Relativistic Parts and Places: A Note on Corner Slices and Shrinking Chairs

Yuri Balashov

Department of Philosophy, University of Georgia, Athens, GA 30602, USA
yuri@uga.edu

[Final version published in C. Calosi and P. Graziani, eds., *Mereology and the Sciences* (Springer, 2014), pp. 35–51]

1. Introduction

Worries about parthood and location continue to stimulate the debate about persistence over time. It is now widely recognized that physical considerations are highly relevant to this debate. Recent work investigating the impact of relativity theory on the ontology of persistence has revealed, not surprisingly, many unexpected dimensions and subtle nuances of this impact. There now appears to be a broad consensus that no interesting metaphysical view of persistence (endurance, perdurance, or exdurance) is decisively refuted by relativistic considerations. There is little consensus as to how and to what extent various such views are supported by them. One should proceed on a case by case basis.

In this paper I review some recent developments focused on an especially intriguing aspect of relativistic persistence. My goal is not so much to adjudicate a mini-dispute in this area as to use it as a case study to draw some lessons about the broader metaphysical implications of the transition from the classical to the relativistic worldview. Some relativistic phenomena (e.g., relativity of simultaneity and time dilation) have no classical analogs and force us to revise the very fundamentals of common-sense ontology (e.g., reject presentism). Others – those that do most of the work in the arguments discussed below – have more familiar classical limits and, as a result, less dramatic metaphysical consequences.

2. Enduring and Perduring Objects in Classical Spacetime

We need to start by situating the major views of persistence in relativistic spacetime. This, by itself, requires taking a stance on a number of controversial issues. The approach sketched below is therefore rather opinionated. Fortunately, except for one aspect of it,[1] this will not bias my discussion of the arguments of interest to me and, at the same time, will allow to avoid orthogonal engagements. Since the arguments in question focus on two rival modes of persistence, *endurance* and *perdurance*, and abstract from *exdurance* (also known as *stage theory*) I will set the latter aside in my discussion too. Finally, I will restrict the discussion to *special* relativity. To smoothen the transition to it, let us begin with the familiar context of classical spacetime.

Classically, a material object *o endures* iff it persists by being multilocated, in its entirety, at many instantaneous "time-slices" of its path in spacetime. "Multilocated" here means multiple *exact location*;[2] "in its entirety" means *wholly* but not *solely*;[3] and "path" is a 4D (four-dimensional) region of spacetime "swept" by *o* during its life career.[4] Enduring objects are 3D (three-dimensional) entities (i) extended in space but not in time, (ii) having spatial but not temporal parts (on which more below), and (iii) persisting by being wholly present at all moments of time at which they exist (Figure 1a).

Classical perdurance can, for our purposes, be taken as involving the denial of all the above. A material object *o perdures* iff it persists by being singly located only at its path. Perduring objects are 4D entities (i) extended in time as well as space, (ii) having temporal as well as spatial parts, and (iii) exactly located only at their 4D paths (Figure 1b).

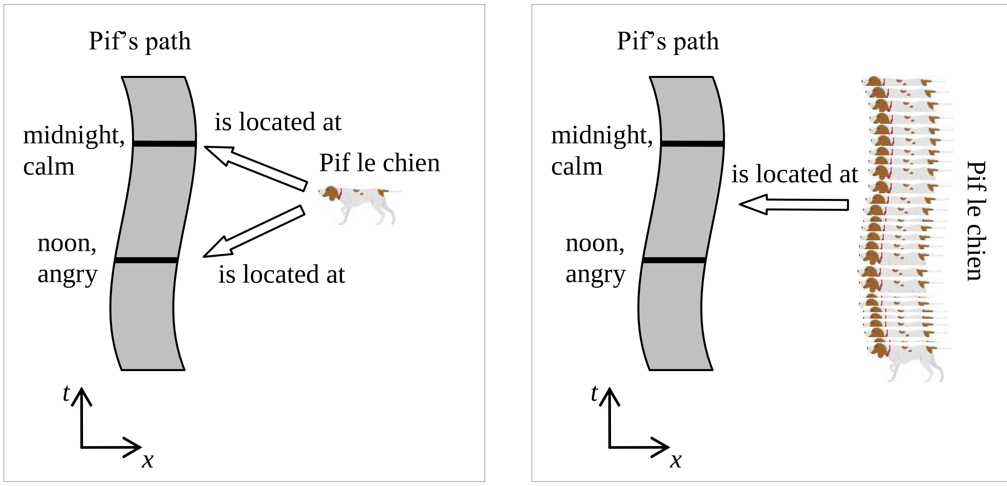
---

[1] Noted in Section 4, note 22.

[2] Intuitively, a material object *o* can be said to be exactly located at a spacetime region R iff *o* and R have exactly the same shape, size, and position. Exact location can be taken as an unanalyzed and intuitively clear primitive (as is done, e.g., in Hudson 2001, Bittner and Donnelly 2004, Gilmore 2006, and Balashov 2008, 2010) or as a defined notion (see, e.g., Parsons 2007 and Gilmore 2008). The choice affects other commitments. Below we abstract from this issue and adopt the first approach.

[3] Roughly, *o* is *wholly* located at R iff no part of *o* is missing from R; while *o* is *solely* located at R iff no region disjoint from R contains any part of *o*. An enduring object is (typically) wholly and exactly located at multiple regions of spacetime without being solely located at any of them.

[4] For now; we will need to make the notion of path more precise later.



(a) (b)

Figure 1. Endurance (a) and perdurance (b) in classical spacetime.

