Neither Presentism nor Eternalism – at What Price?

Vesselin Petkov
Minkowski Institute
Montreal, Quebec, Canada
vpetkov@minkowskiinstitute.org

Abstract

In a recent paper "Neither Presentism nor Eternalism" (*Foundations of Physics* (2019) 49, pp. 1325-1335) Carlo Rovelli argued that there is a way out of the dilemma – presentism or eternalism. However his attempt to avoid it comes at a high price: avoiding to address the fundamental question of the dimensionality of the world and contradicting both Minkowski's arguments for the reality of spacetime, based on the *experiments* at his time, and *the relativistic experimental evidence* after his time. I will summarize the main points of that contradiction and will stress again that *none of the experiments, which confirmed the relativistic kinematic effects, would be possible if spacetime were not real,* which demonstrates that any claim (including Rovelli's), that becoming is objective, directly contradicts the experimental evidence.

Carlo Rovelli's recent paper "Neither Presentism nor Eternalism" [1] can serve as the beginning of a long overdue constructive discussion of the nature of spacetime.[1] 110 years after the publication of Minkowski's world-view-changing paper "Space and Time" [2] we owe such a meaningful and consensus-building discussion to the next generations of not only physicists and philosophers.[2] The reason is that the present situation can hardly be described as satisfactory because of the proliferation of views, *not firmly based on the relativistic experimental evidence*, which reject the reality of spacetime either explicitly or implicitly by defending concepts (e.g., becoming and flow of time) which are incompatible with the spacetime view of the world; at the same time Minkowski's own arguments for the reality of spacetime (based on the experimental evidence at that time) have not been addressed let alone refuted.

I think Rovelli's paper suffers of the same problem. Moreover, his attempt to avoid the dilemma – presentism or eternalism – comes at a high price on five counts:

1. Rejecting "these two naive options" (presentism and eternalism) amounts to avoiding to address the fundamental question of what the dimensionality of the world (at the macroscopic scale) is. Presentism regards the physical world as three-dimensional and evolving in time, whereas according to Minkowski's (spacetime) view,

[1] As this paper examines the statements in Rovelli's paper I have decided to use rather long footnotes, which allows me to support or clarify statements I make in the text while remaining focused on Rovelli's paper in the main text.

[2] One of the appropriate forums for such a discussion can be the biennial spacetime conferences: http://www.minkowskiinstitute.org/conferences/

also called block universe or eternalism (Rovelli uses the latter term), the physical world is four-dimensional with time as the fourth dimension (as *all* moments of time form the fourth dimension they *must* exist equally – as constituents of a dimension they are given at once or *en bloc* like the points of the spatial dimensions). That is why, saying "Neither Presentism nor Eternalism" (that is, "neither three-dimensionalism nor four-dimensionalism") means that the physical world is neither three-dimensional nor four-dimensional. In other words, the title and the central claim of Rovelli's paper implicitly assume that the dimensionality of the world is *not* one of its most fundamental features (which is commonly regarded to be on equal footing with the very existence of the world). If Rovelli really meant that, such a crucial claim should have been explicitly made and arguments, *based on the experimental evidence*, against the accepted view that dimensionality of the world is one of its most fundamental features should have been provided. Moreover, explicitly asking the question of what the dimensionality of the world is avoids the confusion over the notions 'exists' and 'real' – in presentism these notions refer only to the present moment (exists now and real now), whereas in the framework of the spacetime view (Minkowski's view of reality as an absolute four-dimensional world) the notions 'exists' and 'real' are absolute (with no reference to moments of time for the obvious reason that time is not a separate entity in spacetime).

2. Misrepresenting the spacetime view of the world[3] [1, p. 1329]:

> The difficulty with Eternalism (as the idea that past and future events are "real now" as present events) is that it embraces a definition of "to be real now" that clashes manifestly against our common use. It forces us to say that past and future events are "real now", which is nonsense: they are not so, under any reasonable account of the use of "now".

