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Relativistic Objects

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I offer an argument in defense of four-dimensionalism, the view that objects are temporally, as well as spatially extended. The argument is of the inference-to-the-best-explanation variety and is based on relativistic considerations. It deals with the situation in which one and the same object has different three-dimensional shapes at the same time and proceeds by asking what sort of thing it must be in order to present itself in such different ways in various "perspectives" (associated with moving reference frames) without being different from itself. I argue that the best answer is that the object must be four-dimensional. It will then have differing 3D shapes in different perspectives because such shapes are intrinsic properties of its 3D parts.

Three-dimensionalism (3D) is the view that objects persist through time by "enduring," that is, by being wholly present at all times at which they exist. Four-dimensionalism (4D) is the opposite view that objects persist by "perduring," that is, by being temporally, as well as spatially extended, or by having (spatio-)temporal parts. The issue between the 3D and 4D accounts of persistence has become an intensely-debated topic in contemporary metaphysics.[1]

The theory of special relativity is credited with introducing the four-dimensional world of events. Does special relativity (SR) also require the four-dimensional ontology of *objects*? Despite the obvious importance of this question, it has not received due attention. Relativistic considerations are almost entirely absent from the 3D/4D debate. And where they are present (mostly in footnotes and parenthetical remarks), their import is unclear.[2] This paper attempts to remedy the situation by offering an argument, of the inference-to-the-best-explanation variety, for 4D, based on SR. In §1 I prepare the ground for the argument, which I then present in §2. Along the way, I respond to a possible objection suggested by van Inwagen's recent paper (1990). The ideas of his paper are pre-relativistic, but they can easily (and, I hope, fairly) be extrapolated to the relativistic context. In subsequent sections, I discuss other objections that can be raised against my argument.

1.

Imagine yourself an inhabitant of Flatland, a two-dimensional world populated by beings having only two spatial dimensions and wholly confined to a surface. For simplicity, let this surface be a plane and denote it *F*. Suppose you are presented with a series of objects, one at a time,

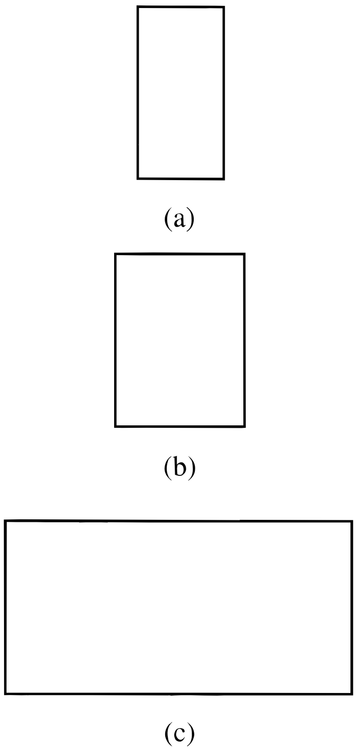
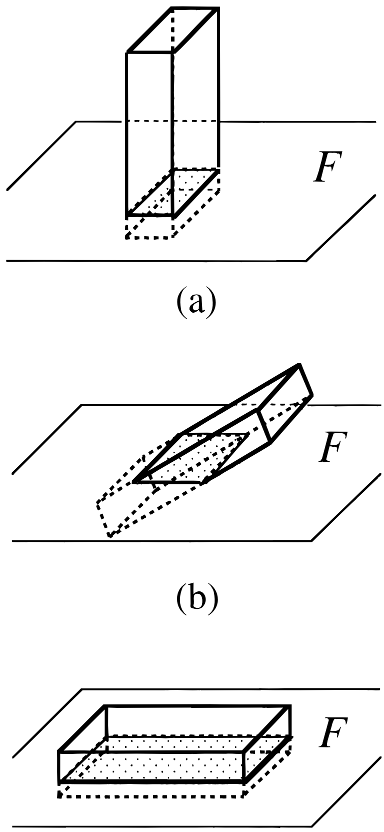


Figure 1.

and are told that these are, in fact, one and the same object. Your first reaction may be to think of a two-dimensional rubber sheet that undergoes extension in the horizontal direction. But you are then advised that no intrinsic change occurs in the object and are asked what sort of thing it could be. You naturally find yourself in a quandary, but only until Flatland's physicists persuade you that Flatland is a part of the three-dimensional world and that (a), (b), and (c) are different two-dimensional parts of the same three-dimensional object, a box (Figure 2).

Now everything falls into place. The box itself does not change. What changes is its relation to Flatland. It is this relation that induces changing shapes of two-

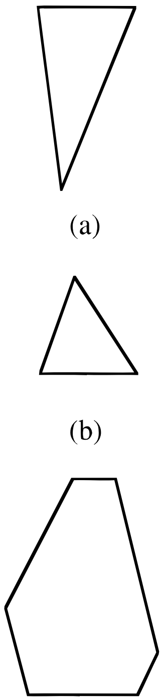


(a) (b) (c)

Figure 2.

dimensional "slices," the latter being objects confined to Flatland and actually perceived by Flatlanders. You can now imagine a more complicated situation where the series of objects induced by the box on Flatland looks like that in Figure 3 (I leave it to the reader to supply the analog of Figure 2 for this situation).

