Relativity and the Dimensionality of the World

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Abstract

The paper pursues two aims. First, to show that the only way for presentism or three-dimensionalism to avoid a direct contradiction with relativity is to regard the existence of the physical world as ontologically relativized. This is done by considering the dimensionality of objects involved in relativity of simultaneity, length contraction, and time dilation. Second, to present arguments based on an analysis of the twin paradox which appear to exclude any possibility of a three-dimensional world and therefore any need to relativize existence.

1 Introduction

One of the most difficult problems that science has posed not only to philosophers but to any representatives of humankind, who want to have their world view in accordance with modern science, came from special relativity. The main question is whether the world is three-dimensional (3D) or four-dimensional (4D). It arises from the issue of the ontological status of Minkowski spacetime which leads to a clear dilemma: Minkowski spacetime should be regarded either as nothing more than a mathematical space which represents an evolving in time 3D world (the present) or as a mathematical model of a timelessly existing 4D world with time entirely given as the forth dimension.

The implications of a 4D world for a number of fundamental issues such as temporal becoming, flow of time, determinism, and free will are profound - in such a world (often called block universe) the whole histories in time of all physical objects are given as completed 4D entities since all moments of time are not "getting actualized" one by one to become the moment "now", but form the forth dimension of the world and therefore all are given at once. And if temporal becoming and flow of time are understood in the traditional way - as involving 3D objects and a 3D world that endure through time - there is no becoming, no flow of time, and no free will in a 4D world. It is these implications of relativity that have posed perhaps the greatest intellectual challenge humankind has ever faced.

With the stakes at the highest level the reaction of physicists and philosophers to that challenge is quite different. The most frequent answer to the question "What is the dimensionality of the world according to relativity?" given by physicists and especially relativists is "Of course, the world is 4D". But when asked about the implications of such a 4D world (not a 4D mathematical space), they start to realize that relativity poses serious interpretive problems. Philosophers of science do better perhaps because one of their raisons d'être is precisely the interpretation of scientific theories. Unfortunately, a pattern can be easily detected - some philosophers of science who write on issues related to the ontology of spacetime regard the block universe view as undoubtedly wrong and believe that some kind of objective becoming and time flow must exist. The assumption that the world cannot be 4D is sometimes considered so self-evident that any attempts to question it are virtually reprimanded. In 1991 H. Stein (1991) criticized the Rietdijk-Putnam-Maxwell argument (Rietdijk 1966; Putnam 1967; Maxwell 1985) designed to demonstrate that special relativity implies that reality is a 4D world. Stein argued that their use of the concept "distant present events" is a fallacy: "The fact that such a fallacy (again, if I am right) not only persists among some writers, but is allowed by referees to find continued publication, is a phenomenon that itself calls for reflection" (Stein 1991, 152). Leaving aside the question of whether Stein is justified in making such a remark, it will be discussed in

Section 2 whether he is right to object to the use of "distant present events" in the framework of special relativity.

Four relativistic effects will be analyzed in this paper - relativity of simultaneity, length contraction, time dilation, and the twin paradox - in order to see whether the belief in objective becoming and flow of time is supported by relativity. In Section 2 I will show that one can preserve the presentist view and still talk about a 3D/4D dilemma in the framework of relativity only (i) if the pre-relativistic division of events into past, present, and future is used, and (ii) if existence is regarded as ontologically relativized. In Section 3 I will argue that the theory of relativity itself allows us to resolve the 3D/4D dilemma by presenting an analysis of the twin paradox which reveals that this effect would be impossible if the twins existed as 3D objects evolving (enduring) in time.

2 Relativity and dimensionality of the world

An attempt to avoid the challenges posed by the interpretation of Minkowski spacetime is to question the very existence of a 3D/4D dilemma. This was implicitly done by Stein (1968, 1991) in his criticism of the Rietdijk-Putnam-Maxwell argument which makes use of that dilemma. He argued that Rietdijk, Putnam, and Maxwell were wrong since they incorrectly used the concept of distant present events which is based on the pre-relativistic division of events into past, present, and future: "in the theory of relativity the only reasonable notion of 'present to a space-time point' is that of the mere identity relation: present to a given point is that point alone - literally 'here-now'" (Stein 1991, 159). It has not been pointed out so far that Stein's criticism of the concept of distant present events in relativity is directed rather against presentism and the three-dimensionality of the world, not against the Rietdijk-Putnam-Maxwell argument. This becomes evident when one takes into account the fact that the only way to define the present (the 3D world existing at the moment "now") is in terms of the pre-relativistic division of events. What Rietdijk and Putnam showed was that the common view on the world (presentism) is incorrect when relativity of simultaneity is taken into account and therefore reality should be regarded as a 4D world. Stein did exactly the same thing with respect to the first half of their argument - he argued that one could not talk about distant present events in relativity which meant that the pre-relativistic division of events into past, present, and future could not be used and therefore an observer could not define his present (or a 3D world) in the framework of relativity. It appears completely unrealistic to assume that Stein would advocate a view according to which one can regard a singe event - the event "here-now" - as the only real one since such a view clearly amounts to event solipsism.