There are two inaccuracies in this representation of the spacetime view (eternalism):

- It is a complete misrepresentation of the spacetime view to say that according to it "past and future events are "real now" as present events" – none of its supporters makes such an obviously self-contradictory statement. Neither the spacetime view nor any of its supporters "embraces a definition of "to be real now"." The very phrase "to be real now" makes sense only in the presentist view. As all events of spacetime have the same existential status no event is *physically* privileged as "now" – that is why it is illegitimate to talk about "real now" in spacetime. The existence of spacetime itself and existence *in* spacetime (e.g., of particles' worldlines) do not refer to any specific event – it is this "static" notion of existence that was employed by Minkowski when he introduced[4] the spacetime view of the world (that reality is an absolute four-dimensional world; Minkowski

[3]It is puzzling why here Rovelli misrepresented the spacetime view (eternalism), whereas on p. 1325 he presented it correctly: "the idea that present, past and future events are "equally real"." My only guess is that it is easy to criticise the self-contradictory definition given in the quote.

[4]Poincaré first published [5] his observation that the Lorentz transformations can be viewed as rotations in a four-dimensional space with time as the fourth dimension but he regarded it as a mathemat-

called it die *Welt*, the World): "The whole world presents itself as resolved into such worldlines" and this (four-dimensional) world and the particles' worldlines simply exist[5] in the sense used by Minkowski and employed in the spacetime view of the world by prominent relativists starting with Einstein ("It appears therefore more natural to think of physical reality as a four-dimensional existence, instead of, as hitherto, the *evolution* of a three-dimensional existence"), Eddington ("Events do not happen; they are just there"), Weyl ("The objective world merely exists, it does not happen"), Geroch ("there is no dynamics in space-time: nothing ever happens there. Space-time is an unchanging, once-and-for-all picture encompassing past, present, and future").

- It is incorrect to talk about past and future events in spacetime since all events of spacetime are equally real and are not physically (objectively) divided into past, present and future.[6]

3. Effectively misinterpreting the physical meaning of Einstein's equations [1, pp. 1328-29]:

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ical construction which does not represent anything in the physical world (Poincaré's conventionalism led him to regard spacetime as a mathematical *convention*, which would be even disadvantageous: "the language of three dimensions seems the best suited to the description of our world" [6]; for more details see [7]). It was Minkowski who first realized that reality is an absolute four-dimensional world with time as the fourth dimension by successfully decoding the profound physical message hidden in the failed experiments (including the Michelson-Morley experiment) to detect absolute motion (see [4] and the summary of Minkowski's arguments for the reality of spacetime below). The recollections of Minkowski's student Max Born also confirm that Minkowski arrived independently at what Einstein called special relativity and at the notion of spacetime, but Einstein [8] and Poincaré [5] published first (for more details see: http://www.minkowskiinstitute.org/born.html). Minkowski did not publish his results earlier since he was developing the four-dimensional formalism of spacetime physics (which we now use) reported in 1907 and published in 1908 as a 59-page treatise. Max Born wrote [9]: "He told me later that it came to him as a great shock when Einstein published his paper in which the equivalence of the different local times of observers moving relative to each other were pronounced; for he had reached the same conclusions independently but did not publish them because he wished first to work out the mathematical structure in all its splendour. He never made a priority claim and always gave Einstein his full share in the great discovery." More importantly, Born recalled that at the seminar organized by Minkowski and Hilbert in the early summer of 1905 "Minkowski occasionally alluded to the fact that he was engaged with the Lorentz transformations, and that he was on the track of new interrelationships" [10]. At the time of the seminar, neither Einstein's paper [8] nor Poincaré's paper [5] were published! *Annalen der Physik* received Einstein's paper "On the Electrodynamics of Moving Bodies" on June 30, 1905; *Rendiconti del Circolo matematico di Palermo* received Poincaré's paper "On the Dynamics of the Electron" (in which Poincaré regarded the Lorentz transformations as rotations in a four-dimensional space with time as the fourth dimension) on July 23, 1905.