The relation between the spatial properties (i.e., shapes) of the box and of the objects perceived by Flatlanders is a rather intimate, ancestral relation. The 2D shapes are directly "inherited" from the 3D shape, as being constituted by one-dimensional sides fully belonging to two-dimensional edges of the original three-dimensional object. In fact, 2D shapes are none other than 3D shapes restricted to a certain *perspective*. Perspectivalism in question is not a merely subjective feature of the restricted vision of individual Flatlanders. It is an objective feature of the way in which Flatland as a whole is situated in the wider three-dimensional



(c)

Figure 3.

"superspace." The main discovery of the Flatland physicists is the discovery of this objective, ontological perspectivalism to which they have been led by an argument to the best explanation. Here is how it might have gone. The physicists had always suspected that objects experienced in series of the sort depicted in Figures 1 and 3 were related, but no intrinsic change was involved. A hypothesis was then put forward that those objects are, in each case, parts of one and the same invariant thing. What sort of being must it be and how ought it to be situated in order to give rise to diverse shapes, such as those reflected in Figures 1 and 3? It must be a three-dimensional being and it ought to be situated with respect to Flatland as shown in Figure 2 (and the reader's figure).

There is a weak point in this reasoning. It started with the assumption that the object present in Figures 1 and 3 does not undergo intrinsic change, contrary to appearance. This fact was simply stipulated: the Flatlanders were told that they dealt with an unchanging object. But for the inference to the best explanation of the kind just sketched to go through, one needs something more than mere stipulation. Ideally, one would like to have independent evidence. It is hard to see what sort of evidence could do the job in this purely hypothetical situation. Perhaps one could modify the example and have the Flatlanders deal, not with a temporal series of 2D objects, but with a collection of such objects given at the same time and provide some reason to believe that all objects in the collection perfectly resemble (in the relevant respect of form) one another. But again, doubts may arise as to whether such a reason can be provided without begging the whole question. Change in shape is always *prima facie* evidence for intrinsic change and seldom, if ever, reason for adding an extra dimension to the extension of objects. We shall see later that the real, relativistic case is remarkably immune to such worries.

Apart from these concerns, a more serious and philosophically pointed objection to the argument for three-dimensionalism can be raised by Flatland philosophers who consider themselves two-dimensionalists. But they are rather sophisticated two-dimensionalists. They are prepared to admit that real physical space may, after all, have three dimensions but, at the same time, they firmly deny that objects are actually extended in the third dimension. They are also willing to grant that no intrinsic change of shape is involved in the series depicted in Figures 1 and 3, but tell their own story about how this lack of change is consistent with the facts represented in these figures. The story might go in three somewhat different ways.

Relationism. Objects by themselves do *not* have any particular shape. What Flatlanders perceive as two-dimensional shapes are in fact *relations* that shapeless objects bear to different perspectives.

Relationism of this sort is hardly sustainable, and for much the same reasons as those advanced by Lewis (1986, pp. 203–4) in defense of "temporary intrinsics." Shapes are "perspectival intrinsics," not relations to perspectives. If something is a triangle, it is so all on its own, not in virtue of a relation to something else. Furthermore, if things by themselves lack two-dimensional shapes, what is left of *two*-dimensionalism, the ontology espoused by two-dimensionalists?

Indexicalism. Objects do have (two-dimensional) shapes but the latter are *perspective-indexed*. One and the same two-dimensional object may have all the shapes shown in Figures 1 and 3, and many more. In contrast to Relationism, perspectives do not bring properties, such as shapes, into existence but simply *exhibit* already existing perspective-indexed properties.

Adverbialism. Perspectives modify, not the properties, but the *having* of them. An object has a particular two-dimensional shape (e.g., the hexagonal one, as in Figure 3c), but this shape is had *perspectivally*.

Indexicalism and Adverbialism as presented here are generalizations of temporal indexicalism and adverbialism advocated, among others, by van Inwagen (1990, pp. 247, 249–50). He considers two three-dimensional regions (corresponding to times t_1 and t_2) of the four-dimensional space-time occupied by one and the same three-dimensional object—Descartes, in his example—and construes Descartes' properties at t_1 and t_2 in the following way: "When we say that Descartes was hungry at t_1, we are saying either (take your pick) that this object bore the relation *having* to the time-indexed property *hunger-at-*t_1, or else that it bore the time-indexed relation *having-at-*t_1 to hunger" (ibid., p. 247). Descartes, on this view, is a 3D being occupying a certain volume of 4D space-time.

How can a 3D object occupy a 4D volume of space-time? The answer, briefly, is (see van Inwagen 1990, p. 251) that what occupies a given 4D volume is a mereological sum of what occupies all its 3D spatial cross-sections, and what occupies all such cross-sections is one and the same 3D thing. In this way, one can believe in 4D regions of space-time points, but avoid a commitment to 4D objects.

This proposal is easily generalized to n-dimensional perspectives on an $(n+1)$-dimensional space, as in the Flatland story, or on an $(n+1)$-dimensional space-time, as in the relativistic case to be considered later. Think of time, or of an extra dimension of space, as a vector. This vector defines, at each point, an associated perspective: a plane (or rather, a hyperplane) orthogonal to this vector. One can, then, say that the same n-dimensional object occupies a volume of $(n+1)$-dimensional space (or space-time), while denying that there is any sense in which the object itself is an $(n+1)$-dimensional being. The object has uncountably many perspective-indexed n-dimensional shapes (or has an n-dimensional shape in uncountably many perspectival ways). The $(n+1)$-dimensional union of the class of n-dimensionally shaped regions must then be occupied by "the mereological sum of the things that individually occupy the members of [that] class" (van Inwagen 1990, p. 251). But each member of the class is occupied by one and the same n-dimensional object. Consequently, there is a rather innocent sense in which the whole $(n+1)$-dimensional volume is occupied by an n-dimensional thing. But there is no sense in which the thing itself is $(n+1)$-dimensional. It is, on the contrary, an n-dimensional entity having various perspective-indexed shapes (Indexicalism) or, alternatively, having an n-dimensional shape in various perspective-indexed ways (Adverbialism).

