of that region. It will also depend on regions to its past and future having the right kind of content. . . and. . . on regions that are spacelike related to it having the right kind of content (statue shaped regions within blocks of marble [do not contain] statues). This gives us variously located three-dimensional objects. But some of these 'objects' are the very same object. Such identity facts will be determined by a mixture of spatiotemporal and causal considerations; but, just as with composition, the precise details may be expected to vary from kind to kind and from object to object. . . We only arrive at the path of an object of a certain type by first determining which three-dimensional regions contain objects of that type and then by determining which regions contain the same object. We then take the union of a set of such regions. But if the path is arrived at in this way, which locations within it are occupied by its object cannot be an interesting question that remains outstanding. We already know the answer. (2006: 187)

But whereas Rea appears to endorse a No-Overlap requirement, Gibson and Pooley do not. The view that they recommend to the endurantist in a relativistic context seems to be this. (1) The phenomenon of overlap is commonplace; each location of a given object typically 'criss-crosses' with many other locations of that same object (2006: 181). (2) The reason for this is not that it falls out of Every Slice or some kindred general principle that determines, for any material object, which subregions of its path it exactly occupies. Rather, the reason stems from facts about the existence conditions and persistence conditions associated with most ordinary object kinds, as these conditions apply to the contents of relativistic spacetime. When we consider an object of some ordinary kind K that exactly occupies a region R, we can typically find many regions criss-crossing with R that satisfy both the *existence conditions* associated with kind K (with the result that each of them, too, is exactly occupied by *some* object of kind K) and the *persistence conditions* associated with K vis-à-vis region R (with the result that each of them is exactly occupied by numerically the *same* object of kind K as is R).

Gibson and Pooley are right to emphasize that the facts about which region is an object's path depend upon the facts about which regions the object exactly occupies, and not vice versa. Of course it does not follow from this that there is no true, informative, and relatively simple general principle, along the lines of 3-6, that captures some systematic relationship between the facts of these two types. Still, perhaps we shouldn't *expect* there to be such a principle, especially in light of Gibson and Pooley's plausible suggestions concerning the complex, case-by-case, kind-sensitive ways in which the facts about exact occupation are determined.

However, even if we follow Gibson and Pooley in rejecting the demand for such a principle as an answer to the Location Question, we should not immediately conclude that all of the associated problems are solved. For the moral of section 6.1 still stands: given relativity, the No-Overlap requirement cannot be plausibly enforced on locational endurantism. Thus if there is something objectionable about rampant overlap of the sort apparently condoned by Gibson and Pooley, then locational endurantism will still be in trouble, even after we have withdrawn our demand for a simple, informative, general answer to the Location Question. Is there anything objectionable about such overlap?

I think so. The main objection arises from a causal principle that I take to govern exact occupation: in order for a material object to exactly occupy distinct spacetime regions R and R*, a causal relation of the appropriate sort (often called 'immanent causation') must hold between the contents of R and the contents of R* (Gilmore 2006). Call this principle *MURIC* (for "MUlti-Location Requires Immanent Causation"). To get a rough sense of what it is for a causal relation to be 'of the appropriate sort,' consider a clear example. Let R1 and R2 be a pair of parallel slices through my path separated by duration of, say, ½-second (as measured by me). I am in a certain overall intrinsic condition in R1: I have a certain mass, shape, temperature, etc. Call this condition C1. Likewise, I am in a certain, slightly

different, overall intrinsic condition, C2, in the later region, R2. My being in C1 in R1 is a cause of my being in C2 in R2 in the sense relevant to MURIC. Similarly, my being the way I was at a certain instant in 1975 is a cause, in the sense relevant to MURIC, of my being the way I am now. MURIC says that the holding of this sort of causation is a *metaphysicially necessary* condition on multi-location for material objects; it is silent on whether the condition is also sufficient. (For discussion of similar principles, see Swoyer 1984 and Zimmerman 1997.)

One important source of motivation for MURIC comes from 'immaculate replacement' thought experiments. (The term is from Swoyer 1984.) Consider a 10-year-long spacetime region, R, that by all outward appearances is the path of an ordinary material object – say, a car. But suppose that there is a causal gap between the first and second halves of R. Perhaps Zeus fires his car-annihilating gun at the original car just as Hera, entirely by coincidence, fires her car-creating gun toward the same spot: Hera causes it to happen that post-gap slices of R contain something with certain intrinsic properties, which – purely by accident – are exactly those that the original car would have had at the relevant locations, had Zeus not fired his gun. Many philosophers have the intuition that in such a situation, there is no material object (and *a fortiori* no car) that exactly occupies both pre-gap and post-gap slices through R.[27] But if not, why not? In light of the fact that this case differs from a case of ordinary persistence mainly in causal respects, the overwhelmingly natural explanation of this lack of multi-location appeals to MURIC.