The fact that presentism is based on the pre-relativistic division of events does not yet constitute a clear contradiction with relativity for two reasons. First, presentists can argue that relativistic causality (reflecting the existence of an upper limit of the velocity of physical interactions) does not appear to exclude the possibility that reality can be a 3D world. They would say that the ordinary 3D world is indeed based on the pre-relativistic division of events into past, present, and future, but this does not mean that the 3D objects existing at the present moment of an observer can interact at that moment. And, obviously, the very existence of objects does not depend on whether or not they interact (at the moment they exist). Presentists could point out that every object lies outside of the light cones of the other objects of the 3D world of a given observer. Such a model, in a different context, was discussed by Dieks (1988). Second, as we will see below, relativity of simultaneity, length contraction, and time dilation all imply the pre-relativistic division of events when the issue of the existence of the objects involved in these effects is explicitly raised.

In a recent paper McCall and Lowe (2003) explicitly questioned the 3D/4D dilemma. Their main argument is based on the fact that "the 3D and the 4D descriptions of the world are equivalent" and therefore "it is not a question of one being true and the other false" (McCall, Lowe 2003, 114). They argue that the equivalence of the 3D and 4D descriptions of the world is an indication that the debate over the 3D/4D ontologies does not reflect a real problem. Although the equivalence of the two descriptions is not questionable, an equivalence of the 3D and 4D ontologies is. The dimensionality of a physical entity is considered to be one of the basic "attributes" that determine its very nature. It is like existence - as an entity cannot be both existent and non-existent it cannot be both 3D and 4D. As the accepted view is that dimensionality is an intrinsic feature of the world, it follows that the world is either 3D or 4D and any claim that there is no 3D/4D issue should obviously explain why the accepted view of dimensionality is wrong.

Any attempt to avoid the challenges from the interpretation of Minkowski spacetime by defending the traditional view of presentism or three-dimensionalism is doomed to failure since this view leads to an immediate contradiction with relativity. Presentism is a pre-relativistic view of reality since it is based on absolute simultaneity - the present (the ordinary 3D world) is defined as everything that exists simultaneously at the moment "now". As presentism is defined in terms of simultaneity the relativity of simultaneity has an immediate impact on this view: having different sets of simultaneous events two observers in relative motion have different presents and therefore different 3D worlds. This demonstrates that the traditional presentism contradicts relativity of simultaneity: if it were only ***the*** present that existed then all observers in relative motion would have a common present and therefore a common set of simultaneous events; hence relativity of simultaneity is impossible. However, to say that "anyone who takes relativity seriously cannot take presentism seriously" (Balashov 2002, 225; Callender 2000; Saunders 2002; Savitt 2000; Sider 2001, §1.4) is a little bit too quick although ultimately right as I will argue later. Traditional presentism directly contradicts relativity if the existence of the world and the physical objects is considered ***absolute*** (observer- or frame-independent). With this in mind there appear to be only two possible ways to avoid the contradiction with the relativity of simultaneity:

- Preserving the absoluteness of existence but giving up the three-dimensionality of the world. In this case the world, whose existence is absolute, is 4D and is represented by Minkowski spacetime. Two observers in relative motion, using the ordinary 3D language, will regard two different 3D "slices" of the absolutely existing spacetime as their presents.
- Preserving the three-dimensionality of the world but giving up the absoluteness of existence. In this case the world is 3D whose existence is relativized – observer- or frame-dependent. Two observers in relative motion will have different 3D worlds (presents) but each of them will claim that only his own 3D world exists.

It should be specifically stressed that a relativized existence of an object does not mean that two observers in relative motion describe the existence of the ***same*** 3D object ***relative*** to their own frames of reference; it means, as we will see later, that the observers have ***different 3D objects*** and for this reason the object's existence is ***ontologically*** relativized.

Let me explain this in more detail. For this purpose and for the analysis of the relativistic effects later on it will be essential to explicitly address the question: What is the dimensionality[1] of the world at the macroscopic level? (or "What is the ***dimensionality*** of the world according to relativity?").

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[1] The explicit addressing of this question may serve as a filter for choosing different theories of time advanced by metaphysicians. I would mention three such theories. The first two are the stage theory (Sider 2000, 2001; Hawley 2002) and the worm theory (Heller 1990). Although Balashov (2002) showed that special relativistic arguments favour the worm theory over the stage theory, an analysis similar to the one in this paper would provide decisive arguments for the worm theory. The third theory has been proposed by Q. Smith. He argues in favour of a theory of "degree presentism", which "holds that what exists in the maximal or perfect degree of existence is only what is present" (Smith 2002, 122). If it is asked "What is the dimensionality of 'what is present'?" two immediate problems become evident. First, as 'what is present' is 3D by definition (as seen in Figure 1), degrees of existence imply degrees of dimensionality. I doubt whether there would be any support from mathematicians or physicists for the idea that an object is 3D to a maximal degree (while being present) and less and less 4D as we consider the distant past and future of that object. Second, relativity of simultaneity inevitably relativizes the 'perfect degree of existence" and one may wonder how a 'perfect existence' can be ontologically relativized.

An immediate result from addressing the question of dimensionality of the world and the physical objects is the realization that on the presentist view the past and the future do not exist in any sense. Since on this view "exist" and "exist now" are equivalent the only reality is the present - the 3D world consisting of all 3D objects and fields that exist *simultaneously* at the moment "now". The past is the set of the previous *states* of the 3D world, whereas the future is the set of the 3D world's forthcoming *states*. It is for this reason that the past and the future do not exist on the presentist view - they are merely *states* of the 3D world which exists solely at the present moment. If the world existed at the other moments too, it would not be a 3D, but a 4D world.