Indexicalism and Adverbialism are initially more plausible than Relationism. They stop short of construing shapes (and other properties normally considered to be monadic) as relations. True, they avoid this at the cost of making shapes (or the having of them) secondary to perspective-indexed shapes (or to having them perspectivally). *Being triangular* (or *having triangularity)*, for example, comes after *being triangular-in-p* (or *having triangularity p-ly)*, where p is a perspective. One might complain that this doesn't seem to get things in the right order. Here I would like to set such complaints aside, however, because I believe that there are more substantial reasons to reject Indexicalism and Adverbialism as acceptable alternatives to three-dimensionalism in the Flatland plot (and to four-dimensionalism in the relativistic case). The reasons, again, have to do with inference to the best explanation and a related issue of realism. On the two-dimensionalism theory, there is *no* such thing as the box, in the Flatland scenario. All there is is a multitude of two-dimensional things (some of them depicted in Figures 1 and 3) having different perspective-indexed shapes (or having shape in different perspectival ways). But these shapes are not unrelated. When appropriately arranged in the three-dimensional space (in which, remember, sophisticated Flatland's two-dimensionalists do believe—they only reject three-dimensional objects), all these two-dimensional configurations line up neatly and fill up a compact three-dimensional box-shaped region. Put another way, all perspective-indexed 2D shapes (or the products of all perspectival ways of having shape) are *unified*, as being different 2D cross-sections of the same 3D volume. But how could the two-dimensionalist explain such a harmonious unity among different 2D shapes? On her view, it must be a complete mystery. That 2D shapes are arrangeable box-wise must simply be accepted as a brute fact, because the "box" was constructed "from bottom up," not given at the beginning as something subject to dissecting.[3] Although the whole box may, in a sense, be occupied by one and the same two-dimensional object, the box is not itself an object but only a geometrical construction out of a multitude of perspective-indexed 2D shapes (or of the products of all perspectival ways of having a 2D shape) lined up in a certain way in 3D space.

Consider now a natural way in which the harmonious unity among 2D shapes is explained on the 3D theory. On that theory, the box is a real object and all the different 2D configurations are its parts (themselves further objects—those existing in Flatland). Here one goes "from top down," by starting with the 3D box and slicing it in various ways. One discovers a harmonious unity among the slices just because they belong to the same perspective-invariant three-dimensional object.

I take the above to be a strong "no-miracle" challenge to the Flatland two-dimensionalism. Before turning to quite similar considerations defending four-dimensionalism in the context of the real world, the world of relativistic physics, I'd like to consider another possible objection to the inference to the best explanation presented in this section.[4]

The objector might simply deny that there is any "miracle" involved in the fact that a set of 2D shapes is arrangeable box-wise in the 3D space of the Flatland universe. *Any* arbitrary set of such shapes would be arrangeable one way or the other giving rise to various 3D configurations. Very few resulting configurations would, of course, have nice 3D forms. But it would seem that being "nice" in respect of shape no more requires explanation relevant for the purposes of ontology than being "ugly" does. What makes some 3D shapes "nice" and others "ugly" is human convention and aesthetic judgment, and these cannot by themselves ontologically privilege any particular shape.

But consider an analogy. Suppose you are given a set of jigsaw puzzle pieces arrangeable neatly into a smooth global figure without gaps. It won't do to say that the fact is unremarkable, as any set of jigsaw pieces would be arrangeable, one way or the other, into a global figure having, however, gaps in it. There is something special about non-gappy arrangeability of certain sets that favors them objectively over those that cannot be so arranged. And this fact by itself requires an explanation, the best one being that the pieces have been carved out from a pre-existing figure.

It is not difficult to find an analog of "non-gappiness" in the Flatland scenario. "Nice" 3D forms—those that require special explanation—have this feature in common: they are all *smooth*, that is, not "corrugated" and without "dents." "Ugly" shapes, on the contrary, lack this feature, and this has nothing to do with merely subjective human tastes. One should not expect to be able to assemble a nice 3D shape with these properties out of an arbitrary collection of 2D shapes, except by sheer coincidence. If you are not convinced, try to obtain a nice 3D shape out of the set of six 2D shapes shown in Figures 1 and 3, with the hexagon (Figure 3c) replaced by a heptagon.

Let us finally turn to the real-world, relativistic scenario.

2.

Suppose you are presented with a series of pictures of a single object taken from the same place at the same time

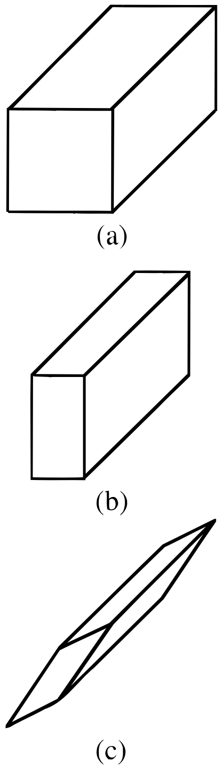


Figure 4.

and are asked what sort of thing it could be. You find yourself in a quandary: the pictures display such a difference in three-dimensional shape and yet the object did not undergo any change. This quandary, unlike the difficulty of your Flatland counterpart, cannot be alleviated by noting that no non-question-begging reason for the absence of change can be given. Such a reason is now obvious: the pictures were taken from the *same place* at the *same time*.