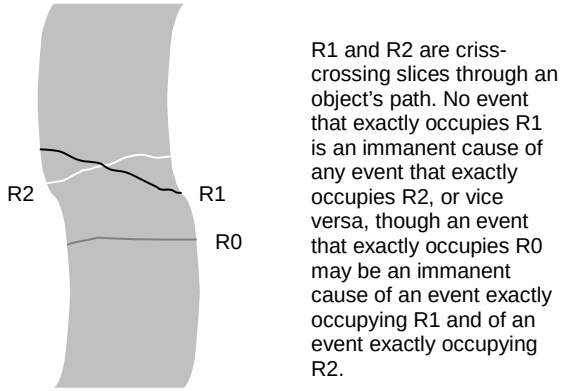


Figure 4

The objection to rampant overlap, then, is that the contents of typical criss-crossing regions do not stand in the sorts of causal relations that are necessary for those regions to be exactly occupied by one and the same material object. Where R1 and R2 are criss-crossing regions, we will find that a full half of R1 (the 'northwest arm of the X') fails to lie in the causal past of any point in R2, in which case nothing that goes on in that part of R1 is a cause of anything that goes on in R2. *Mutatis mutandis* for half of R2 (the northeast arm of the X) and any point in R1. (See fig. 4.) It seems to me that this disqualifies the

contents of R1 and R2 from standing in the appropriate causal relation.[28] (Suppose – counterpossibly, perhaps – that some material object O exactly occupies each of R1 and R2. Can we say that O is the way it is in R1 because O is the way it is in R2? Or that O is the way it is in R2 because it is the way it is in R1? I think not.) Accordingly, MURIC rules out rampant[29] overlap. The problem can be avoided either by rejecting mutlilocation altogether (as, e.g., locational perdurantists do[30]) or by retaining locational endurantism but rejecting rampant overlap.

To be sure, in the case above, there is presumably some earlier region, R0, that does not intersect either R1 or R2 and whose contents *are* an appropriate cause both of the contents of R1 and of the contents of R2. (See fig. 4.) So while R1 and R2 may not stand in the appropriate causal relation to *each other*, each of them stands in such a relation to some *third* region. Perhaps this is enough, so far as purely causal constraints are concerned, for R1 and R2 to be exactly occupied by the same material object.

It is not. To see why, ask: What happens to a material object that undergoes fission, amoeba-style? One suggestion is that the original object becomes spatially bilocated, exactly occupying each of two simultaneous (or spacelike separated) spacetime regions. I take it that most locational endurantists want to deny the possibility of this outcome.[31] But on what grounds? In my view, the best argument against this possibility appeals to some causal principle like MURIC: the reason why fission never results in a spatially bilocated object is that bilocation requires a kind of causation that (absent closed timelike curves or other causal anomalies) does not obtain between the contents of spacelike separated regions.[32] Note, however, that if our causal principle were weakened in the manner suggested in the previous paragraph, it would be powerless to rule out fission-induced spatial bilocation. In a fission case, for any pair of spacelike separated regions allegedly exactly occupied by the bilocated fission product, there always will be some third region (lying before the fission) that stands in the appropriate causal relation to each of them. We want to have a causal principle strong enough to forbid material objects from 'jumping the causal gap' in immaculate replacement cases and from becoming spatially bilocated in fission cases. It seems to me that MURIC is the simplest and most natural principle that can do the job.

Granted, there are other principles that would do this same job while, unlike MURIC, still permitting a material object to exactly occupy criss-crossing regions in relativistic spacetimes. For example, rather than requiring that for each pair of an object's locations, the contents of those locations stand in the appropriate causal relation to each other, one might instead require merely that each pair of an object's locations be achronal slices of a path such that, for *some* foliation f of that path into achronal slices, each pair of members of f are such that *their* contents stand in the appropriate causal relation. Call this *MURIC**.[33] In light of the availability of principles like MURIC*, the point here is not that the *only* way of ruling out gap-jumping in immaculate replacement cases and spatial bilocation in fission cases is to appeal to some principle that also rules out rampant overlap; the point, rather, is that the *simplest*, most

natural way of ruling out the former also rules out the latter. This is obviously not a knock-down argument against rampant overlap, but it does, I think, show that there is something suspiciously *ad hoc* about allowing such overlap while at the same time ruling out gap-jumping and spatial bilocation on causal grounds. It is a position that one might be *driven to* if one becomes aware of the problems with the No-Overlap requirement and remains unwilling to give up locational endurantism, but it does not exactly glow with independent plausibility.