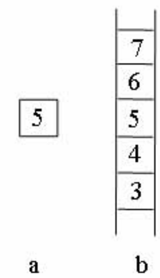

Figure 1

This can be demonstrated by considering how three-dimensionalists (presentists) and four-dimensionalists think of a physical object. Figure 1a depicts a digital clock existing at its present moment indicated by the 5th second on its screen (i.e. the clock exists at the 5th second of its proper time; the proper time of an object is measured by a clock located at the point where the object is). The presentists contend that the clock exists neither in its past nor in its future. It retains its identity *as a 3D object* - at all moments of its history it is the *same* 3D clock. Four-dimensionalists believe that what is real is the worldline of the clock (instead of "worldtube" of an object I will be using "worldline" in this paper) - a 4D object representing the clock at all moments of its history (Figure 1b). At every different moment the clock is a *different* 3D object (different "slice" of the clock's worldline) which means that it does not preserve its identity as a 3D object. However, what makes the clock the same clock is the fact that it retains its identity *as a 4D object* - it is a continuous 4D object which is not objectively divided into 3D "slices" (or 3D cross-sections); we talk of 3D "slices" in the framework of relativity only when we use our everyday 3D language which reflects the fact that we perceive 3D images of the physical objects. Figure 1 demonstrates why a 3D object can exist only at one moment (at the present moment of its proper time); if an object exists at more than one moment, then that object is 4D - like the worldline of the clock in Figure 1b (Figure 1 is not very rigorous in one respect - the screens of the clocks are extended in the forth dimension; 3D clocks should be represented by horizontal lines only). Figure 1a and Figure 1b represent the three-dimensionalist and four-dimensionalist views on what a clock is. The essential question is whether it can be shown that one of these alternative views contradicts relativity.

Now we are in a position to see why presentism can be reconciled with relativity only if the existence of the world and the physical objects is ontologically relativized. Consider two observers A and B in relative motion whose worldlines are depicted in Figure 2. Two clocks C_1 and C_2 at rest in observer A's frame of reference are also represented by their worldlines. Using Figure 2 we will try to determine whether the theory of relativity (more specifically, relativity of simultaneity) can help us determine which view - the three-dimensionalist (Figure 1a) or the four-dimensionalist (Figure 1b) - is the correct one.

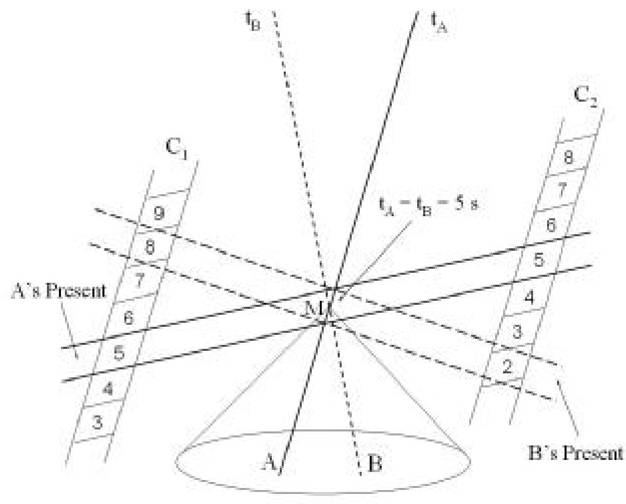

Figure 2

At the moment the observers meet at event M they set their own clocks (located where the observers are) at the 5th second of their proper times: $t_A = t_B = 5$s. According to special relativity A and B have different sets of simultaneous events. Now let us see what the meaning of the relativity of simultaneity is by explicitly asking the questions of the existence and dimensionality of the two clocks. On the presentist view (recognizing only the existence of 3D objects) each clock exists only at the moment "now" of its proper time as shown in Figure 1a. According to observer A both clocks exist at the 5th second of the coordinate time measured in A's reference frame. As in an ***inertial*** reference frame the coordinate (global) time coincides with the proper times of all objects at rest in that frame, it follows that A comes to the conclusion that C_1 and C_2 both exist at the 5th second of their proper times. In fact, for presentists all objects existing in A's present (no matter whether they are at rest in A's frame or in motion relative to A) must exist at the present moments of their proper times since an object exists only at the moment "now" of its proper time. This means that the present moments of the proper times of all objects existing in A's present must be simultaneous for A.

What is simultaneous for A, however, is not simultaneous for B. As seen in Figure 2 what is simultaneous for B at the 5th second of B's time (when B meets A at M) is clock C_1 existing at the 8th second of its proper time and clock C_2 existing at the 2nd second of its proper time. Therefore, for B the moment "now" of the proper time of C_1 is the 8th second of its proper time, whereas the present moment of C_2 is the 2nd second of its proper time. So, when A and B meet at M they will disagree on which is the present moment of each of the clocks and on what exists for them at the moment of meeting (at the 5th second of A's time and the 5th second of B's time): for A each of the two clocks exists at the 5th second of its proper time (at its "now"), whereas for B clock C_1 exists at the 8th second of its proper time (at its "now") and clock C_2 exists at the 2nd second of its proper time (at its "now"). Therefore relativity of simultaneity is possible in the framework of the presentist view if different pairs of clocks exist for A and B at M (and at any other moment of A's and B's times while the two observers are in relative motion). At event M one pair of clocks exists simultaneously with M according to A and another pair exists simultaneously with M according to B. This is only possible if each of the two clocks exists as a ***different 3D object*** at every ***different*** moment of its proper time. For instance, when A and B meet at M, C_1 exists as ***different*** 3D objects for A and B - one existing at the 5th second of the proper time of C_1 and belonging to A's present, the other - existing at the 8th second of the proper time of C_1 and belonging to B's present (this conclusion holds at every moment of A's and B's times while they are in relative motion).