You are then told that the pictures were taken by observers (or automata) zipping at large velocities in front of the object in different directions and are urged to remember the basics of special relativity. The sense of wonder now starts to diminish. You recall that, associated with every moving observer is a reference frame, or “perspective,” that decomposes the single four-dimensional Minkowski space-time into the spatial and temporal elements. In different such perspectives an object presents itself in different shapes (as in Figure 4) related by Lorentz transformations. But what sort of thing must the object be in order to present itself in such different ways in various perspectives without being different from itself? The answer can by now be anticipated: the object must be four-dimensional, it must be extended in time as well as space. It will then have different 3D shapes in different perspectives because such shapes will be intrinsic properties of its 3D parts.[5]

The task of depicting the 4D object (in plane projection) underlying the 3D perspectival representations of Figure 4 defies my stereometric imagination and I leave this task to a more able reader. To illustrate my idea I shall resort to the usual technique of suppressing two spatial dimensions and shall speak, not of 3D shapes of 4D objects, but of 1D “shapes” (i.e., lengths) of a 2D spatio-temporal object. Such an object, shown as the shaded area in the Minkowski diagram (Figure 5), presents itself as a one-meter stick OA in perspective (x, t), a 0.5-meter stick OA′ in perspective (x', t') associated with a reference frame moving at speed approximately 260,000 km/s relative to (x, t), as a 0.25-meter stick OA″ in per-

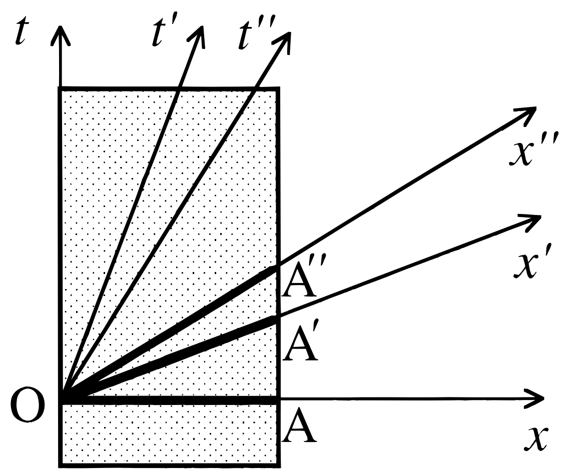


Figure 5.

spective (x'', t'') associated with a reference frame moving at speed approximately 290,000 km/s relative to (x, t), and so on.

OA, OA′ and OA″ are 1D parts of the same relativistically-invariant 2D thing, parts that present their shapes as spatial lengths in perspectives (x, t), (x', t'), and (x'', t'') respectively. Notice that there is a sense in which a spatial length of OA′ "takes up" some of the temporal dimension of the (x, t) perspective and becomes, as a result, shorter than OA,[6] and vice versa. It is worth emphasizing that perspectives associated with various (inertial) reference frames have little to do with the "subjectivity" of (real or potential) observers. 4D objects objectively possess their differing 3D shapes in different perspectives, no matter whether they are actually observed by anybody, or even observable.

Let me summarize the above considerations in the form of an inference to the best explanation. The same object has different 3D shapes. There are strong reasons to believe that the difference is due neither to intrinsic change (shapes are observed at the same time) nor to the variation of a merely spatial perspective (shapes are observed from the same place; furthermore, even if they were not, it is hard to see how a variation of a merely spatial perspective could affect the *three*-dimensional shape of an object). The explanation is that one is dealing with a 4D object presenting its various 3D parts in different *spatio-temporal* perspectives associated with the state of motion of different inertial reference frames.

This argument might be countered by a three-dimensionalist who believes in 4D Minkowski space of events but not in 4D objects.[7] Instead of such an object, she would speak of an invariant 4D volume occupied by one and the same 3D object assuming different perspective-indexed 3D shapes (or assuming a 3D shape in different perspectival ways). This means, once again (see van Inwagen 1990, p. 251), that, rather than containing a 4D object, the 4D volume is but a union of the class of 3D regions, each member of the class being occupied by one and the same 3D thing having, in each case, a certain 3D perspective-indexed shape (or having a 3D shape in a certain perspectival way). What occupies the 4D volume is, then, the mereological sum of what occupies uncountably many 3D regions, and, since every such region is occupied by the same 3D object, there is a sense in which the whole 4D volume is occupied by that object. But there is no sense, in which the object itself is a 4D being.

The response to such proposals will go along the lines sketched in the previous section. The sophisticated three-dimensionalist 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 entity, the three-dimensionalist must regard it as a brute fact, indeed, as a complete mystery.[8]

3.

The argument to the best explanation of the previous section is not immune to objections. Before considering them, a point of clarification is in order.[9] What requires explanation is not the fact that only a "nice" 4D space-time volume is a good candidate for containing a single object rather than a number of different objects. Both 3D and 4D theorists could legitimately refer to this feature (i.e., niceness) in privileging certain 4D volumes for the purposes of ontology (being aware, of course, that far from all nice volumes are occupied by single objects). Rather, what needs explaining is a different state of affairs: that some collections of 3D shapes *can be* arranged in four dimensions into nice volumes, much as some collections of jigsaw pieces can be arranged into gapless figures. The four-dimensionalist can explain such a "dispositional" property of certain collections of 3D shapes by pointing to a further fact that all such shapes are cross sections of preexisting and nice 4D volumes occupied by real 4D objects. The three-dimensionalist, on the other hand, can at best *reconstruct* such volumes "from bottom up," by finding, in each particular case, a neat way of lining up all perspectival 3D shapes in four dimensions. But what has to be explained is precisely the fact that such a way *can be found*. Clearly, the three-dimensionalist cannot discharge her explanatory task just by pointing to this very fact.