[5] One can easily get rid of the temptation to declare that Minkowski's World (spacetime) is nothing more than a four-dimensional mathematical manifold by examining Minkowski's arguments (summarized below) of why the *experimental evidence* at his time unambiguously demonstrated that reality is a four-dimensional world modeled by his die *Welt* (spacetime).

[6] In the context of relativistic causality, we do talk about past and future events (lying in the past and the future light cones at a given event, respectively), but this has nothing to do with their reality; moreover, events that are past and future for a given event (serving as the apex of a light cone at that event) can be neither past nor future for another event (the apex of another light cone separated by some spacelike interval from the apex of the first light cone), which is a separate proof that spacetime events are not physically (objectively) divided into past, present and future.

> The Einstein's equations are evolution equations, like any other equations of physics. There is no reason for not taking them as describing the unfolding of events, coherently with our experience.

I wonder how many relativists would agree with this interpretation of Einstein's equations. The accepted interpretation of general relativity (that directly follows from its mathematical formalism and the experimental fact,[7] which confirmed the geodesic principle, that falling bodies *do not resist* their downward acceleration) is that Einstein's equations determine the spacetime geometry induced by the distribution of matter in spacetime (what is described by the stress-energy tensor on the right-hand side of Einstein's equations).[8]

Once the spacetime geometry is determined, it, in turn, determines the geodesic worldlines which represent the entire history / evolution in time of particles moving by inertia (i.e., non-resistantly). This is in the case of curved spacetimes when Einstein's equations determine what spacetime geometry corresponds to a given distribution of matter in the Universe. However, in both special and general relativity (i.e., in both flat and curved spacetime) "the unfolding of events" is represented by a forever given web of worldlines in spacetime, that is, it is *realized "at once"* (given *en bloc*) in spacetime[9] – (to repeat Minkowski's famous expression) "The whole world presents itself as resolved into such worldlines."

This is the reason for "not taking them [Einstein's equations] as describing the unfolding of events, coherently with our experience." Here is a specific example – the unfolding of events involving a free particle (i.e., its evolution in time) is represented by a timelike geodesic worldline in spacetime (the particle's history in time); there does not exist even a hint in general (or special) relativity that the events comprising the particle's worldline are becoming real (coming into existence), one after the other[10] – the events of the particle's worldline (like all events comprising spacetime) are *equally real*; otherwise, if they were not given "at once," no worldline would exist. Again, a

[7]This is the experimental fact, which demonstrated that there is no gravitational force in Nature: falling particles *do not resist* their fall, which *proves* that no gravitational force is acting on the particles. A gravitational force would be required to accelerate them downwards if and only if the particles *resisted* their acceleration, because *only then a gravitational force would be needed to overcome that resistance.* Moreover, general relativity demonstrated that the downward acceleration of a falling particle is not a true acceleration (represented by a curvature, or rather deformation, of the particle's worldline) since its true (curved-spacetime) acceleration $a^\mu = d^2x^\mu/d\tau^2 + \Gamma^\mu_{\alpha\beta}(dx^\alpha/d\tau)(dx^\beta/d\tau)$ is zero, which demonstrates that the falling particle does move by inertia (non-resistantly); the apparent downward acceleration of the falling particle is caused by geodesic deviation, which is a manifestation of the fact that the particle's worldline and the Earth's worldtube converge because there are no parallel worldlines in the non-Euclidean spacetime region in the vicinity of the Earth's worldtube.

[8]I think the only way to challenge the accepted natural interpretation of general relativity is to question the experimental fact (!), mentioned above, and to argue that both spacetime and worldlines do not represent anything in the physical world and are only mathematical abstractions.

[9]Perhaps the visualization that works the best in a class on relativity is the film strip of an old movie – what we watch on the screen appears to be a real unfolding of events, but we know that that unfolding of events is realized "at once" on the film strip.

[10]As proper time is length along a timelike worldline (whose events *exist equally* and are *not* coming into existence one by one), it is evident that *objective* becoming or *real* flow of time cannot be associated with proper time (length does not flow!).

brute-force objection – worldlines do not represent anything in the physical world – must obviously refute Minkowski's arguments for the reality of spacetime (a web of such worldlines) and specifically his argument for the reality of the worldline (rather worldtube) of a body undergoing relativistic contraction of its length (Minkowski's explanation of length contraction, which is the accepted explanation).