A bit more precisely, one could start with a three-place relation of parthood "*p* is a part of *o* at a region $R_\perp$" relativized to a temporally unextended region of spacetime $R_\perp$. The regions of interest are, of course, instantaneous "time-slices" ("*t*-slices") of objects' paths, which can be indexed by moments of time (in the classical context) or by moments of time in frames (in the relativistic context), allowing one to simplify the notation and speak of "parts at times" (or "parts at frame-relative times") and thus anchor the technical language of persistence in familiar notions of common language. Where *p*, *o* and a *t*-slice of *o*'s path, $\varnothing_{\perp t}$, stand in such a relativized parthood relation we shall say that *p* is a *spatial part* (*s-part*) *of o at t*:

(1) $p_\perp$ is a *spatial part* (*s-part*) of *o* at $t =_{df} p_\perp$ is a part of *o* at $\varnothing_{\perp t}$.

Temporal parthood can then be defined as follows (cf. Sider 2001: 59):

(2) $p_\parallel$ is a *temporal part* (*t-part*) of *o* at $t =_{df}$ (i) $p_\parallel$ is located at $\varnothing_{\perp t}$ but only at $\varnothing_{\perp t}$, (ii) $p_\parallel$ is a part of *o* at $\varnothing_{\perp t}$, and (iii) $p_\parallel$ overlaps at $\varnothing_{\perp t}$ everything that is a part of *o* at $\varnothing_{\perp t}$.

The subscripts '$_\perp$' and '$_\parallel$' indicate that the relevant dimensions are, respectively, "orthogonal" or "parallel" to the direction of time.

Given this background, classical endurance and perdurance amount to the following:

(3) *o endures* in classical spacetime $=_{\text{df}}$ (i) *o*'s path is temporally extended, (ii) *o* is located at every *t*-slice of its path, (iii) *o* located only at *t*-slices of its path.

(i) ensures that *o* persists; (ii) says that an enduring object is "wholly present" at all moments of classical time at which it exists; (iii) precludes *o* from being extended in time.

(4) *o perdures* in classical spacetime $=_{\text{df}}$ (i) *o*'s path is temporally extended, (ii) *o* is located only at its path, (iii) the object located at any *t*-slice of *o*'s path is a proper *t*-part of *o* at that slice.

(ii) indicates that *o* is temporally extended and is as long as its path, while (iii) guarantees that *o* has a distinct proper temporal part at each moment of its career.[5]

To say what properties a persisting object has at a classical moment of time both endurantism and perdurantism must relativize possession of properties to times. The endurantist can do it in a number of ways that bring with them somewhat distinct metaphysics of temporal modification, each coupled with a corresponding semantic of temporal predication.[6] We can abstract from these details and put the guiding idea as follows:

(5) Enduring object *o* has Φ at *t* (i.e., at $\mathbb{O}_{\perp t}$) in classical spacetime $=_{\text{df}}$ *o* bears Φ-at to *t*.

The perdurantist, in her turn, must endorse the following analysis, or some analog:

(6) Perduring object *o* has Φ at *t* (i.e., at $\mathbb{O}_{\perp t}$) in classical spacetime $=_{\text{df}}$ *o*'s *t*-part has Φ.

---

[5] As noted above, these formulations are opinionated and gloss over some controversial issues. First, there are exotic counterexamples, e.g., objects enduring according to (3), but having temporal parts according to (4). Similarly, an object might be a *temporally extended simple* that has no temporal parts. Some authors take exotica of this sort seriously enough to motivate a more fine-grained classification of different ontologies of persistence distinguishing *locational* endurance and perdurance (where the disagreement boils down to the issue of whether or not objects are temporally extended) from their *mereological* counterparts (where the disagreement is about possession of temporal parts). See, in particular, Gilmore 2006 and 2008, where these distinctions are developed in detail and amply illustrated. We will abstract from the exotic cases below and focus on natural combinations of locational and mereological views.

[6] For details, see Lewis 1988, Haslanger 2003, and Balashov 2010: 18–22, 74–77.

To illustrate, consider Pif, a dog that, as we normally say, is angry at noon and calm at midnight. The endurantist underwrites this talk by making Pif bear two tenseless relations *angry-at* and *calm-at* to, respectively, noon and midnight. For the perdurantist, Pif is a 4D entity extended both in space and time. It persists by having distinct temporal parts at every moment of its existence. When we say that Pif is angry at noon and calm at midnight what we really mean is that Pif's noon part is simply angry and his midnight part simply calm (see Figure 1).

Obviously, endurance and perdurance represent two very different metaphysical and semantic views. The question of whether ordinary material objects endure or perdure continues to dominate the debate about persistence. Special relativity adds new features to it.

3. Enduring and Perduring Objects in Special Relativistic (Minkowski) Spacetime

The spacetime of special relativity (Minkowski spacetime) does not support the notion of absolute simultaneity and the associated partition of spacetime events into equivalence simultaneity classes. Instead it embodies an absolute metrical relation between events known as the Interval,[7] which imposes partial order on them.[8] Global chronological precedence thus gives way to local relations of timelike and lightlike separation. Simultaneity becomes a frame-relative notion, and moments of time (i.e. hyperplanes of simultaneity) in different reference frames crisscross (see Figure 2 below).[9]

As we have seen, in classical spacetime, locations of persisting objects, their parts, and temporary properties were indexed to moments of absolute time (more precisely, to *t*-slices of the objects' paths). A natural adaptation of this strategy to Minkowski spacetime suggests further relativization to inertial frames of reference[10] resulting in the replacement of the classical 't' with a two-parameter index 't^F' referring to moments of time in a given inertial reference frame F. As before, one could begin with a three-place relation "*p* is a part of *o* at a temporally unextended region $R_\perp$." Temporally unextended regions of interest are now "t^F-slices" – spacelike intersections of time hyperplanes with the objects' paths in

[7] Expressed in a given inertial reference frame as $I = c^2\Delta t^2 - \Delta \mathbf{r}^2$.

