Quantum physics and presentism

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Abstract

The paper argues that the case of presentism is open both from the physical and the metaphysical point of view. It is open from the physical point of view, since we do not have an elaborate account at our disposal of how quantum non-locality can exist in the space-time of special relativity, without presupposing an objective foliation of space-time into spatial hypersurfaces that are ordered in time. The GRW flash ontology is the proposal in the current debate that to a certain extent comes close to such an account, but meets with serious reservations. The case of presentism is open from a metaphysical point of view as well, since an ontology of matter in motion implies endurantism and thereby, as one can argue, presentism. Again, we do not have a precisely worked out proposal at our disposal that replaces an ontology of matter in motion with an ontology of properties existing at space-time points in a block universe, and any such proposal meets with serious reservations.

1. Introduction

Presentism is the view that only what is present exists. What is past no longer exists, and what is future does not exist as yet. On the most widespread understanding of presentism, it is the view that only what there is at a certain time exists, but not the view that only what there is in a certain region of space exists. That is to say, presentism is not the solipsistic stance that maintains that only what there is at a certain space-time point (that is, the point where I am now) exists.[1] Presentism, thus construed, presupposes objective simultaneity. More precisely, it takes for granted that there is exactly one global, objective foliation of four-dimensional space-time into three-dimensional spatial hypersurfaces that are ordered in time.[2] It is the view that these hypersurfaces come into and go out of existence such that always only one such hypersurface exists – the present one. Monton (2006, p. 264) characterizes this view as "Heraclitean presentism", because its central tenet is the reality of change in the sense of events coming into being and going out of being. Presentism thus is opposed to eternalism according to which everything that there is in space-time simply exists.

The claim of this paper is that the case of presentism is open. The structure of the paper is as follows: I first recall the standard argument from the special and the general theory of relativity that refutes presentism (section 2). I then show that this argument is strongly challenged by the experimentally proven fact of quantum non-locality (section 3). That is why the case of presentism is open from the physical point of view. I then argue that the issue of

1 But see Harrington (2008) for the defence of such a view.

2 But see Fine (2005, ch. 8, § 10, pp. 298-307) for a view that relativizes existence to inertial frames.

presentism vs. eternalism goes deeper than the question of the compatibility of our two current main fundamental physical theories (quantum physics and general relativity theory), concerning the general metaphysics of objects and properties (section 4). That is why the case of presentism is open from the metaphysical point of view as well.

2. *The argument against presentism from the special and the general theory of relativity*

The special theory of relativity (Einstein 1905) is built on the following two principles:

1. All inertial reference frames are equivalent for the description of physical phenomena.
2. The velocity of light is a constant, being independent of the state of motion of its source and thus the same in all inertial reference frames.

Principle (1) is taken over from pre-relativistic physics, going back to Galilei. Principle (2) is a consequence of the field solution to the action-at-a-distance problem in Newton's theory of gravity: according to the field solution, interactions propagate from a space-time point to its neighbouring points and thus with a finite velocity (local action). In fact, the velocity of light is the upper limit velocity for the propagation of effects. This principle implies that we have to replace the Galilean transformations with the Lorentz transformations when switching from one inertial reference frame to another one. The latter unify space and time in the following sense: only the four-dimensional, spatio-temporal distance between any two events is an invariant. This is the reason for the claim that according to the special theory of relativity, space and time are not separate entities, but unified in a four-dimensional space-time. Both these principles apply also to the general theory of relativity. In particular, both the special and the general theory of relativity entail that there is no privileged or objective foliation of space-time into three-dimensional, spatial hypersurfaces that are ordered in time.

The contradiction between the conjunction of these two principles and presentism consists in the fact that presentism as characterized above presupposes an objective foliation of space-time into three-dimensional, spatial hypersurfaces that are ordered in time. In other words, presentism takes for granted that for any one event that exists, there are indefinitely many other events that exist as well and that are simultaneous with the event in question, constituting a spatial hypersurface of the universe. But the special and the general theory of relativity imply that there is no objective simultaneity, because any two events that are simultaneous in one inertial reference frame are not simultaneous in other inertial reference frames, and all inertial reference frames are equivalent; in other words, there is no objective foliation of space-time into spatial hypersurfaces that are ordered in time.[3]

Special and general relativity therefore suggest eternalism, that is, the view that the whole of space-time with all its content simply exists. Wüthrich (2012, sections 3-6) examines various strategies to avoid this conclusion and argues that none of these strategies is convincing. His assessment is correct to my mind. Hence, to put it in a nutshell, if the special and the general theory of relativity told the whole story of fundamental physics, the only reasonable position to take would be eternalism, and the case of presentism in a metaphysics based on science would be closed.