But perhaps she could point to some other facts that have not explicitly emerged in our discussion so far. Ted Sider (forthcoming, personal communication) has suggested that this is indeed the case.[10] The endurantist, he argues, could refer to the physical facts about the occupation of space-time points by fundamental particles (or fundamental stuff of some sort) to restore explanatory parity with the perdurantist. She could start by putting her finger on the worldlines of such particles to find out what space-time point is occupied by what particle. She could note, next, that a given 3D object at a given time and a given reference frame is composed of a definite collection of fundamental particles. Finally, she could use this information to assemble together the genidentity lines of the fundamental constituents of a particular 3D object in space-time. Such lines would fill a nice 4D volume, thereby resolving the puzzle.

As far as I can see, there is, generally speaking, nothing wrong with this procedure. The question is whether it could do the explanatory job in the context with which the inference to the best explanation of §2 is concerned. I think not. Every genuine explanation is expected to enhance understanding of a certain state of affairs by invoking *another* state of affairs to account for the former. Typically, understanding of this sort goes along with unification of disparate phenomena by subsuming them under a general fact that is different in kind from the facts involved in the explanandum. No explanatory gain is achieved just by restating or paraphrasing the explanandum. One needs to go beyond it. I believe that attempting to explain the arrangeability of 3D shapes in a nice 4D space-time volume by referring to the facts about the occupation of space-time points by fundamental particles fails to satisfy these desiderata.

To see this, notice that, if there are fundamental particles, then there is a sense in which the facts about the occupation of space-time points by such particles could be deemed to render all other explanations of any macroscopic phenomenon redundant. Since such phenomena supervene on the totality of the microphysical facts,[11] the latter are, in principle, sufficient to "explain" (or explain away) all the puzzles of the physical world. But such “explanations” are very rarely (if at all) regarded as acceptable. Suppose, for example, that every time two chemical substances are put in contact, an explosion results. Clearly, it won’t do to explain this generic phenomenon by following, in each particular case, the trajectories of the fundamental particles composing the substances in the process of explosion. The behavior of these particles is part of what needs explaining, and one normally explains it by invoking a single mechanism (a certain kind of chemical reaction) responsible for the explosive behavior in all instances. As another example, consider the second law of thermodynamics. Various approaches have been proposed to deal with it: Boltzmann’s H-theorem, “coarse graining,” and others. The relative merits of these purported explanations are a matter of ongoing debates. Suppose one wants to override such candidate explanations by pointing to the facts about the occupation of space-time points by the micro-particles (e.g., molecules of a certain gas) and by claiming that the totality of such facts is sufficient to establish that the entropy of any closed macro-system in the universe does not decrease. Obviously, this “ultimate” explanation is not satisfactory. In fact, it explains nothing, because it does not offer an answer to a “why” question posed in a particular framework. What needs be explained is not the fact that the entropy of a particular volume of gas does not decrease, but rather a general fact that the entropy of any closed macro-system behaves in this way. This fact cannot be accounted for by listing all such macro-systems and showing (by registering the actual motion of their macro-constituents) that their entropy does not decrease. One wants to know *why* it doesn’t. Whereas other approaches attempt to attack this question by grounding the universal behavior of entropy in some physical mechanism (e.g., “mixing” in phase space), the “ultimate explanation” states, in effect, that the entropy of a given gas increases (or stays the same) because it does, thereby achieving no explanatory gain.[12]

Same considerations apply, *mutatis mutandis,* to other macrophysical phenomena subject to explanation. As the final example, consider superconductivity. One way to explain it is in terms of the formation of Cooper pairs of electrons at low temperature in the process known as Bose condensation. It won’t do to override this explanation by pointing to the fundamental facts about the actual motion of the electrons in certain media at low temperature. Such motion is precisely what cries out for explanation and, hence, cannot be part of the explanans.

I submit that the case of 3D perspectival shapes is similar. We are invited to account for a general macro-fact about certain collections of 3D shapes, namely that they can be arranged in nice 4D volumes. There is a sense in which an appeal to fundamental particles (enduring or perduring) jointly occupying definite regions of space-time makes all such explanations redundant. But such an appeal is no more enlightening in this particular context than an appeal to micro-particles and their trajectories is in “explaining” explosion or the behavior of entropy in thermodynamics and of electrons in superconductors. In both cases, instead of offering a real explanans for a general fact, the move, in effect, boils down to restating the explanandum.

Thus, the microphysical facts about the occupation of space-time points by enduring or perduring particles are fundamental and important in their own right. But they are irrelevant to the "why" question posed in §2. To illustrate the point from yet another angle, recall the jigsaw puzzle analogy again. Suppose you are given a collection of jigsaw pieces that can be assembled in a neat overall figure. To mimic the "microphysical" approach considered above, one could refer to numerous facts about the details of shape of these pieces and show that, given the full knowledge of all such details, the pieces can indeed be put together neatly. Perhaps one could even invoke relations (the analogs of genidentity relations among space-time points occupied by various 3D configurations in the original situation) between adjacent points across boundaries separating individual pieces. In this way, one would attempt to explain the arrangeability of the pieces into a global figure without gaps. But such an explanation would really amount to stating that the pieces fit together just because they do, as a matter of fact. The opponent of this approach, on the other hand, would say that the pieces have been carved out from a preexisting figure, because such global figures are legitimate units of her "ontology." She would have no need to appeal to the details of particular shapes of the pieces to fulfil her explanatory duty.