[8] The sense in which Minkowski spacetime is partially ordered is the sense in which its points can be ordered by the relation $R^+(q,p) \equiv c^2[t(q)-t(p)]^2 - [\mathbf{r}(q)-\mathbf{r}(p)]^2 \geq 0 \wedge t(q)-t(p) \geq 0$, which is reflexive, antisymmetric and transitive.

[9] For useful non-technical introductions to the geometrical structure of Minkowski spacetime see Geroch 1978 and Balashov 2010: Ch. 3.

[10] A move made by Sider 2001: 59, 84–6; Rea 1998; Sattig 2006: §§1.6 and 5.4; and defended by Balashov 2010: §5.2, but strongly resisted by Ian Gibson and Oliver Pooley (2006: 160–5) and, to some extent, by Gilmore (2008).

Minkowski spacetime. Where *p*, *o* and a t^{F}-slice $\varnothing_{\perp t^{F}}$ of *o*'s path $\varnothing$ stand in such a relation, we shall say that *p* is a *spatial part* (s^{F}*-part*) *of o at* $\varnothing_{\perp t^{F}}$:

(7) $p_{\perp}$ is a *spatial part* (s^{F}*-part*) of *o* at t^{F} $=_{df}$ $p_{\perp}$ is a part of *o* at $\varnothing_{\perp t^{F}}$.

And we explicate the notion of temporal parthood as follows:

(8) $p_{\|}$ is a *temporal part* (t^{F}*-part*) of *o* at t^{F} $=_{df}$ (i) $p_{\|}$ is located at $\varnothing_{\perp t^{F}}$ but only at $\varnothing_{\perp t^{F}}$, (ii) $p_{\|}$ is a part of *o* at $\varnothing_{\perp t^{F}}$, and (iii) $p_{\|}$ overlaps at $\varnothing_{\perp t^{F}}$ everything that is a part of *o* at $\varnothing_{\perp t^{F}}$.

These notions can then be employed to give a tentative analysis[11] of relativistic endurance and perdurance:

(9) *o endures* in Minkowski spacetime $=_{df}$ (i) *o*'s path is temporally extended,[12] (ii) *o* is located at every t^{F}-slice of its path, (iii) *o* is located only at t^{F}-slices of its path.

(10) *o perdures* in Minkowski spacetime $=_{df}$ (i) *o*'s path is temporally extended, (ii) *o* is located only at its path, (iii) the object located at any t^{F}-slice of *o*'s path is a proper t^{F}-part of *o* at that slice.

As before, these definitions must be supplemented with an account of the relativization of temporary properties of persisting objects to their locations (in the case of endurance), or the locations of their t^{F}-parts (in the case of perdurance). Such locations are, of course, t^{F}-slices of the objects' paths, which can be usefully labeled with the same two parameter-index that figures in the above definitions:

(11) Enduring object *o* has Φ at t^{F} (i.e., at $\varnothing_{\perp t^{F}}$) in Minkowski spacetime $=_{df}$ *o* bears Φ-at to t^{F}.

(12) Perduring object *o* has Φ at t^{F} (i.e., at $\varnothing_{\perp t^{F}}$) in Minkowski spacetime $=_{df}$ *o*'s t^{F}-part has Φ.

Thus, while in the classical framework objects have properties at absolute moments of time (more precisely, at absolute time slices of the objects' paths), in the Minkowskian framework possession of temporary properties is relativized, in

[11] Important refinements will be made in Section 4.
[12] That is, includes at least two timelike separated points.

effect, to times-in-frames (more precisely, to frame-relative time slices of the objects' paths). This brings new features. Consider, for example, an object whose path is a "cylindrical" region in Figure 2 (with one dimension of space suppressed). Even if the object does not change its *proper shape* (i.e. the shape it has in its rest frame), it exemplifies different shapes at time slices of its path drawn in different reference frames, such as (x,y,t) and (x',y',t'). The endurantist will say that the object is located at both slices and bears the *spherical-at* relation to *t*•, a moment of time (i.e. a time plane) in the frame (x,y,t) hosting one of the slices and the *oblong-at* relation to *t′*⬬, in the frame (x',y',t'), hosting the other slice. The perdurantist will say that the object is located at its path and has two distinct *t*-parts, the *t*•-part and the *t′*⬬-part, with different corresponding shapes. This is, of course, none other than the familiar relativistic effect of Lorentz contraction dressed in modern metaphysical clothes. Geometrically speaking, the effect is grounded in different (non-parallel) orientations of time hyperplanes, containing time-slices of the object's paths, in different reference frames – a distinctly relativistic phenomenon absent from the geometry of classical spacetime.

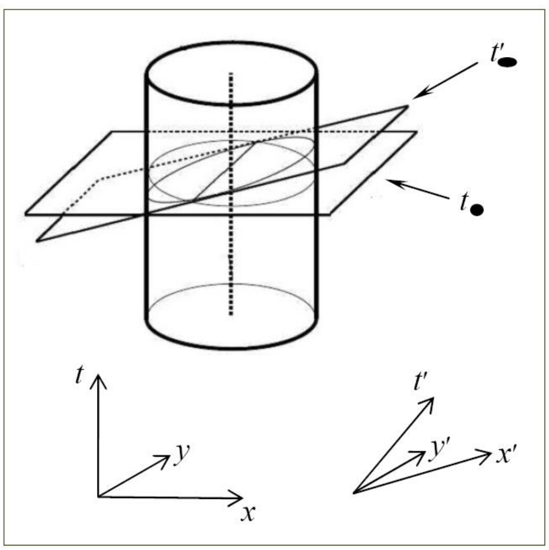


Figure 2. A persisting spherical object in Minkowski spacetime.