6. Conclusion

This paper has been silent on an important question: whether relativity theory or something relevantly similar to it is actually true. There is, after all, a famous *prima facie* conflict between quantum mechanics and GTR (Weinstein 2008, Greene 1999: 127-131), and many believe that it is GTR that will have to give way. We should keep in the mind the possibility that the outcome of this conflict (in the form, perhaps, of a theory of quantum gravity) may differ from GTR in such a way as to undermine some or all of the relativity-based arguments against endurantism discussed here. Likewise, the paper has had nothing to say about the impact of extant quantum theories themselves on issues about the metaphysics of persistence. For all I have said here, e.g., quantum field theory in its current form may decisively settle these issues in favor of one of the views already on the table or, alternatively, it may show that the current range of options is incomplete or somehow ill-formulated.

Still, I have reached some conclusions, albeit tentatively. Endurantists have traditionally embraced two main claims, sometimes without distinguishing them: first, that material objects persist *without having temporal parts* (mereological endurantism) and, second, that material objects persist *without being temporally extended* (locational endurantism). The transition from pre-relativistic spacetimes to the spacetimes of STR and GTR affects the two endurantist views differently. Mereological endurantism, which merely denies that material objects have temporal parts, is not directly affected by this transition, whereas locational endurantism, according to which material objects exactly occupy only achronal regions, is harmed by it – though maybe not fatally.

Of the *endurantist* views discussed here, therefore, the one that does best in a relativistic spacetime is the view that says that material objects (i) *do* persist without having temporal parts but (ii) are *not* in any robust sense multi-located within their paths, either because each of them exactly occupies only its path as a whole or because 'exactly occupies' is unintelligible. Whether such a view is worth having, and whether it survives other objections that might be raised against it, are questions for another time.[34]

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('*' indicates entries with some explicit discussion of the bearing of relativity on debates about persistence.)

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[1] For introductory overviews of the debate and further references, see Balashov (forthcoming b), Haslanger (2003), Hawley (2004), McGrath (2007), or Sider (2008).
[2] Informally, a temporal part of me would be something that (i) has exactly the same size, shape, spatial location, and constituent matter as I do at any instant at which it exists, but that (ii) exists at only some (a proper subset) of the instants at which I exist. An *instantaneous* temporal part of me is a temporal part of me that exists at just a single instant. Temporally extended temporal parts last longer and can overlap one another, one beginning before the other ends. Instantaneous temporal parts tend to be the focus of discussion, though see Butterfield (2006) for an exception. (In a relativistic setting, as we shall see, even instantaneous temporal parts of thing can intersect each other.)
[3] There is also a third view, 'exdurantism' or 'stage theory', according to which ordinary objects are instantaneous entities that persist by bearing a temporal counterpart relation to numerically distinct stages located at other times (Hawley 2001, Sider 2001). For brevity I ignore this view in what follows. One relativity-based objection to exdurantism is explored in Balashov (2002).
[4] Very roughly, substantivalism about spacetime is the view that points and/or regions of spacetime are real entities that exist in their own right and are not somehow reducible to material objects or events. The opposing view is relationism, according to which all talk of spacetime regions is to be reduced to talk of material objects and events standing in spatiotemporal relations.
[5] One might take the so-called 'hole argument' (Norton 2008) to show that General Relativity (GTR) undermines certain forms of spacetime substantivalism, but substantivalist replies are available. Indeed, many would argue that, far from undermining substantivalism, GTR provides especially strong support for that view. For an accessible introduction to these issues and further references, see Dainton (2001).
[6] *Prima facie*, B-theoretic endurantists are committed to times or spacetime regions in two ways: first via their appeal to times as entities to which changing objects bear shape relations (the candle bears the straight-at relation to one time and the bent-at relation to another), and second via the common formulation of endurantism as the thesis that a persisting object exactly occupies multiple regions or is wholly present at multiple times. Following Parsons (2000), one might try to avoid the first commitment by denying that shapes are fundamentally relations to times and holding instead that B-theoretic endurantists can account for change in shape by appeal to non-relational, irreducibly 'distributional' shape properties such as being-first-bent-then-several-hours-later-straight. Again following Parsons (2000, 2007), one might try to avoid the second commitment by playing down any talk of robust multi-location in favor of the view that enduring things merely lack temporal parts. Thus, just as a spatially extended simple would lack spatial parts but need not be, any robust sense, multi-located in space, a persisting simple (e.g., an electron) would lack temporal parts but need not be in any robust sense multi-located in time: rather, it might merely be temporally extended. See Hawthorne and Sider (2006) for a detailed case against endurantist relationism.
[7] I have in mind the time travel via closed timelike curves in General Relativistic spacetimes first highlighted by Gödel (1949). For discussion see, e.g., Yourgrau (1999) and Arntzenius and Maudlin (2005).
[8] Sider (2001, 2004) argues that the possibility of certain (especially exotic, non-Gödelian) forms of time travel undermine endurantism. Markosian (2004), Simon (2005), and Miller (2006) reply. Effingham and Robson (2007) argue that endurantism is undermined (for reasons stemming from part-whole theory) even by less exotic cases, which require nothing more than Gödelian time travel. Gilmore (2007) argues that mere Godelian time travel gives rise to special problems for *perdurantism*; Eagle (forthcoming) replies. Keller and Nelson (2000) argue that time travel is compatible not merely with endurantism but also with presentism; Sider (2005) replies.