In a similar vein, the perdurantist has no need to invoke irrelevant microphysical facts about the occupation of space-time points by the fundamental constituents of material objects. What she is required to explain is not a multitude of singular facts about the arrangeability of certain collections of 3D shapes in neat 4D volumes, but rather a general fact that some such collections all have the relevant "dispositional" property. And this general fact is explained by making an equally general point that such collections are cross sections of "preexisting" units—4D volumes occupied by 4D material objects, the inhabitants of her ontology.

4.

The relativistic case examined in §2 is in an important respect different from the Flatland scenario. In the latter, various 2D perspectives on 3D objects were induced by the changing orientation of the whole Flatland world with respect to a *transcendent* spatial dimension. The temporal dimension of the relativistic world, on the other hand, is *immanent* to it (although the three-dimensionalist would insist that it is not immanent to objects populating this world). Whereas Flatlanders have no control over Flatland's orientation in 3D space and, hence, over the perspective resulting from such orientation: they can only passively record their observations and propose theories, such as 3D versus 2D, to account for them,—the inhabitants of the relativistic world (i.e., ourselves) are, on the contrary, in full control of their respective perspectives, for it is up to them (at least in principle) to bring a certain perspective about by invoking a reference frame moving at a corresponding speed *within* their world.

An advantage of this freedom for the four-dimensionalist was already noted: unlike the Flatland three-dimensionalist, our own four-dimensionalist can exclude the possibility of intrinsic change in the object observed in various perspectives (and thus strengthen her argument) by referring all such perspectives to the same vantage place and time. This freedom to control perspectives, however, gives rise to another objection to the 4D story.

This objection pertains to an earlier stage in the argument. To address it, let us return to the original problem. An object exhibits a variety of 3D shapes but no intrinsic change is involved. The four-dimensionalist explains this by noting that different 3D shapes are properties of 3D parts of one and the same 4D object. It is the objective 4D shape of a perduring whole that stands behind the entire collection of 3D shapes of its parts, each of them being wholly confined to a particular space-time perspective associated with a moving reference frame. The variety of disparate appearances is thus explained by reference to something permanent producing them all.

The three-dimensionalist, however, might object that not all 3D shapes are "mere appearances." Among the 3D shapes brought about by various immanent spatio-temporal perspectives, the objector may note, one particular shape really stands out, namely, the *proper* shape, which the object has in its rest frame. This suggests a different answer to the question posed earlier: What sort of thing must the object be in order to present itself in such different ways in various perspectives without being different from itself? Instead of insisting that the object must be four-dimensional thus having an invariant 4D shape, one could maintain that the object might well be a three-dimensional enduring being having one and the same proper shape that is variously distorted in different perspectives due to Lorentz contraction. The object, in other words, has its *proper* shape in its rest frame of reference and many *distorted* shapes in other frames without, however, being different from itself.

To illustrate the point, consider again the two-dimensional version of the situation (Figure 5). The one-dimensionalist (i.e., the advocate of endurance in that idealized situation) would single out the proper length OA of the meter stick (OA = 1 m) as the *real* one and would say that this length *appears* variously contracted (OA′ = 0.5 m, OA″ = 0.25 m, etc.) in moving frames.

The objection hinges on the distinction between the proper shape of an enduring object, taken to be "real" and "permanent," and "distorted" shapes regarded as mere "appearances." To ensure parity with the perdurantist story, the proper shape must indeed be granted objective status and permanence that distorted shapes lack. This distinction, however, is not borne out by special relativity. One lesson of this theory is that the notion of a *rigid* object is no longer valid. Any shape an object may have, be it "proper" or "distorted," is always restricted to a space-time perspective. It is incorrect to say that an object has, at a given time and in a given moving frame, a certain distorted shape and, *besides*, a real proper shape. An object can only possess one 3D shape, which it has in a given frame.

Furthermore, no frame is objectively distinguished from any other. Hence no shape, including the proper shape, can be singled out for special treatment, to begin with. The reason is that relativistic invariance does not apply separately to spatial and temporal characteristics of objects (and events) in a given frame. It only applies to a specific "mixture" of both characteristics known as the interval.

One might agree that no frame is objectively privileged and yet insist that, *given* a particular object, its proper shape is a well-defined notion. To see that this is not the case, suppose that, at $t' = 0$, the meter stick shown in Figure 5 is suddenly, and only for a moment, given a boost in the positive direction of x that imparts to it velocity 260,000 km/sec. At that moment ($t' = 0$), the stick *changes* its proper length to 0.5 m (OA′). Indeed, proper length and, in general, proper shape is, by definition, the length or shape an object has in its rest frame. Since (x', t') becomes a new rest frame of the meter stick at $t' = 0$, whatever length it has in that frame becomes its new proper length.

This is not to say that the notion of proper length has no physical meaning and useful application, but only that its actual meaning in SR disqualifies it from playing the ontological role assigned to it in the above objection, on the part of the endurantist. Proper 3D shape is not an invariant perspective-independent property that can "stand behind" other perspective-restricted shapes. It is itself restricted to a perspective.