The implications of this phenomenon are more dramatic than it may appear. David Lewis (1988) has famously said that nothing can be bent and straight in the same respect. This seems to imply, a fortiori, that nothing can be both *bending* and *keeping straight*. But there is a sense in which this is not true in relativistic spacetime. Consider a granite block moving with velocity v (which is a considerable fraction of the speed of light) and suspended from vertical threads moving along with it (Figure 3).[13]

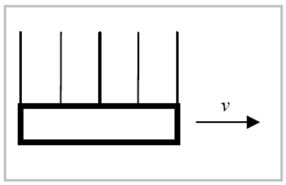


Figure 3. Granite block in horizontal motion.

At a certain moment all threads are cut and the block starts to fall, continuing at the same time its inertial horizontal motion. Figure 4 represents a series of snapshots showing the block at some stages in this process.[14]

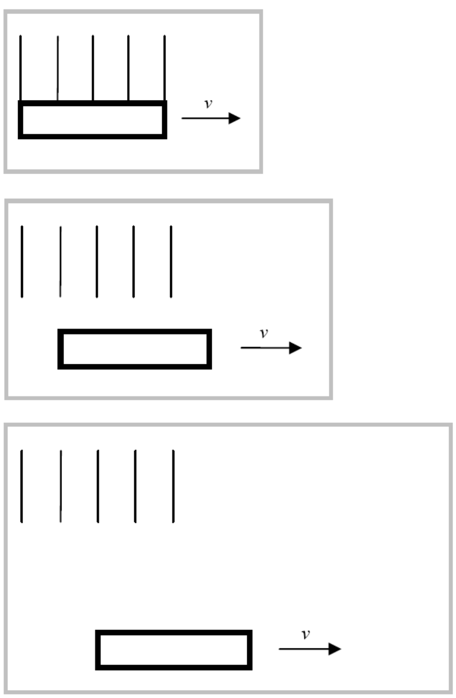


Figure 4. Granite block in free fall, continuing to move horizontally.

---

[13] The essential details of the scenario come from Sartori 1996: 185–190, where it is used to illustrate one of the lesser-known "paradoxes" of special relativity, first introduced by Wolfgang Rindler (1961). My exposition of the case comes from Balashov 2010: 198–200. Thanks to Oxford University Press for permission to use this material.

[14] Figures 3–5 are *not* spacetime diagrams but series of merely spatial "snapshots" taken at different moments of time in two reference frames.

Figure 5 represents a similar series of snapshots taken in the original rest frame of the block.

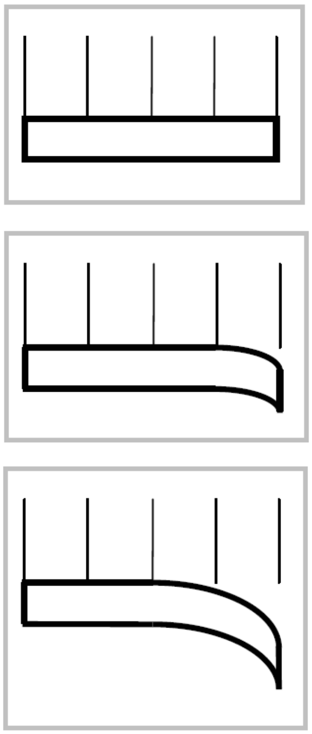


Figure 5. Granite block in "free fall" with snapshots taken in its rest frame.

The block remains straight in the first series but becomes progressively bent in the second. How could it be? There may, initially, be two worries about it. First, the block is made of granite and thus simply cannot bend. (If you think granite is insufficiently rigid, pretend that the block is made of *super*granite.) Second, the block cannot *both* remain straight *and* undergo bending (here is where we may come up against Lewis's dictum).

These worries are, of course, misplaced. The block does both things, i.e., is both bending and keeping straight over the same stretch of its career (loosely speaking). And it bends no matter how rigid its material is. Moreover, it always bends in the same way. How so? The key lies in the relativity of simultaneity. The threads suspending the block are cut *simultaneously* in the "laboratory frame" resulting in free fall of all segments of the block (Figure 4). In the original rest frame of the block, however, the cutting events occur *successively* (Figure 5). When the rightmost thread is cut the part of the block previously held by it begins to fall immediately. But the rest of the block remains horizontal. By the time the next thread is cut the segment of the block just underneath it still "does not know" that the rightmost part is already in free fall and, hence, does not have a chance to exert a sheer force that could stop the bending of the right end of the block. Why? Because the cutting events are simultaneous in the laboratory frame, hence, spacelike separated from each other. Therefore, no physical influence can propagate from one such event to the next. Nothing can stop a given segment of the block from free fall, once the thread holding it is cut. Accordingly, nothing can stop the block from bending. The strength of the material is beside the point.