4. Ignoring and contradicting Minkowski's arguments for the reality of spacetime by stating that "There is nothing in relativity which is in contradiction with our experience of time, or that suggests that our experience is "illusory" [1, p. 1326]." Again, I wonder how many physicists (and philosophers of physics) would agree with this statement.[11] In his famous lecture "Space and Time" delivered on September 21, 1908 (and published in 1909) Minkowski showed that the situation is just the opposite – all *experiments* which failed to detect absolute motion revealed that what Einstein called special theory is, in fact, a theory of an absolute four-dimensional world (flat spacetime), which is drastically different from our perception of time because all events of this world are real, which means that there is no becoming and no time flow in it; that is why Minkowski began his lecture by announcing the radical changes in our understanding of space and time [2, p. 57]:

> The views of space and time which I want to present to you arose from the domain of experimental physics, and therein lies their strength. Their tendency is radical. From now onwards space by itself and time by itself shall completely fade into mere shadows and only a specific union of the two will still stand independently on its own.

Recognizing this challenging new world view (whose tendency is indeed radical), the first attempts[12] to reconcile the spacetime view (all events of spacetime are real) and our perception of time (we are aware of ourselves and of the external world only at a single and constantly changing moment – the moment 'now') were made by Eddington [12]:

> Events do not happen; they are just there, and we come across them.

and Weyl [13]:

> The objective world merely exists, it does not happen; as a whole it has no history. Only before the eye of the consciousness climbing up in the world line of my body, a section of this world "comes to life" and moves past it as a spatial image engaged in temporal transformation.

[11] I guess many might point out that not only relativity "is in contradiction with our experience of time" but even classical physics contradicts our perception of time because we believe only the moment 'now' is real, whereas there is *nothing* in the classical physical theories which shows that one moment of time is physically privileged as the moment 'now.'

[12] I am unaware of any other efforts to overcome or at least to address adequately that disturbing contradiction.

I guess if Minkowski were alive he would probably point out that *real* becoming (unfolding of events) in spacetime amounts to a contradiction in terms. I think the only way to avoid such a contradiction is to declare explicitly that spacetime does not represent anything in the physical world and is nothing more than a mathematical space. But such a declaration should come after refuting Minkowski's arguments for the reality of spacetime. In his 1908 lecture Minkowski gave two arguments – a general and a specific argument. Here is a summary of his arguments and I think any explicit or implicit rejection of the reality of spacetime should obvious come after refuting them.

Minkowski's main argument that the world is four-dimensional

It should be stressed that Minkowski deduced this argument from the *experiments* that failed to detect absolute motion (from Galileo's experiments to the Michelson-Morley experiment). He himself emphasized it in the beginning of his lecture (quoted above) when he announced the revolutionary view of space and time pointing out that he deduced it from those experiments : "The views of space and time which I want to present to you arose from the domain of experimental physics, and therein lies their strength."

Here is Minkowski's most general argument that the world is four-dimensional. To explain the experiment of Michelson-Morley, which failed to detect the Earth's absolute motion, Lorentz suggested that observers on Earth can formally use a time that is different from the true time of an observer at absolute rest. Einstein *postulated* that the times of different observers in relative motion are equally good, that is, each observer has his own time, and that for Einstein meant that time is relative.