[9] Let me mention several relativity-based arguments against endurantism that I do not discuss in the main text. (1) Nerlich (1979) claims that GTR rules out endurantism; Mellor (1980) replies. (2) Balashov (2000) argues that the only adequate, relativistically acceptable account of the notion of *coexistence* (or temporal co-location) is one that presupposes perdurantism. Gilmore (2002) is a reply, and Balashov's (2005) is a rejoinder. Gibson and Pooley (2006) nicely summarize the exchange and reply to Balashov's rejoinder. (3) Hales and Johnson (2003) argue that STR is incompatible with the claim that objects are wholly present at each moment of their careers. Miller (2004) replies, as do Gibson and Pooley (2006); Harrington (2005) offers a critique Miller's paper. (4) Hales and Johnson (2007) argue that no plausible endurantist account of qualitative change is available given STR. Mellor (1981: 128-132), Simons (1987: 126-127) Oderberg (1993: 105-204), and Rea (1998) all defend endurantism against relativity-based arguments of their own making.

[10] This is the difference between Galilean spacetime and *Newtonian* spacetime, another much-discussed pre-relativistic spacetime. Spatial distance between non-simultaneous points, and hence absolute velocity, is well defined in Newtonian spacetime. See Dainton (2001: 181-188) for discussion and references.

[11] Still *other* endurance-like views that are apparently consistent with the existence of temporal parts are formulated and explored by Hawthorne (2006: 85-109). It is an interesting question whether and how relativity theory bears on these views. Unfortunately I cannot pursue this question here.

[12] More formally: P's path is a maximal achronal subregion of O's path, i.e., (a) P's path is achronal, (b) P's path is a subregion of O's path, and (c) P's path is not a proper subregion of any achronal subregion of O's path.

[13] The intuitive idea here is that, *at the relevant region* (though perhaps not at all regions at which they are located), they are both entirely made up of exactly the same stuff. How to express this in formal terms raises interesting questions about how to adapt temporally relativized formal theories of parthood to the context of relativistic spacetime while preserving their neutrality vis-à-vis the endurantism v. perdurantism debate. We cannot hope to settle theses issues here, but one starting point is to appeal to a three-place predicate, 'x is part of y at R', where this is thought of as entailing 'x and y are each weakly located at R'. Using this predicate, we can say that x and y *overlap* at R iff some z is part of x and R and part of y at R, and we can say that x is *composed* of the ps at R iff each of the ps is a part of x at R and anything that is a part of x at R overlaps-at-R at least one of the ps. Finally, we can say that x and y are *co-composed* at R iff there are some ps that compose x at R and compose y at R. For a rigorous discussion of the options concerning 'x is part of y at R', see Donnelly (unpublished).

[14] I have not defined 'R is a continuous temporal chunk of R*' or 'x is a temporally extended temporal part of y at region R'; I take it that their intended sense is clear enough as is. According to Butterfield (2006), the mereological perdurantist can solve the 'rotating disks' problem by holding that objects are 'gunky along the temporal dimension', so that each of them has a different temporal part for each different extended interval in its career but no instantaneous temporal parts. He also argues that such a position is recommended by physics. For discussion of Butterfield, see Hawthorne (2006: 111-143).