The immediate consequence of the relativity of simultaneity (as depicted in Figure 2) that a given object exists as a different 3D object at every different moment of its history seems to contradict the presentist view according to which a physical body retains its identity as a 3D object through time (as shown in Figure 1a). However, to see the contradiction between presentism and relativity we need to clarify what we mean by saying "an object exists for an observer". In other words, we must explicitly state whether the existence of the object is ***absolute*** (observer- or frame-independent) or ***relative*** (observer- or frame-dependent).

If existence is regarded as absolute, it is clear from the discussion of relativity of simultaneity why the traditional presentism (assuming that an object exists only at its present moment) directly contradicts relativity - if the clocks existed at the 5th seconds of their proper times all observers in relative motion should acknowledge this fact and therefore the same pair of 3D clocks (the clocks existing at their 5th seconds) would exist simultaneously for A and B at M. Obviously this would mean that simultaneity would be absolute.

If presentists regard the clocks' existence as absolute but in view of relativity of simultaneity agree that at M different pairs of 3D clocks exist for A and B, they will inevitably arrive at the four-dimensionalist view: each of the clocks C_1 and C_2 will exist at two moments of its proper time which is only possible if the clocks are 4D objects as depicted in Figure 2b.

The only way for presentism to avoid the contradiction with relativity is to regard the existence of the 3D clocks as relativized. In the relativized version of presentism the observers disagree on what exists - for observer A clock C_1 does not exist at its 8th second since it lies in A's future; C_2 does not exist at its 2nd second either because it already existed at that moment three seconds before the meeting and therefore is in A's past. Observer B denies the existence of C_1 and C_2 in their 5th second since C_1 at its 5th second is in B's past, whereas C_2 existing at the 5th second of its proper time is in B's future. All this means that every observer recognizes only the existence of the pair of 3D clocks which belongs to his present but denies the existence of the pair of 3D clocks which is part of the other observer's present.

In my view, the concept of existence employed by a relativized version of presentism is so twisted that Nature is unlikely to be impressed by this pushing of the human imagination to such an extreme that allows observer A to claim that C_1 at its 8th second does not exist for him but exists for B. However, even the relativized version of presentism cannot deny the consequence of relativity of simultaneity that different pairs of clocks exist for A and B which means that every clock exists as a *different* 3D object at the *different* moments of its proper time. At the *same* event M observers A and B claim that clock C_1 exists *as two different 3D objects* for them: C_1 existing at its 5th second is simultaneous with M according to A (and therefore exists for A at $t_A = 5$ s), whereas C_1 existing at its 8th second is simultaneous with M according to B (and therefore exists for B at $t_B = 5$ s). Observer A acknowledges the existence of the clock C_1 at its 5th second when he meets B at M, but *knows* (due to relativity of simultaneity) that C_1 exists at its 8th second as a different 3D object for B at the moment of the meeting. B is in the same situation - he acknowledges the existence of the clock C_1 at its 8th second but *knows* that C_1 exists at its 5th second as a different 3D object for A. This shows why the price presentism should pay to avoid a contradiction with relativity is an ontological relativization of existence.

The consequence of relativity of simultaneity that a given object exists as a *different 3D object* at every moment of its history is fully consistent with the definition of an event in relativity: *an object (or a field point, or a point in space) at a given moment of its proper time*. In relativity we cannot talk about *different events that happen with the same 3D object* - such a statement would be a contradiction in terms. To see this better, consider again clock C_1. Two different events associated with C_1 are simultaneous with M according to A and B - the event "C_1 existing at its 5th second" is simultaneous with M according to A, whereas the event "C_1 existing at its 8th second" is simultaneous with M according to B. However, these two different events are two *different* 3D objects - the clock C_1 at its 5th and at its 8th seconds; if C_1 did not exist as two different 3D objects at its 5th and 8th seconds no relativity of simultaneity would be possible no matter whether existence is considered absolute or relative (if existence is absolute, C_1 exists either at its 5th or 8th second for *both* A and B; if existence is relative, C_1 exists at its 5th second for A, but A knows that C_1 exists at its 8th second as a different 3D object for B at the moment of the meeting $t_B = 5$ s).

The proper understanding of what an event is in relativity is crucial since one might be tempted to think that the *same 3D object* exists for two observers in relative motion (which appears more than obvious according to our everyday experience!) but different events of that object belong to the different presents of the observers. The impossibility for one pair of 3D clocks to exist for both observers A and B but the readings of those clocks to be different for the observers is evident from the fact that what is simultaneous for the observers is not what they *see* at their present moments, but what exists simultaneously at their moments "now". At M both observers will see precisely the same thing - the past light cone at event M (Figure 2). For this reason the fact that two observers in relative motion have different sets of simultaneous events does mean that the observers have different sets of 3D objects that exist simultaneously at the observers' present moments in full agreement with the definition of an event.

Four-dimensionalists have no problem explaining the relativity of simultaneity. They regard the worldlines of the clocks as real 4D objects which explains why different pairs of 3D clocks exist for the observers A and B at M. In terms of our everyday 3D language, the observers' presents "cut off" different pairs of 3D "slices" from the clocks' worldlines. However, the worldlines of the clocks are not objectively divided into 3D "slices" which shows that, on the four-dimensionalist view, the concept of a 3D clock is just a description and does not have any objective meaning.