The four-dimensional shape, on the other hand, falls in a completely different category. Not being perspectival at all, it is capable of generating a variety of 3D shapes, in virtue of standing in ancestral relations to them, in a way a proper 3D shape is not, as being just one perspective-restricted property, on a par with others.

5.

Why does four-dimensionalism continue to provoke "incredulous stares"? One reason may be that it is just very hard to get used to the notion of temporal extension. But this notion is strictly separate from that of merely spatial extension only in a classical setting.

Compare again the Flatland story with the relativistic argument for 4D. Many might well be inclined to accept the arguments of the Flatland scenario prompting one to add the third spatial dimension to those already present in that situation. But many would, no doubt, maintain that adding, in ontological seriousness, a temporal dimension to any number of spatial dimensions that material beings may possess is an entirely different matter. Time, one is often reminded, is not like space, and being extended in time is surely different from being extended in space. Consequently, one cannot put time on the same footing with space. In particular, one cannot rely on considerations of space in inquiring about the properties of the temporal dimension of reality.

To be sure, this intuition is pre-relativistic. But it could be refined to accommodate the change in worldview precipitated by SR. Thus one might concede that time and space may, after all, be abstractions from a single spatio-temporal reality, the Minkowski world, and yet insist that they are very *different* abstractions, as reflected, for example, in the *pseudo*-Euclidean metric of Minkowski geometry.[13]

In light of such considerations, one might be prompted to conclude that *being extended in time* is a concept that should not be taken literally. After all, our common idea of extension is grounded in the perception of purely spatial distance relations in the Euclidean framework, and we simply do not have a way of extrapolating this concept to the framework of Minkowski space-time—because we do not have a way of visualizing that framework. What could be more counterintuitive than the fact that the distance between two distinct points in a certain metrical space (namely, between two null-separated events in Minkowski space-time) can be literally zero? If "distances" and, hence, "extensions" behave in this way, they surely cannot be *real* distances and extensions!

Such a reaction, natural though it might appear, would tend to beg the whole question. Science constantly forces us to revise and tame our intuitions. We have already been forced to abandon the idea of absolute simultaneity. But the idea of purely spatial extension is in the same package. If the real arena of fundamental physical processes has an intrinsic structure constituted by the relativistic relations among space-time points—and we know that it is; the sophisticated three-dimensionalist, the principal opponent of my argument, would certainly concede this much—then this arena is a pseudo-Euclidean 4D manifold that simply cannot be objectively decomposed into space and time. There are no merely spatial and merely temporal distances and extensions in the Minkowski world. True, there are space-*like* and time-*like* ones. But none of them is exclusively spatial or temporal in the old sense. These two aspects are now inextricably mixed up: being extended in space in one 3D perspective involves being extended in time in another such perspective. And since no perspective is objectively privileged, the only notion of extension that survives in the Minkowski world is that of spatio-temporal extension. If you know what the spatial dimension of extension is (based on your experience in a particular frame of reference), you must know, virtually "by acquaintance," what its temporal dimension is, because what you experience as purely spatial (in a given frame)—and what you claim to have strong intuitions about—is, in fact, already spatio-temporal, as it incorporates time in all other frames. Abstraction from time or space is always only partial and frame-dependent, and what is frame-dependent lacks objective status. Moreover, a transformation by means of which one goes from a given spatio-temporal perspective to another such perspective is physically on a par with transformations relating one partially spatial perspective to another, in abstraction from time, and one partially temporal perspective to another, in abstraction from space.[14]

The natural way to explain this parity, or mixing-up, of spatial and temporal dimensions of objects is to grant objects both dimensions. An object viewed as a 4D being is relativistically invariant in a sense in which its 3D parts are not. And relativistic invariance has become an important criterion of reality in physics. To paraphrase Minkowski, spatial and temporal aspects of things, when taken in abstraction from one another, "are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality" (Minkowski [1908] 1952, p. 75).[15]

Notes

[1] The literature on the topic is extensive. In this paper, I do not attempt to adjudicate any of the diverse issues already raised in the 3D/4D debate but rather am concerned to add a new issue to its agenda. Consequently, my bibliography is highly selective. For a recent review of the whole landscape, including the distinction between different senses of three- and four-dimensionalism, the definitions of key notions, such as 'temporal part' and 'being wholly present at *t*,' as well as a comprehensive list of references, the reader is advised to consult Sider 1997.

[2] There are some exceptions. Thus, Smart (1987) went beyond the claim that 4D is suggested by the spirit of SR (many others have urged this much) and argued that the letter of SR, in fact, requires 4D. In my (1999), I argue that 4D, but not 3D, has adequate resources to accommodate the concept of coexistence in the framework of special relativity. My argumentative strategy in the present paper has something in common with Smart's. I believe, however, that a strategy of this kind is open to objections that have not, in my knowledge, been properly addressed so far—a defect I seek to overcome here.

[3] Hud Hudson has suggested in conversation that the Flatland two-dimensionalist could invoke a *causal* connection among successive 2D shapes to explain their smooth development in time. This could account for the box-shaped volume "traced out" by a particular 2D object in a series, such as that of Figure 1.

It is doubtful, however, that the relationship among *all* 2D shapes figuring in the Flatland scenario can be construed as a causal relationship. The task of the Flatland two-dimensionalist is to explain why a smooth box-shaped 3D region can be neatly filled up, not just with 2D shapes generated in a *single* series (assumed, for a moment, to be cemented by a causal glue), but with all such shapes, which can be drawn at random from different "causal series." It would appear that there could be no overall, "trans-serial" causal relationship unifying all such shapes.