Along with some other "paradoxes," this scenario is sometimes taken to show that there are no rigid bodies in special relativity, that is to say, no bodies that can keep their shape invariant, even in the idealized limit.[15] (Thus supergranite is of no help.) Shape and other arrangements in 3D space are, in this theory, merely *perspectival* phenomena. But there must be something permanent standing behind all the different perspectives, such as those shown in Figures 4 and 5. What stands behind them is, of course, a 4D invariant shape of the path of the persisting object.[16] If this object perdures then it is temporally as long as its path and fits exactly in it. This fact could then be used to explain the unity behind many perspectivally restricted shapes of the object's temporal parts (see Balashov 2010: Ch. 8). If the object endures such an explanation is unavailable (or so I argue in *ibid*.), but one can still derive comfort from the notion that a single enduring 3D object can fill its 4D path by exhibiting different 3D shapes – as drastically different as *bent* and *straight* – at its rampantly crisscrossing locations slicing its path at various angles in spacetime. Indeed, according to our understanding of relativistic endurance so far, the object is located at *every* t^F-slice of its path.

But it has been argued that this leads to problems, just around the corner. I discuss these arguments in the next section, where I also draw some morals for the broader understanding of relativistic persistence.

4. Corner Slices and Shrinking Chairs

As they now stand, our accounts of relativistic endurance and perdurance, (9) and (10), embrace a very liberal view of location allowing each enduring object to be located at *every* t^F-slice of its path and each perduring object to have a t^F-part at *every* t^F-slice of its path, as per clauses (ii) and (iii) of the corresponding definitions. In classical spacetime, liberalism of this sort appears unproblematic, especially when combined with a very natural understanding of the notion of path

[15] See, e.g., Sartori 1996: 184–5.
[16] I make no attempt to depict it.

of a persisting object as a *union*[17] of regions at which the object is located (see Gilmore 2006). Suppose objects endure. If we start by saying that an enduring object *o* is wholly present at all absolute moments of time from a certain range Δt and arrive at the notion of its path by taking the union of the instantaneous spacetime regions at which *o* is thus multilocated then it is anything but surprising that *o* is located at every (absolute) time-slice of its path. This is reassuring, even if not particularly enlightening.

Things are importantly different in relativistic spacetime. Suppose *o* endures and is located at each of a continuous family of instantaneous regions forming its path, but at *no* other region (Figure 6). Then each member of this family supplies, quite trivially, a legitimate location of *o*. But this is not true of any "slanted" instantaneous slice of *o*'s path, such as $\mathcal{O}_{\perp}*$. The same holds, mutatis mutandis, of perdurance. Suppose *o* perdures, and each of the continuous family of instantaneous slices of its path hosts *o*'s temporal part. This does not automatically grant the same privilege to the "slanted" slice $\mathcal{O}_{\perp}*$. For all we know, $\mathcal{O}_{\perp}*$ may fail to contain a temporal part of *o*. Imagine Unicolor, a persisting object one of whose essential properties is to be *uniformly colored* (cf. Smart 1987: 63–64). Suppose further that Unicolor uniformly changes its color with time in a certain inertial reference frame F. Consider a t^{F*}-slice of Unicolor's path that is at an angle to hyperplanes of simultaneity in F. Whatever (if anything) is located at such a slice is not uniformly colored and, hence, must be distinct from Unicolor, even though it is filled with the (differently colored) material components of Unicolor.[18]

[17] Or perhaps a *sum*. This depends on whether regions are taken to be set-theoretical or mereological notions. We adopt the first strategy, primarily for convenience, not as a matter of principle.

[18] For another illustration of the same point, see Gilmore 2006: 210–211.

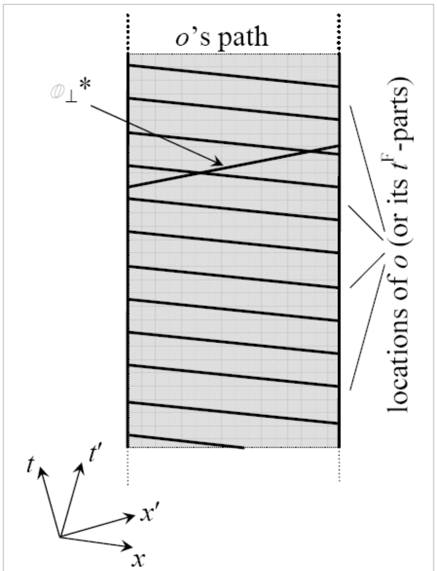


Figure 6. Crisscrossing locations of persisting objects, or their t^{F}-parts, in Minkowski spacetime.

Admittedly, cases such as the Unicolor are metaphysically recherché (what in reality grounds Unicolor's mysterious essential property *being uniformly colored*?) and could probably be set aside. However, according to Cody Gilmore (2006: 212–213) and Thomas Sattig (forthcoming *a* and *b*), the feature of Minkowski spacetime that underlies such cases leads to a more tangible problem. Gilmore argues that this problem eventually undermines the viability of relativistic endurance. Sattig argues that the problem affects relativistic perdurance as well as endurance, albeit for different reasons, and gives additional support to his double-layered ontology of ordinary objects.