The analysis of relativity of simultaneity supports the four-dimensionalist view but does not provide a decisive argument against the relativized version of presentism. We have seen, however, that relativity of simultaneity forces presentists to admit that a physical object must exist as different 3D objects at the different moments of its proper time, which means that the presentist view of a physical object (depicted in Figure 1a) must be relativized to avoid a direct contradiction with relativity.

It should be noted that when the existence of the clocks involved in relativity of simultaneity as shown in Figure 2 is considered, it becomes clear that this effect is formulated in terms of the *pre-relativistic* division of events which is applied to each of the observers. And indeed if at event M the observers A and B in Figure 2 ask at what moment of its proper time each of the clocks exists, the only answer that is consistent with relativity is dictated by the relativity of simultaneity: for observer A both clocks exist at the 5th second of their proper times; for observer B clock C_1 exists at the 8th second of its proper time, whereas clock C_2 exists at the 2nd second of its proper time. Observer A would not say that C_1 and C_2 exist (for A) at the 8th and 2nd seconds of their proper times, respectively, since these two events are not simultaneous with the event of the meeting M. Therefore, when the existence of C_1 and C_2 is considered, relativity of simultaneity makes sense only if each of the observers applies the pre-relativistic division of events into past, present (existing), and future. That is why the presentness (existence) of the remote clocks for the observers A and B is crucial for them if relativity of simultaneity is to have any meaning - if A and B insisted, when they met at the event M, that only M (the event here-now) were present and therefore real for them, they would not be able to say anything about the existence of the remote clocks C_1 and C_2 and would not be able to make any statement about what existed simultaneously for them at M. This shows that Stein was not right when he wrote: "the fact that there is no experience of the presentness of remote events was one of Einstein's basic starting points" (Stein, 1968, 16; 1991, 155); strictly speaking Stein is right since the concept of present events is indeed incompatible with the concept of spacetime, but that incompatibility implies four-dimensionalism.

The employment of pre-relativistic division of events by each of two observers in relative motion when they determine what is simultaneous for them is not surprising since in its original 1905 formulation special relativity was implicitly based on the existing world view that it is only the present that exists. In Minkowski's formulation of special relativity, relativity of simultaneity makes sense only when two observers in relative motion describe the indivisible spacetime in terms of our everyday 3D language which is based on the presentist view.

Two other relativistic effects - length contraction and time dilation - originate from the relativity of simultaneity, i.e. from the fact that having different sets of simultaneous events the observers in relative motion have different 3D spaces (different presents according to the presentist view). As relativity of simultaneity is behind these effects their analysis also demonstrates that presentism can avoid an immediate contradiction with relativity only if the existence of the physical objects is ontologically relativized. Consider again two observers A and B in relative motion (Figure 3). A meter ruler of proper length L_A is at rest with respect to observer A and its worldline is represented by the strip in Figure 3. Special relativity predicts that if observer B measures the length of the meter ruler he will find a shorter length $L_B < L_A$.

Any attempt to explain this contraction of the ruler in terms of a real deformation involving forces between the atoms of the contracted body faces insurmountable problems - if an object is deformed it is objectively deformed (for everyone) and not only for some specific observers. In the relativistic length contraction, however, it is clear that by definition the ruler is not deformed for the A observer; it is contracted only for the B observer. Also, this effect is relative or reciprocal - if B has the same type of ruler then A will find that B's ruler is shortened. But the most serious problem the force explanation of the length contraction encounters is when the following question must be answered: "Are forces causing the contraction of space as well (where there are no atoms)?". In special relativity everything that is in relative motion contacts, including space. For instance, the muon experiment cannot be explained if it is assumed that space does not contract relativistically.

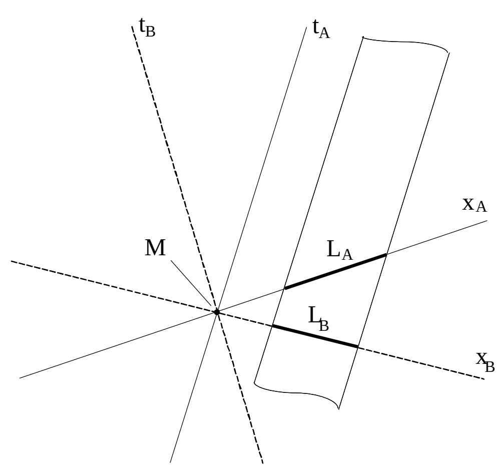

Figure 3

The real explanation of the length contraction effect is that the 3D spaces of A and B intersect the ruler's worldstrip (worldline) at different angles (Minkowski 1908; Hartle 2003, 70) - A's 3D space "cuts" the ruler's worldstrip in the 3D cross section L_A, whereas B's 3D space intersects the ruler's worldstrip in the cross section L_B and due to the different angle of the two cross sections $L_B < L_A$.