In any event, the relativistic case considered below does not lend itself to such a causal interpretation for yet another reason. In that case, one deals, not with temporal series of shapes, but with different 3D shapes possessed by an object *at the same time* in different spatio-temporal perspectives generated by moving reference frames. This effect has to do with Lorentz contraction, which, according to SR, is not a causal phenomenon but one grounded in the geometry of special relativistic space-time.

[4] My thanks to Arthur Fine for bringing this objection to my attention.

[5] The reader should be warned that the story here told is oversimplified in one respect that is important in its own right but does not affect the substance of the argument. The visual appearance of rapidly moving objects is, in general, influenced by two different factors, the Lorentz contraction in the direction of motion *and* the fact that seeing or photographing an object requires receiving light signals emitted by its various parts, when they arrive simultaneously at a particular point. Consequently, more distant parts have emitted light earlier than those located closer to the hypothetical observer or camera. As a result, the perceived shape of the object is not only Lorentz-contracted but also distorted. Obviously, this latter effect (very unlike the former one) is not distinctively relativistic, as it is present in the classical situation as well.

Incidentally, standard expositions of SR had virtually overlooked the distortion effect described above until James Terrell first drew attention to it in 1959 (see Weisskopf 1960). He showed that, remarkably, for small objects the distortion almost exactly compensates the Lorentz contraction so that objects appear undistorted but only rotated. This is not so for larger objects.

In any case, here I am concerned not with the subjective *appearance* of objects but with the way they *are* in and of themselves. "Picturing" and "viewing," therefore, must be taken as capturing the effect of the Lorentz contraction only, according to the standard relativistic procedure of coordinate measurements in moving reference frames.

[6] Although it appears longer in Figure 5 due to the fact that the metric of Minkowski space-time is pseudo-Euclidean, having signature $(1, -1, -1, -1)$, whereas plane diagrams, such as Figure 5, naturally invite an Euclidean metric. This, however, ought to be regarded as merely an unfortunate

difficulty associated with the embedding of non-Euclidean relations characteristic of Minkowski space-time in the Euclidean framework of a purely spatial representation.

[7] The belief in the 4D world of events, as here understood, is arguably incompatible with a certain view of time known as "A-theory of time" or "dynamic time." The most radical version of this view is *presentism*, the idea that only the present exists. It has recently been intimated (see Carter and Hestevold 1994, Merricks 1995) that the 3D ontology of objects (i.e., endurantism) entails A-theory of time or even presentism and is inconsistent with the opposite, B-theory of time, or "static time"—the time of modern physics. If this is so, sophisticated endurantism, my principal target in this essay, may be a non-starter.

Although I believe that arguments for the link between endurantism and "dynamic time" are unsound, I do not consider the issue in the present paper. Instead, I assume that there is no link and, hence, the combination of endurantism with realism about 4D Minkowski world of events is a tenable one. My purpose, then, is to argue against endurantism the hard way, or directly, without linking it to presentism and showing that the latter is ruled out by special relativity—a rather straightforward task. See, however, Hinchliff (1996, §7), for a recent defense of presentism in the context of relativity.

[8] Apparently, the endurantist will have no such problems in dealing with the idealized situation in which two dimensions of space are suppressed (Figure 5) and 3D shapes are reduced to 1D lengths: *any* collection of lengths can be arranged in a "nice" (i.e., dentless and corrugation-free) 2D box of infinite time-like extension. This feature, however, is peculiar to the idealization at hand. In the 4D set-up, the three-dimensionalist has to take care of two other spatial dimensions (see Figure 4), and there is where real problems emerge.

[9] I owe this point to a referee for this journal.

[10] A referee for this journal made a similar suggestion.

[11] Here I abstract from the question of whether there are any macro-facts that do not supervene (in one of the senses of 'supervenience' distinguished in the literature) on the microphysical facts.

[12] One should not discount the possibility that none of the physical mechanisms proposed to explain the growth of disorder in the universe eventually succeeds and physicists will have to acknowledge that this process is just a brute cosmological fact, in which case the "ultimate explanation" will not be far from the truth. But clearly, this would amount to acknowledging that no genuine explanation is forthcoming and none is needed. In any event, this hypothetical scenario does not detract from the point I seek to make here.

[13] And, as a consequence, in the fact that time and space contribute different signs to the expression of the relativistically-invariant interval: $I = (c\Delta t)^2 - \Delta x^2 - \Delta y^2 - \Delta z^2$.

[14] This is reflected in the fact that all coordinate transformations preserving relativistic invariance form a group that includes, completely on a par, merely spatial translations and rotations, merely temporal translations, and spatio-temporal "rotations." The latter are none other than the famous Lorentz transformations relating, in SR, frames in different states of motion and responsible for such relativistic effects as time dilation and length contraction.

[15] By far, my greatest debt is to Peter van Inwagen, Ted Sider, and an anonymous referee, who all have provided valuable comments on earlier drafts. A shorter version of this paper was read at the 1998 Central Division Meetings of the American Philosophical Association. I am grateful to my commentator, Robert Rynasiewicz, and to Arthur Fine, Hud Hudson, and others present at the session for pressing me on many important points. Thanks are due to Peter Bokulich, Jim Cushing, and Dean Zimmerman for stimulating discussions.

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