The common set-up of both arguments is as follows (see Gilmore 2006: 212–213). A persisting object *o* composed of many particles pops into existence at time t_1 and pops out of existence at t_2, in a frame (x,t). Its path $\varnothing$ is a shaded region in Figure 7.[19] Both t_1- and t_2-slices of $\varnothing$ are good candidates for hosting *o* (if *o* endures) or *o*'s temporal parts (if *o* perdures), and so are all the *t*-slices between t_1 and t_2 in the frame (x,t). But consider a "corner slice" $\varnothing_{\perp t'_{\angle}}$ drawn through a corner of $\varnothing$ at the time $t'_{\angle}$ in the frame (x',t'). Being a temporally unextended slice of $\varnothing$ it must be a location of *o*, or its temporal part, according to clauses (ii) and (iii) of our accounts (9) and (10) of relativistic endurance and

[19] Strictly speaking, *o*'s path is not a continuous hyper-rectangle but a densely packed "multifilament region." We ignore this complication here.

perdurance so far. But this is problematic. The $t'_{\angle}$-slice of *o* is a single point[20] hosting, at most, a single particle of *o*, so can hardly qualify as a suitable location of *o*, or its temporal part. To use Sattig's example, suppose *o* is a chair. According to our ordinary conception of material objects, a chair, in particular, cannot shrink to a point without going out of existence. Ordinary objects cannot undergo radical variation in shape without ceasing to be the kind of objects they are. According to a very intuitive geometrical interpretation of special relativity,[21] however, they do undergo such radical variation, as demonstrated by the corner-slice scenario.

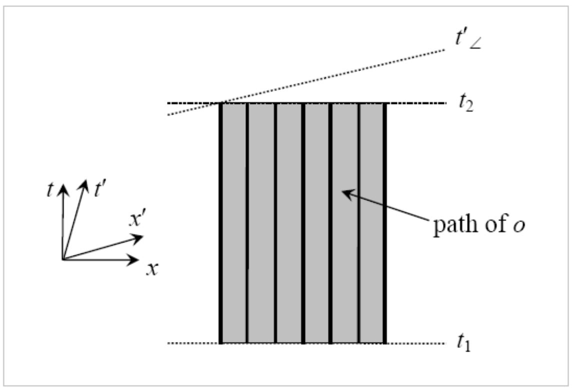


Figure 7. "Corner slice" (Gilmore 2006: 212–213).

Both Gilmore and Sattig agree that scenarios of this sort create a tension between our ordinary conception of persistence and relativity. But they derive different lessons from this. Gilmore argues that corner-slice scenarios cast doubt on the very tenability of the above statement of endurance in Minkowski spacetime, while not negatively affecting perdurance.[22] Sattig, on the other hand, uses the "point-shaped chair" problem to reinforce his case for a "double-layered" ontology of ordinary material objects, with a view of resolving the tension described above.[23] Their disagreement about the proper lessons of the scenarios,

---

[20] Or so we assume; alternatively, it could be a one-dimensional line or a two-dimensional surface, with the same effect.

[21] Amply illustrated in Figure 7 and other figures in this paper.

[22] See Gilmore 2006. Gilmore himself takes the case to demonstrate, first and foremost, the need to allow enduring objects to be located, not just at flat time-slices, but at *arbitrary maximal* spacelike slices of their paths in relativistic spacetime, including curved such slices, a move raising further objections developed in Gibson and Pooley (2006: 186). I argue against admitting curved slices as legitimate locations of persisting objects in Minkowski spacetime on independent grounds in Balashov 2008: §5 and 2010: §5.2.

[23] Sattig's neo-Aristotelian ontology, systematically developed in (forthcoming *a*) and a number of earlier papers, regards ordinary objects as "double-layered compounds of matter and

however, interests me less than their common attitude toward such scenarios. I believe, they both overreact to them. I will show it by looking more critically at the details of two somewhat different versions of the corner slice / shrinking chair case: "abrupt" and "gradual." I will argue below that abrupt scenarios involve violation of conservation laws of physics, whereas the relativistic considerations underlying the arguments in question presuppose their validity. This undermines the consistency of abrupt scenarios. Gradual scenarios are more complicated. They conform with the physical laws but crucially involve *vagueness* of material composition. I believe that a proper account of the vagueness factor takes the sting from the problem of corner slices / shrinking chairs.

The "abrupt" version is essentially as above. One can resist the arguments based on it by simply denying the possibility of abrupt corner slices / shrinking chairs scenarios. More carefully, the careers of the objects represented in them violate the conservation laws of physics (because the careers represent objects as popping into and out of existence), while the whole line of reasoning based thereon and motivating pessimism about the viability of relativistic endurance (in Gilmore's case) or about the prospects of familiar single-layered ontologies (in Sattig's case), assumes the physics of relativity which requires strict validity of conservation laws. The incoherence of this sort makes physically impossible states of affairs, such as that depicted in Figure 7, irrelevant to the discussion in hand, even if they are not impossible *tout court*.

This motivates a transition[24] from the abrupt to a gradual version of the scenario. Suppose that, instead of popping in and out of existence, initially scattered particles come to compose object o at t_1 and stop doing so at t_2, when they "break up" and begin to separate (Figure 8). What do we now say of the $t'_{\angle}$-slice of o's path? It still appears to contain a single point, so the problem recurs, but conservation laws are now respected.

---

form." The centerpiece of his theory is the thesis that the material and the formal "layers" of ordinary objects ground two different perspectives on them, which generate divergent truth conditions of various claims about objects. Both perspectives – the material (or sortal-abstract) and the formal (or sortal-sensitive) – are equally important, and both are found in ordinary discourse. Some of our thinking about ordinary objects tracks their underlying matter (e.g., when we reflect that two distinct objects cannot occupy the same region of space, or spacetime), while other intuitions track sortal-sensitive "careers" of objects, whose various stages may include materially distinct subjects (e.g., when we re-identify a certain cat composed of a particular mass of matter today with a certain cat composed of a numerically different mass of matter tomorrow). Sattig argues – systematically, rigorously, and persuasively – that the availability of these two perspectives holds key to resolving various problems, including the problem of corner slices / point-shaped chairs (if the latter is a problem). For details, see Sattig, forthcoming *a* and forthcoming *b*, Chapter 8.