As a mathematician Minkowski probably immediately realized that as observers in relative motion have different equally real times, they inescapably have *different spaces*[13] as well, because space is defined as a set of simultaneous events and different times imply different simultaneity, i.e., different spaces (or simply – different times imply different spaces because space is perpendicular to time) [2, p. 62]:

> "Hereafter we would then have in the world no more *the* space, but an infinite number of spaces analogously as there is an infinite number of planes in three-dimensional space. Three-dimensional geometry becomes a chapter in four-dimensional physics. You see why I said at the beginning

[13]Minkowski specifically pointed out that "Neither Einstein nor Lorentz disputed the concept of space" [2, p. 65] and provided an additional insight from his analysis of the mathematical formalism of classical mechanics (in his efforts to reveal the physical meaning of the failed experiments to detect absolute motion) that led him to the concept of an absolute four-dimensional world – die *Welt* (spacetime): "To go beyond the concept of space in such a way is an instance of what can only be imputed to the audacity of mathematical culture. After this further step, which is indispensable for the true understanding of the group G_c, I think the word *relativity postulate* used for the requirement of invariance under the group G_c is very feeble. Since the meaning of the postulate is that through the phenomena only the four-dimensional world in space and time is given, but the projection in space and in time can still be made with certain freedom, I want to give this affirmation rather the name *the postulate of the absolute world* (or shortly the world postulate)."

that space and time will recede completely to become mere shadows and only a world in itself will exist."

Therefore the failure of all experiments to detect absolute motion (encapsulated in the principle of relativity – physical phenomena look the same in all inertial reference frames[14]) has indeed a profound physical meaning – all those experiments failed to detect absolute motion (i.e., uniform motion in the absolute space) because there exists not a single (and therefore absolute) space, but many spaces (and many times) in the world; physical phenomena look the same for all observers in relative motion, because each observer performs experiments in his own space and uses his own time (e.g., the speed of light is the same for all observers in relative motion since each observer measures it in his own space by using his own time).

Now Minkowski's argument, deduced from the experimental evidence, that the world is four-dimensional, becomes evident: *the world must be four-dimensional in order that observers in relative motion have different spaces (and times).*

Minkowski did not stress that the experimental results (that gave rise to the principle of relativity) would be *impossible* (i.e., the failure to detect absolute motion by experiments would no longer be observed and absolute motion would become detectable), if the world were three-dimensional (which would mean that there would exist a single and therefore absolute three-dimensional space and a single and therefore absolute time) most probably because he regarded it as self-evident. And, indeed, *if the physical world were three-dimensional, there would exist a* ***single*** *(and therefore absolute) space, i.e. a single class of simultaneous events (a single time), which would mean that simultaneity and time would be absolute in contradiction with both the theory of relativity and, most importantly, with the experiments which failed to detect absolute motion.*

I hope it is now clear why explicitly addressing the issue of the dimensionality of the world (at the macroscopic scale) is crucial in the debate over the nature of spacetime – I believe it is seen that Minkowski's general argument is sufficient to prove that the world is four-dimensional.[15]

Minkowski's specific argument

Minkowski's concrete argument for the reality of worldlines (or rather worldtubes in the case of spatially extended bodies), and therefore for the four-dimensionality of the world, is given in his explanation of the deep physical meaning of length contraction depicted in the right-hand part of Fig. 1 of his paper "Space and Time" and reproduced here as Fig. 1.

The essence of his explanation (which is the accepted correct explanation) is that the relativistic length contraction of a body is a manifestation of the reality of the body's worldtube. Minkowski considered two bodies in uniform relative motion represented by their worldtubes as shown in Fig. 1. To understand why *the worldtube*

[14]If they did not look the same, absolute motion would be detected.

[15]Because *experimental results* (the experimental failure to detect absolute motion) would be *impossible* if the world were *not* four-dimensional – uniform motion with respect to the single (absolute) space of a three-dimensional world would be detected by experiment.

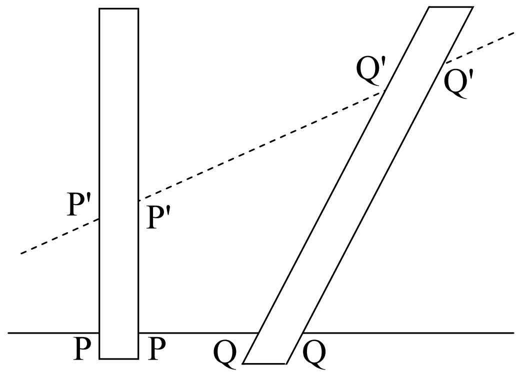

Figure 1: The right-hand part of Fig. 1 in Minkowski's paper "Space and Time"