[15] So stated, both are true in any world that is devoid of persisting material objects; similarly for *locational* endurantism and perdurantism as stated below.

[16] Those who – at least apparently – take themselves to grasp such a predicate include van Inwagen (1990: 4), Rea (1998), Hudson (2001, 2006, 2008), Gibson and Pooley (2006: 164), Sattig (2006: 48), McDaniel (2007), Balashov (2008) and Donnelly (forthcoming). For a more thorough characterization and tentative defense of the predicate, see Gilmore (2006: 200-202).

[17] This definition has unwelcome consequences, however. First, it entails that an instantaneous, spatially point-sized object in a spacetime without instantaneous, point-sized regions would not only fail to exactly occupy any region (which is intuitively correct) but would also fail to be weakly located at any region (which is intuitively incorrect). Such a spacetime might be 'gunky', so that each of its regions had proper subregions, but all of these regions had some finite spatial and/or temporal extent (Arntzenius forthcoming), or it might be made up of extended, simple 'grains' (Braddon-Mitchell and Miller 2006). Second, suppose that each spacetime region is composed of simple unextended points, but that each region is a proper subregion of some other region, so that there is no maximal region. Suppose that despite this, each two points are less than 10 feet apart in space and less than 10 seconds apart in time, so that if all the points *did* have a fusion (a maximal region), it *would* be finite in size. Finally, suppose that there is what we would ordinarily think of as an 'omnipresent' material object in this world, an object whose shape, size, and location exactly matches the shape, size, and location that the maximal region *would* have, if there were such a region. The object in question does not exactly occupy any region in the given world (none is big enough), but intuitively it seems to be weakly located at every region. As Parsons (2007) points out, however, the definition of 'weakly located' in terms of 'exactly occupies' entails that the object is not weakly located anywhere.

[18] See especially Parsons (2007 and 2008), who attacks the predicate, and Hudson (2008), who defends it.

[19] We might, e.g., say that a thing locationally *dysdures* just in case it persists and exactly occupies more than one region but each of these is a temporally extended *temporal chunk* of its path.
[20] If all objects are gunky and hence there are no simples, one might still pursue this strategy by appealing to the facts about 'relatively small' objects that compose the Earth.
[21] A third response would be to argue that while the perdurantist explanation of the data is the best available, and that while this does confer support upon perdurantism, the perdurantist explanation is only slightly better than the microreductive explanation, and so the degree of support conferred upon perdurantism by the argument is correspondingly very small and easily overridden by other considerations.
[22] A version of this question was first put forward as posing a problem for endurantism by J. J. C. Smart (1972: 7). Smart considers what I below call the *Rest Frame* answer, and he suggests that it encounters difficulties associated with objects whose parts are in motion relative to one another, but he does not say exactly what the difficulty is, nor does he consider any other answers to the question. Gilmore (2006) elaborates on Smart's initial worry.
[23] See Balashov (MS: 236-239) for a tentative proposal as to how rest frame foliations might be specified.
[24] Since there are different ways of singling out a preferred foliation, there are different versions of Top Down. I do not know whether all versions of the principle allow for the possibility in question. But this possibility is surely in the spirit of the view.
[25] This fact is the basis of the 'Twins Paradox': twins are separated at birth, one stays at rest while the other accelerates away for several decades and accelerates back for several more, and at their reunion they find that more proper time has elapsed for the stationary twin than for her accelerating sister.
[26] Presumably most friends of temporal parts will hold that a thing has a different temporal part for each different achronal slice of its path, in which case Rea's question asks which of these temporal parts are *privileged* for the object in such a way as to (e.g.) instantiate *simpliciter* the mental properties that the object instantiates *at a time*. Now suppose that the privileged temporal parts of an object are its 'rest frame' temporal parts – i.e., those that are perpendicular to the object's path; and return to the case involving and my red blood cell and me. For reasons analogous to those I gave in my discussion of Rest Frame, the cell's privileged temporal parts won't be parts of my privileged temporal parts. But – and this is where the analogy breaks down – it will have *nonprivileged* temporal parts that are parts of my privileged temporal parts, and its privileged temporal parts will be parts of some of my nonprivileged temporal parts. This is a far more palatable outcome than in the case of locational endurantism. All this assumes that there are nonprivileged temporal parts in addition to privileged ones, but virtually all perdurantists accept principles governing composition and decomposition that would yield such parts.
[27] This is not to say that R is not the path of some material object. Most perdurantists accept a plenitude principle according to which any matter-filled spacetime region, no matter how scattered or causally unrelated its contents might be, is the path of some material object (if only an 'arbitrary sum'). (For a minority view see Balashov 2003a,b). This principle would of course tell us that R *is* the path of some material object. Perdurantists typically go on to accept a causal constraint on persistence for ordinary objects to the effect that a thing does not fall under any ordinary object kind (such as *car* or *human being*) unless it is composed of some set of pairwise causally related instantaneous temporal parts. According to this constraint, while R may be the path of some material object (e.g., an arbitrary sum of two consecutive cars), it is not the path of a car. Locational perdurantists and locational endurantists will both agree, however, that no material object *exactly occupies* both pre- and post- gap slices of R. Locational perdurantists deny multi-location altogether.
[28] Of course, as Gibson and Pooley note (2006: 181), no part of R1 will be causally *cut off* from each part of R2: each point in R1 will either be such that its contents can be a cause of something going on somewhere in R2 or can be caused by something going on somewhere in R2. Similarly, no part of R2 is causally cut off in that sense from R1. But when endurantists have spoken of immanent causation, clearly what they have had in mind is a relation in which the state of a thing *as a whole* at one time is a cause of the state of that thing *as a whole* at another time, and Gibson and Pooley admit that *this* relation does not hold between the contents of criss-crossing regions such as R1 and R2. They nevertheless conclude that the causal relation between the contents of these regions is sufficiently intimate as to satisfy any causal constraints on multi-location.
[29]MURIC does not rule out overlap altogether. (1) Perhaps if a pair of regions criss-crossed not near their middles but only near their edges, then their contents could stand in the appropriate causal relation. But it is hard to see how this sort of overlap could occur systematically without the sort discussed in the main text also occurring. (2) In a case of time travel (even in a Galilean spacetime) in which a thing returns to its past and comes to share a part with its younger self (say, I become fused with my younger self at the foot, so that we share a big toe), a thing's locations can overlap without even the slightest appearance of tension with MURIC. I have no objection to such a case, but clearly it does nothing to help the locational endurantist here.