[24] Suggested by Gilmore in personal correspondence and developed in some detail in Sattig forthcoming *a* and forthcoming *b*, Chapter 8.

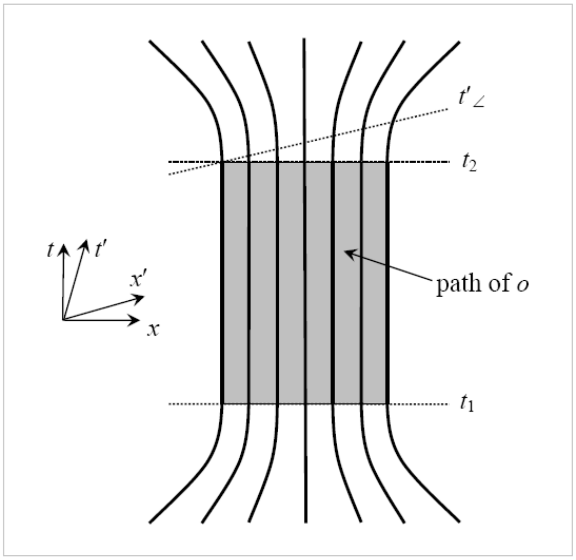


Figure 8. Gradual "corner-slice" scenario.

Let us consider the situation more carefully. The "break up" of *o*'s particles ending its career cannot be instantaneous. It must grounded, perhaps in a complicated way, in the rapidly changing pattern of their causal interaction. In all likelihood, the grounding conditions will be vague, resulting in an extended interval of "fading away," with no sharp temporal boundaries, such as t_2. Hence it is not so clear, after all, that the $t'_{\angle}$-slice of ∅ is ineligible to be one of *o*'s locations (or a location of its temporal part). Any verdict to this effect will depend on the fine details of the relevant theory of spatial composition, the nature of the object in question, and the exact trajectories of its particles. And even when all that is taken into account, the answer will perhaps remain vague. Thus drawing the path of *o* in the form of a clear cut rectangle (as in Figures 7 and 8) is misleading. But it is precisely such clear cut drawing that generates the problem of corner slices / point-shaped chairs in the first place.

What is the real upshot of these considerations? One should recognize that on any view of vagueness, some t^F-slice of ∅ or other will *not* be eligible (perhaps, on some precisification) to serve as *o*'s location (or a location of its temporal part), or at least not determinately so eligible. The notion of *eligibility* must thus be written into an official account of relativistic persistence. But considerations of eligibility, stemming from widespread worries about the vagueness of material composition, cannot be neglected even in the classical setting. They arise, for example, whenever we ask whether a progressively scattering composite object *still exists* at a certain moment of absolute time. If we think that this question does not have a determinate answer then considerations of vagueness must be taken into account in the explication of the notion of the object's *path* even in classical spacetime. Relativity does not add anything new to this step. What appears to be new emerges at the next step: *after* the path of a persisting object in relativistic spacetime has been assembled from its eligible momentary locations indexed to a particular reference frame (which already presumes coming to terms with vagueness), one apparently gains unrestricted freedom to slice the path thus produced at various angles, including those generating "corner slices." The freedom comes from rampant crisscrossing of time hyperplanes in Minkowski spacetime. The question is whether one can exploit it at will, in the way suggested.

I submit that one cannot. "Unbridled crisscrossing" must be rejected in favor of "disciplined crisscrossing," and considerations ruling over the process at this stage are essentially the same as those at play at its first step, that of assembling the path of a persisting object from its eligible momentary locations in a particular reference frame. The same sort of vagueness may inflict both of them, but if so, it must be dealt with in the same way. And the need to deal with it is as urgent in classical spacetime as it is in Minkowski spacetime. To see this, return to Figure 8 and consider the evolution of *o* in (x',t'). From the physical point of view, (x',t') is a legitimate frame of reference, which represents *o* as moving as a whole while progressively shedding particles until the process reaches the corner slice $\mathcal{O}_{\perp t'_{\angle}}$ (Figure 9).[25] How many particles could *o* shed without ceasing to exist? Maybe just a few, or maybe the majority of them. Exactly at what point in (x',t') did *o* go out of existence? More likely than not, before $t'_{\angle}$; but there is hardly more to be said. Perhaps there is no general answer to such questions, and the answer depends, in each case, on the nature of the object under consideration. But when the evolution of *o* is viewed from this perspective it becomes clear that (i) questions of this sort must be settled *before* one attempts to draw the boundaries of *o*'s path, and (ii) *exactly the same* questions would arise if spacetime were classical and time planes in (x',t') represented *absolute* time planes.

[25] For simplicity, Figure 9 does not represent the first episode of the original scenario, when the initially scattered particles come to compose *o* in the first place. But similar considerations apply, mutatis mutandis, to such "coming into existence" episodes as well.

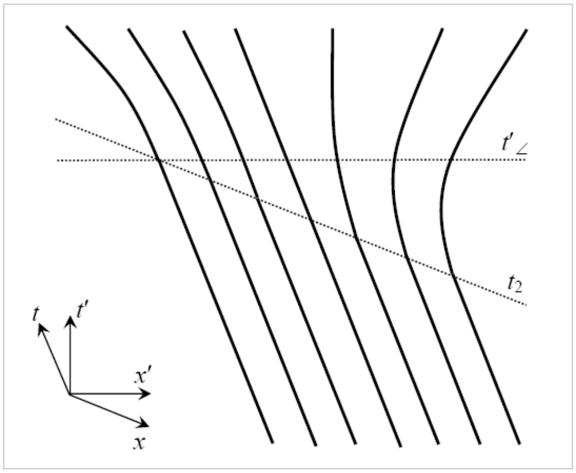


Figure 9. Progressive shedding of particles by a moving object.