of a body must be real in order that length contraction be possible, consider the body represented by the vertical worldtube. The three-dimensional cross-section PP, resulting from the intersection of the body's worldtube and the space (represented by the horizontal line in Fig. 1) of an observer at rest with respect to the body, is the body's proper length. The three-dimensional cross-section $P'P'$, resulting from the intersection of the body's worldtube and the space (represented by the inclined dashed line) of an observer at rest with respect to the second body (represented by the inclined worldtube), is the relativistically contracted length of the body measured by that observer (the cross-section $P'P'$ only appears longer than PP because a fact of the pseudo-Euclidean geometry of spacetime is represented on the Euclidean surface of the page). Note that while measuring the *same* body, the two observers measure *two* three-dimensional bodies represented by the cross-sections PP and $P'P'$ in Fig. 1 (this situation is not paradoxical because what is meant by "the same body" is the body's worldtube).

In order to feel the strength of the argument that length contraction is impossible in a three-dimensional world, assume that reality were indeed a three-dimensional world, which would mean that the worldtube of the body did not exist as a four-dimensional object and were nothing more than an abstract geometrical construction. Then, what would exist would be a single three-dimensional body, represented by the proper cross-section PP, and both observers would measure the *same* three-dimensional body of the *same* length. Therefore, not only would length contraction be *impossible*, but relativity of simultaneity would be also impossible since a spatially extended three-dimensional object is defined in terms of *simultaneity* – all parts of a body taken *simultaneously* at a given moment – and as both observers in relative motion would measure the same three-dimensional body (represented by the cross-section PP) they would share the *same* class of simultaneous events in contradiction with relativity.

So, Minkowski's specific argument for the reality of spacetime is: *the worldtube of a body undergoing length contraction must be real in order that relativistic length contraction be possible.*[16] Again, Minkowski did not state it this way probably because

[16]One may object that Minkowski's argument is irrefutable only if existence is regarded as abso-

it looked obvious to him or maybe he did not anticipate that the spacetime structure of the world, which he discovered, would meet such a resistance.

5. Ignoring and contradicting the relativistic experimental evidence after Minkowski's time. It should be particularly emphasized that all experiments, which confirmed the relativistic kinematic effects,[17] would be *impossible, if the world were three-dimensional*, because there would exist a single (absolute) time, a single (absolute) space and therefore a single (absolute) class of simultaneous events which means that the experiments that confirmed the relativistic effects of time dilation and length contraction[18] would be impossible because these effects are specific manifestations of relativity of simultaneity (for details see [4], [15], [17]). Therefore, when the issue of the dimensionality of the world is explicitly addressed, it becomes clear that the experiments, which proved the relativistic kinematic effects, unambiguously demonstrate that spacetime is real, i.e., that all spacetime events have equal existence. That is why, Rovelli's claim that there exists objective becoming (i.e., that spacetime is not real) directly contradicts the experimental evidence.

Here it is worth mentioning that Minkowski's general argument for the reality of spacetime (to stress it again, *deduced from the experimental evidence*) – not only do observers in relative motion have different times, but they have different spaces, which is impossible in a three-dimensional world – revealed the physical meaning not only of relativity of simultaneity[19] (it is impossible in a three-dimensional world; reality is an absolute four-dimensional world and observers in relative motion can choose[20] from the equally existing spacetime events different three-dimensional spacelike hypersurfaces as their spaces, i.e., as their classes of simultaneous events), but also of conventionality of simultaneity. It turned out that both relativity of simultaneity and conventionality of simultaneity have the *same* physical meaning – reality is an absolute four-dimensional world which makes it possible, when we describe it in the ordinary three-dimensional

lute. If existence is relativized (regarded as frame-dependent) then length contraction and the other relativistic effects would be explained in the framework of a relativized presentist view. I wonder how many physicists and philosophers would adopt such a view, especially if it is examined closely; not only would such an examination reveal unsurmountable problems [15], but would also demonstrate that a relativized presentism contradicts the relativistic experimental evidence (the twin paradox) [15].