Many regard the spacetime diagram in Figure 3 as nothing more than a mere graphical representation that should not be taken too seriously. Let us see whether this is really the case. The first thing that is immediately evident is that this effect makes sense only if what every observer measures is a 3D object - the meter ruler is by definition a 3D object of proper length L_A. As seen in Figure 1a, a 3D object exists only at its moment "now"; an object that exists at once at more moments of its history is a 4D object as shown in Figure 1b. If the 3D object is extended like the meter ruler, then all its parts must exist simultaneously at the moment "now" of an observer. Therefore, *an extended 3D object is defined by an observer in terms of the pre-relativistic division of events* - all parts of the ruler exist simultaneously at the present moment of the observer which means that they constitute a set of present events (the ruler existing at the observer's moment "now"). As the observers A and B have different sets of simultaneous events it follows that they have different 3D objects as their ruler, which is by definition one object. This paradox disappears if what is depicted in Figure 3 represents the true situation - that the ruler is indeed one object which, however, is 4D represented by the ruler's worldstrip and the 3D spaces of A and B "cut" it in two different 3D cross-sections.

If presentists regard existence as absolute they cannot explain this relativistic effect: if we assume that the ruler exists as a single 3D object as the presentist view holds (and as our everyday experience suggests) then this 3D object will be common to both A and B and no contraction is possible. The only option for the presentist view is to regard the existence of the 3D ruler as ontologically relativized - one 3D ruler exists for A and another for B but A and B recognize only the existence of their own 3D ruler.

Presentism can avoid an immediate contradiction with the time dilation effect and the experimental evidence supporting it also by assuming that the existence of the clocks involved in this effect is ontologically relativized. Consider two clocks A and B in relative motion whose worldlines are depicted in Figure 4. The time axes of the two inertial reference frames S_A and S_B in which the clocks are at rest coincide with the worldlines of the clocks. Two instantaneous 3D spaces corresponding to two moments of the time of each frame are depicted in Figure 4; the 3D spaces are represented only by their *x* axes in the figure. The worldline and the instantaneous 3D spaces of clock B are given with dashed lines.

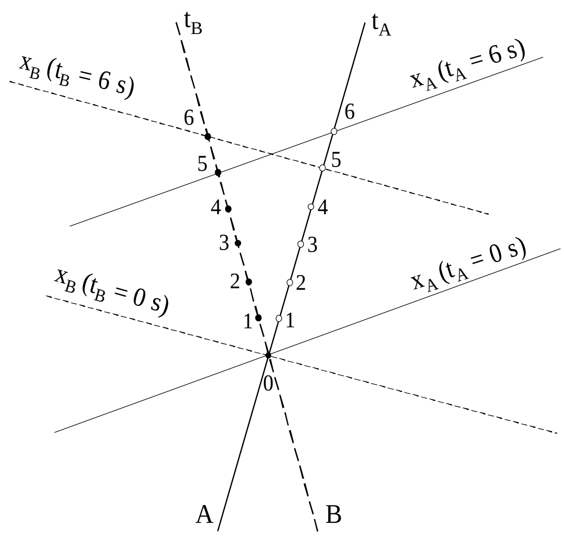

Figure 4

Let the clocks measure two identical processes that are taking place in the frames S_A and S_B. Every process lasts 5 s as measured in its rest frame. At the moment the clocks meet, two observers at rest in S_A and S_B set them to zero and turn on the processes. Let us now see what the duration of the two processes will be as determined by the A- and B-observers.

As the A and B clocks measure the proper times in S_A and S_B, respectively, the A-observer will determine that the A-process lasts 5 s in S_A and the B-observer will also find that it takes 5 s for the B-process to finish in S_B. This follows from the relativity principle - the laws of physics (and all physical phenomena) are the same in all inertial reference frames. In other words, the *proper* times of the two observers "flow" exactly in the same way - one second of the A-clock measured in S_A is precisely equal to one second of the B-clock determined in S_B. In Figure 4 this fact is reflected by the same distance between the marks of two successive seconds on the worldlines of the clocks. For this reason *the worldline of a clock can be regarded as a time ruler*.

Now, each of the observers tries to determine the duration of the process taking place in the other frame. In order to measure the end of the B-process, the A-observer should determine which second on the screen of the A-clock is simultaneous with the end of the B-process (i.e. with the 5th second on the screen of the B-clock). As seen in Figure 4 the 5th second of the B-clock falls in the instantaneous 3D space x_A (t_A = 6 s) which corresponds to the 6th second of the A-observer's proper time. Since the 5th second of the B-clock (marking the end of the B-process in S_B) is simultaneous with the 6th second of the A-clock the A-observer concludes that the duration of the B-process as determined in S_A is 6 s. This is the well-known time dilation effect. It is a relative (reciprocal) effect as seen in Figure 4: the B-observer finds that the A-process lasts 6 s since the 5th second of the A-clock (the end of the A-process in S_A) falls in the instantaneous 3D space x_B (t_B = 6 s) of the B-observer that corresponds to the 6th second of his proper time.

The time dilation effect looks pretty clear on the spacetime diagram in Figure 4. But that clarity is quite illusory. The most important question that should be asked here is about the existence and dimensionality of the clocks: whether they exist as 3D objects enduring through time or as 4D objects which contain the whole history in time of the ordinary (3D) clocks and which are represented by the worldlines A and B of the clocks in Figure 4. If the two worldlines of the clocks represent real 4D clocks, the time dilation is indeed clear. As the clocks are in relative motion their worldlines are not parallel and their 3D spaces do not coincide - they form an angle. As a result, the two instantaneous 3D spaces x_A (t_A = 0 s) and x_A (t_A = 6 s) corresponding to the 0th and 6th seconds of the A-observer's proper time "cut off" different lengths from the two clocks' worldlines - 6 s from A-clock's worldline and 5 s from B-clock's worldline.