[30] This move would of course be of no help if one then went on to accept the following analogue of MURIC: in order for a material object to be *weakly located* in distinct regions R and R*, the contents of those regions must stand in an appropriate causal relation. This new principle would prevent (e.g.) a locationally perduring object from being weakly located at criss-crossing slices of its path. But no one finds the new principle plausible. On the assumption that the contents of spacelike separated regions are causally unrelated, the new principle rules out any object that is not always spatially point-like.

[31] See Dainton (2008: ch. 12) for an interesting exception. As Dainton notes, if one holds that fission can result in bilocation, then one faces pressure to accept (which Dainton does) an even more implausible claim: that fusion deserves a parallel treatment, according to which if a and b fuse, then a=b, and the relevant object (a/b) was spatially bilocated *prior* to the fusion. Together with natural assumptions about a and b's origin(s), Dainton observes, this would seem to violate Locke's principle that a thing cannot have more than one beginning of its existence. It also raises the question of why a thing couldn't live two entirely unconnected, parallel lives.

[32] One alternative argument appeals to the thought that there is something especially problematic about *spatial* bilocation in itself. Another argument appeals to thought that if an object were spatially bilocated, it would be able to have contrary properties (e.g., bentness and straightness) at the same time, but that this is in fact not possible. Neither argument will have force on an endurantist who (as I think he should) accepts the possibility of cases of backward time travel in which a thing is spatially bilocated. Such endurantists will presumably want to allow the thing to have contrary shapes in different, spacelike separated regions, perhaps by treating the fundamental shapes as relations that things bear to regions that they exactly occupy (or to the moments of their personal or proper time at which they exactly occupy these regions). The most natural explanation of why time-travel-related spatial bilocation is possible whereas fission-related spatial bilocation is not is one that appeals to MURIC. (In the time travel case, the contents of the spacelike separated regions do stand in the relevant causal relation.)

[33] In the case of an immaculate replacement, the alleged path is not foliable into pair-wise causally related slices: none of the post-gap slices is caused by any of the pre-gap slices. In a fission case, the "Y"-shaped path is so foliable, but the alleged post-fission locations are not members of that foliation, for those locations are not *slices* of the full path; rather, each of them is a mere slice of a 'branch' of the path. A post-fission *slice* of the path is a scattered region, made of a slice of the left branch and a slice of the right branch.

[34] I would like to thank Yuri Balashov, Adam Sennet, Gabriel Uzquiano, and a referee for this journal for helpful comments.