The real lesson of the corner-slice / shrinking chair scenarios is, therefore, that questions of *locational eligibility* are metaphysically *prior* to questions about the exact boundaries of *o*'s path in relativistic spacetime.[26] This motivates the following modifications to our earlier accounts of relativistic endurance and perdurance:

(9′) *o endures* in Minkowski spacetime $=_{df}$ (i) *o*'s path is temporally extended, (ii) *o* is located at every *o*-eligible t^F-slice of its path, (iii) *o* is located only at t^F-slices of its path.

(10′) *o perdures* in Minkowski spacetime $=_{df}$ (i) *o*'s path is temporally extended, (ii) *o* is located only at its path, (iii) the object located at any *o*-eligible t^F-slice of *o*'s path is a proper t^F-part of *o* at that slice.

An intuitive picture underlying these accounts is as follows:

Certain particles come together to compose an object *o* at time t_1 in a particular reference frame (x,t) and stop composing it at t_2. By anyone's lights, a complete description of the process requires a well-developed theory of composition addressing, among other things, the issue of vagueness. The very same resources are needed to give an account of a similar process in the classical framework.

[26] Cf. Gibson and Pooley 2006: 186–187, who develop a very similar suggestion.

All the momentary locations of *o* (or the locations of its temporal parts) in frame (x,t) comprise *o*'s *partial path* $\wp(x,t)$. The very same particles that compose *o* (or the *t*-parts of *o*) at all moments $t \in [t_1,t_2]$ in (x,t) *may* or *may not also* compose *o* (or *o*'s t'-part) at a particular "slanted" slice of $\wp(x,t)$ corresponding to a moment of time t' in another frame. Whether or not they do is a question whose answer requires the very same metaphysical resources as the answer to the first question.

Finally, in the spirit of relativity, there is nothing special about the initial choice of the frame (x,t). One could start with assembling a partial path of *o* in (x',t'), $\wp(x',t')$, and *then* raise a question about weather any particular *t*-slice of $\wp(x',t')$ is eligible to host *o* as well.

The *full* path of *o* is then simply the union of all its partial paths in all inertial frames of reference. In some idealized cases it will be clear-cut. In more realistic cases it will have a well-delineated *core* along with a possibly ragged "penumbra." How the core is stitched together with the penumbra is a question that cannot be addressed here. But in light of the above considerations it should be clear that this question too has nothing distinctly relativistic about it.[27]

References

Balashov, Yuri (2008), "Persistence and Multilocation in Spacetime," in D. Dieks (ed.), *The Ontology of Spacetime*, Vol. 2 (Amsterdam: Elsevier), pp. 59–81.

——— (2010), *Persistence and Spacetime* (Oxford: Oxford University Press).

Bittner, Thomas, and Donnelly, Maureen (2004), "The Mereology of Stages and Persistent Entities," in R. Lopez de Mantaras and L. Saitta (eds.), *Proceedings of the European Conference of Artificial Intelligence* (IOS Press), pp. 283–287.

Geroch, Robert (1978), *General Relativity from A to B* (Chicago and London: The University of Chicago Press).

Gibson, Ian, and Pooley, Oliver (2006), "Relativistic Persistence," in J. Hawthorne (ed.), *Philosophical Perspectives*, Vol. 20, *Metaphysics* (Oxford: Blackwell), pp. 157–198.

Gilmore, Cody (2006), "Where in the Relativistic World Are We?" in J. Hawthorne (ed.), *Philosophical Perspectives*, Vol. 20, *Metaphysics* (Oxford: Blackwell), pp. 199–236.

——— (2008), "Persistence and Location in Relativistic Spacetime," *Philosophy Compass* 3/6: 1224–1254.

[27] I am very grateful to Cody Gilmore and Thomas Sattig for their comments on the draft of this paper.

Haslanger, Sally (2003), "Persistence Through Time," in M.J. Loux and D.W. Zimmerman (eds.), *The Oxford Handbook of Metaphysics* (Oxford: Oxford University Press), pp. 315–54.

Hudson, Hud (2001), *A Materialist Metaphysics of the Human Person* (Ithaca: Cornell University Press).

Lewis, David (1988), "Rearrangement of Particles: Reply to Lowe," *Analysis* 48: 65–72.

Parsons, Josh (2000), "Theories of Location," in D.W. Zimmerman (ed.), *Oxford Studies in Metaphysics*, Vol. 3 (Oxford: Oxford University Press), pp. 201–232.

Rea, Michael (1998), "Temporal Parts Unmotivated", *Philosophical Review* 107: 225–260.

Rindler, Wolfgang (1961), "Length Contraction Paradox," *American Journal of Physics* 29: 365–366.

Sartori, Leo (1996), *Understanding Relativity* (Berkeley: University of California Press).

Sattig, Thomas (2006), *The Language and Reality of Time* (Oxford: Clarendon Press).

——— (forthcoming *a*), "Ordinary Objects in the Relativistic World," forthcoming in *Chronos: The Proceedings of the Phil Time Society*.

——— (forthcoming *b*), *The Double Lives of Objects*.

Sider, Theodore (2001), *Four-Dimensionalism: An Ontology of Persistence and Time* (Oxford: Clarendon Press).

Smart, J.J.C. (1987), "‘Space-Time and Individuals," in J.J.C. Smart, *Essays Metaphysical and Moral: Selected Philosophical Papers* (Oxford: Blackwell), pp. 61–77.