However, if we believe (on the basis of our everyday experience) that the clocks are 3D objects that evolve in time, then the tough questions start. The first thing that becomes immediately evident is what we have already established in the case of relativity of simultaneity represented in Figure 2 and the length contraction depicted in Figure 3 - that the existence of a 3D object cannot be absolute. Consider the time dilation effect determined by the A-observer: in S_A the A-clock with the 6th second on its screen is simultaneous with the B-clock showing the 5th second on its screen. Up to now in the discussions of the time dilation effect it has not been paid close attention to the fact that the A-observer should implicitly assume that what is real for him at the 6th second of his proper time is everything that exists at that moment which is his present represented by his instantaneous 3D space x_A (t_A = 6 s) in Figure 4. That assumption is necessary for the A-observer to conclude that the B-process lasts 6 s in S_A - the B-clock with the 5th second on its screen (indicating the end of the B-process in S_B) comes into existence at the 6th second of the A-observer's proper time. This is the reason why the A-observer regards the B-process as lasting six seconds in S_A. If existence were absolute, both observers should agree that the A-clock existed in its 6th second, whereas the B-clock existed in its 5th second. This obviously contradicts relativity since the time dilation effect could not be reciprocal if the clocks existed in an absolute manner. It is precisely here where the traditional presentism is manifestly wrong.

The presentist view that the clocks are 3D objects can be preserved only if the clocks' existence is relativized. Then the A-clock in its 6th second and the B-clock in its 5th second will exist in S_A at the 6th second of A's the proper time, whereas the A-clock with the 5th second on its screen and the B-clock showing its 6th second will be real in S_B at the 6th second of B's proper time. Here too it becomes evident that different pairs of 3D clocks exist for the two observers. Consider clock A. In order for the time dilation to be reciprocal, clock A should exist as *two 3D objects* - clock A with the 6th second on its screen exists for the A-observer, whereas clock A in its 5th second exists for the B-observer. Therefore different pairs of 3D clocks must exist for the A- and B-observers. If the observers are presentists and believe only in the existence of 3D objects, then each of them will hold that only his pair of 3D clocks exists and will deny the existence of the other observer's pair of 3D clocks. This, however, is precisely an ontological relativization of the existence of physical objects.

If existence is *ontologically* relativized the 3D/4D dilemma seems to remain in the framework of relativity. At first glance it even appears that special relativity would support such relativization of existence since one is tempted to think that after having relativized motion and simultaneity special relativity would require the relativization of existence as well. However, the very idea that the most fundamental "attribute" of reality - existence - might lose its absolute status and become observer- or frame-dependent in an ontological sense appears disturbing. As Gödel put it "[t]he concept of existence … cannot be relativized without destroying its meaning completely" (Gödel 1949: 558]). This can be developed into a strong philosophical argument, but I would prefer to concentrate on arguments demonstrating that special relativity itself rejects the view which regards existence as ontologically relativized.

3 Relativization of existence and the twin paradox

We have seen that relativity of simultaneity forces the presentists to relativize existence in order to preserve the view of reality as a 3D world. To demonstrate that even a relativized presentism contradicts relativity let us consider the twin paradox which is an absolute effect with no relativity of simultaneity involved (sometimes relativity of simultaneity is used when each of the twins *describes* the rate of the other twin's clock, but the effect itself is absolute and cannot be *explained* by the relativity of simultaneity). The worldlines of twins A and B are depicted in Figure 5. Initially A and B are at rest with respect to each other - their worldlines are parallel before the event D at which twin B departs, and after turning back at event T meets again A at the event M. Twin A's worldline is a straight line which means that it is he who does not change its state of motion.

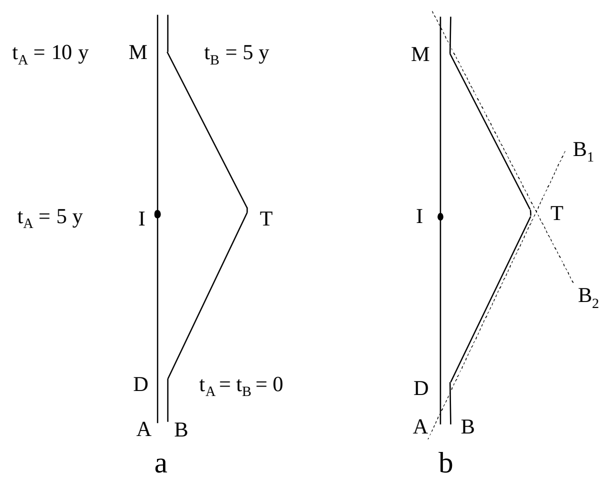

Figure 5

In Euclidean geometry the straight line is the shortest distance between two points. In the pseudo-Euclidean geometry of Minkowski spacetime, however, among all worldlines connecting two events the straight worldline is the longest. As the proper time of an observer is measured along his worldline each of the twins measure his elapsed proper time along his worldline. The time that has elapsed between events D and M according to twin A is greater than the time as measured by twin B - A's worldline between D and M is longer than B's worldline between the same events (in Figure 5 it is the opposite since the diagram is drawn in the ordinary Euclidean geometry).

Let us assume that when A and B meet at M five years have passed for B and ten years for A. Both twins agree that more time has elapsed for A - they directly compare their clocks at M. The time difference between A and B is an *absolute* effect - no relativity of simultaneity is involved and no relativization of existence is necessary to explain it. Not only is the relativization of existence unnecessary for the explanation of the twin paradox, but also an analysis when the issue of dimensionality of reality is explicitly taken into account shows that this effect is possible if the worldlines of the twins are real 4D objects.