[17]For example, it is an experimental fact, used every fraction of a second by the GPS, that observers in relative motion have different times, which is impossible in a three-dimensional world, where there are a single space and a single time.

[18]Along with time dilation, the muon experiment effectively tested length contraction experimentally as well: "In the muon's reference frame, we reconcile the theoretical and experimental results by use of the length contraction effect, and the experiment serves as a verification of this effect" [16].

[19]On the spacetime view, accepted in physics (because it is firmly supported by the relativistic experimental evidence), simultaneity is relative and any claim that simultaneity can be absolute (by questioning that or redefining the notion of simultaneity [18]) must obviously either demonstrate that that claim is compatible with the spacetime view (all spacetime events are real) or refute the arguments for the reality of spacetime.

[20]This is the key point – the absolute four-dimensional world must exist in order that observers in relative motion *have from where to choose* different three-dimensional spacelike hypersurfaces; that is why relativity of simultaneity is impossible in a three-dimensional world – it "contains" a single (therefore absolute) space, i.e., a single (therefore absolute) class of simultaneous events.

language, to have from where to choose freely (by convention) *any* (spacelike) three-dimensional hypersurface as our space, i.e., as our class of simultaneous events [19]. That is why relativity of simultaneity implies conventionality of simultaneity and vice versa [20]. Any claim that simultaneity is relative but not conventional is another manifestation of the contradiction in terms mentioned above: there is no objectively privileged (the only one that exists) class of simultaneous events (due to relativity of simultaneity), but there is an objectively privileged (the only one that exists) class of simultaneous events (due to the non-conventionality of simultaneity).

Therefore, conventionality of simultaneity is also an argument for the reality of spacetime[21] because it is "contained" in Minkowski's general argument.

To summarize: taking into account even only Minkowski's own arguments for the reality of spacetime[22] demonstrates that "The "third option" between Presentism and Eternalism" [1, p. 1334] – "The "present" is not illusory: it is well defined, but relative to a location" – proposed by Rovelli contradicts Minkowski's arguments because Rovelli explicitly states that, not the whole spacetime, but only the "local becomings" are real [1, p. 1334]:[23]

> The four-dimensional spacetime is only a cartography of the relations between these multiple local becomings.

I believe it is now obvious that questioning the reality of spacetime should come after Minkowski's arguments are addressed and refuted. I do not see any other scientific option.

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[21]In a recent paper Thyssen [21] made two objections:

- Stating that"the transitivity objection still applies" ("transitivity of the relation 'is real for"') to such an argument; that may be true for Weingard's original argument [22], but not for Minkowski's general argument (which explained the physical meaning of both conventionality of simultaneity and relativity of simultaneity), because there is no "relation 'is real for"' in Minkowski's (spacetime) view – in the absolute four-dimensional world existence is absolute. That conventionality of simultaneity (along with relativity of simultaneity) is an argument for the reality of spacetime is immediately seen by that fact that conventionality of simultaneity is impossible in a three-dimensional world which has a single class of simultaneous events. So reality must be a four-dimensional world (where an observer has the freedom to choose different spacelike hypersurfaces as his class of simultaneous events). That is why the issue of the dimensionality of the world is crucial for revealing the nature of spacetime.
- Insisting that special relativity "leaves the debate on the dimensionality of the world *underdetermined*." I completely disagree – here I have done my best to summarize Minkowski's arguments (not mentioned in Thyssen's paper) for the reality of spacetime (and the experiments that were performed after Minkowski) and to demonstrate that experiments would be impossible if reality were *not* an absolute four-dimensional world.

[22]The arguments demonstrating that the experiments, which confirmed the relativistic kinematic effects, would be impossible, if spacetime did not exist powerfully reinforce Minkowski's arguments.

[23]This statement is not sufficiently elaborated in Rovelli's paper but it seems it implies relativized existence, which, as pointed out above, ultimately also contradicts the experimental evidence.

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