To see that the twin paradox effect is only possible in a 4D world in which the twins' worldlines are real 4D objects, let us start from the opposite view - that their worldlines are not real, that the twins exist as ordinary 3D objects that evolve as time objectively flows (Petkov 1986, 2005). In such a case both A and B should exist at the event M - otherwise what kind of a meeting it would be if they are not both present there. The only way A and B can explain the time difference of five years is to assume that B's time somehow "slowed down" during his journey. As the only difference in the states of motion of A and B is the acceleration that B has undergone during his journey it follows that it should be responsible for the time difference. Also, it is the acceleration that showed the asymmetry between the twins and demonstrated that the twin paradox was not a paradox, but a real effect. However, according to the so-called "clock hypothesis" the rate of an ideal clock is unaffected by its acceleration (d'Inverno 1992, 33; Naber 1992, 55). And indeed it has been shown that the acceleration does not cause the slowing down of B's time by considering the so called three-clock version of the twin paradox shown in Figure 5b (see for example Kroes 1983). Instead of twin B who accelerates four times during his journey consider two clocks B_1 and B_2 which move with constant velocities. At the event D the readings of clock B_1 and A's clock are set to zero (when B_1 passes A). When B_1 reaches the turning point at T, it is intercepted by the second clock B_2 and the readings of the two clocks are instantaneously synchronized. The readings of clock B_2 and A's clock are compared at M at the instant B_2 passes A. The calculations show that the difference in the readings of B_2 and A's clock at M will be again five years. As the acceleration does not cause the slowing down of B's time and since no other hypothesis for that slowing down has ever been proposed it appears virtually certain that the flow of B's time is not affected in any way.

That A's and B's times flow in exactly the same way rigorously follows from the fact that A's and B's clocks measure *proper* times. To my knowledge the fact that at the event M the twins compare their proper times which according to the relativity principle are subjected to no dilation has been overlooked. As we have seen in Figure 4 the A-process and the B-process take the same amounts of the A- and B-observer's proper times, respectively. *What is time dilated is the duration of the B-process as measured by the A-observer and vice versa.* As *proper times are not relativistically dilated* the proper times of observers in relative motion (existing at their present moments as 3D objects according to the presentist view) must flow equally. This means that if the clocks were 3D objects (like the one shown in Figure 1a) in the three clock version of the twin paradox (Figure 5b), where only inertial motion is involved, there would be no time difference when the clocks A and B_2 directly compare their proper times at M. Therefore the twin paradox would be impossible.

Let us consider the spacetime diagram in Figure 5a. According to the presentist view the twins' worldlines are not real 4D objects - they are rather trajectories along which the twins' 3D bodies evolve in time. As A's and B's proper times objectively flow in the same way, if five years have passed for B (when he exists at event M), five years would have elapsed for A as well and he would exist at event I. Therefore A and B could not meet at all. The impossibility of the twin paradox if formulated in terms of the presentist view shows the incorrectness of our initial assumption - that A and B exist only as 3D objects subjected to an objective flow of time as required by the relativized version of presentism.

The twin paradox is consistently explained if A's and B's worldlines are real 4D objects; then twin A exists not only at event M (where he meets with B) and event I, but at all events comprising his worldline. The time difference of five years when the twins "meet" at M comes from the different lengths of the twins' worldlines between the events D and M; that is, the different amounts of the proper times of the twins between D and M. The four-dimensionalist view offers a natural explanation of why the acceleration does not affect the amount of proper time measured by twin B in Figure 5a: the acceleration which twin B suffers is merely an indication that his worldline is curved but this curvature does not affect his proper time since the length of a worldline does not change if it is curved. The only role of the acceleration in Figure 5a is to show that B's worldline is curved and that it is a different path from event D to event M which due to the pseudo-Euclidean nature of Minkowski spacetime is shorter than the path given by A's worldline. If B's worldline is straighten and superimposed on A's worldline, the length of B's worldline will be equal to the segment DI of A's worldline. No matter how mysterious it might look, the twin paradox is merely the triangle inequality in the case of the pseudo-Euclidean geometry of Minkowski spacetime.

4 Conclusions

By addressing the question of dimensionality of objects involved in relativity of simultaneity, length contraction, and time dilation it has been shown that the presentist view can avoid a direct contradiction with relativity if the existence of those objects is regarded as ontologically relativized. However, even this relativized version of presentism contradicts relativity as shown by the analysis of the twin paradox in Section 3. Therefore the only view that is consistent with relativity is four-dimensionalism.

An independent argument for four-dimensionalism comes from the conventionality of simultaneity. Indeed, due to the conventionality of simultaneity all events outside of the light cone of an event exist which leads to the view that all events of spacetime are real (Weingard 1972). In fact, the profound meaning of the conventionality of simultaneity (and of the vicious circle reached when one tries to determine the one-way velocity of light) is that reality is a four-dimensional world whose mathematical model is Minkowski spacetime (Petkov 1989, 2005): as all events of spacetime exist it is really a matter of convention which class of events lying outside of the light cone of an event will be considered simultaneous; this means that since an observer is free to choose his instantaneous space from the region outside of the light cone the back and forth velocities of light will obviously depend on that choice. It should be specifically stressed that no objective simultaneity is possible in a 4D world.

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