3. *Quantum non-locality and the case for presentism*

However, the general theory of relativity does *not* tell the full story about what happens in space-time. John Bell, in one of his last papers entitled "La nouvelle cuisine" (1990),

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[3] See notably Saunders (2002) and Wüthrich (2012, section 2) for a clear exposition of this contradiction.

formulates a principle of local causality: "The direct causes (and effects) of events are near by, and even the indirect causes (and effects) are no further away than permitted by the velocity of light" (quoted from Bell 2004, p. 239). No particular notion of causation is implied here (see Bell 2004, p. 240). The idea is that whatever events whose occurrence contributes to determining the probabilities for a given event to happen at a certain space-time point are located in the past light-cone of that event. This is one way of formulating the principle of local action that is implemented in classical field theories and that overcomes Newtonian action-at-a-distance. Relativity physics endorses this principle. That is why relativity physics can waive the commitment to an objective, global temporal order of events and thus the commitment to an objective simultaneity of events: whatever contributes to determining a given event is situated in its past light cone; consequently, there is no need to settle for an objective temporal order of events that are situated outside each others light cones.

In view of considering quantum physics, Bell makes his definition more precise in the following manner; "local beable" is Bell's neologism for whatever exists as localized in space-time according to the theory under consideration:

> A theory will be said to be locally causal if the probabilities attached to values of local beables in a space-time region 1 are unaltered by specification of values of local beables in a space-like separated region 2, when what happens in the backward light cone of 1 is already sufficiently specified, for example by a full specification of local beables in a space-time region 3. (Quoted from Bell 2004, pp. 239-240)

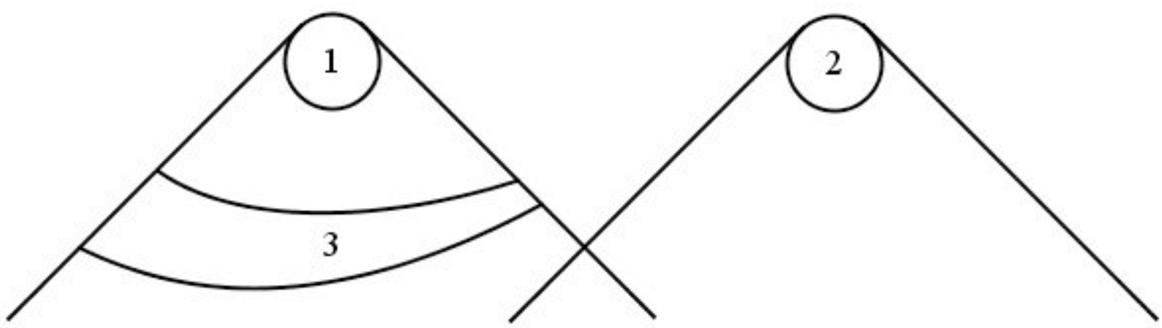

Fig. 1: Illustration of Bell's definition of local causality; figure copied from http://www.scholarpedia.org/article/Bell's_theorem

Bell's theorem (Bell 1964, reprinted in Bell 2004, chap. 2) proves that any theory that complies with the experimentally confirmed predictions of quantum mechanics has to violate Bell's principle of local causality: in some cases, specifying the local beables in region 2 changes the probabilities attached to values of local beables in region 1, although the beables in the backward light cone of region 1 are already specified. Switching from quantum mechanics to quantum field theory does not alter that issue: also in quantum field theory, in some cases, specifying the local beables in region 2 changes the probabilities attached to values of local beables in region 1, although the beables in the backward light cone of that region are already specified. On this basis, Maudlin (2011, chap. 1-6) convincingly argues that quantum non-locality implies the existence of superluminal influences and thereby the existence of superluminal causation (again, no specific theory of causation is presupposed).

However, quantum non-locality does not permit sending superluminal signals. The reason is that one cannot control the relevant local beables in space-time region 2 (that is, the outcomes of quantum mechanical measurements made in this region). Consequently, one cannot employ the local beables in space-time region 2 to send superluminal signals to space-time region 1. Nonetheless, on the ontological by contrast to the operational level, there is a conflict between quantum theory (quantum mechanics, quantum field theory) and relativity theory (special relativity, general relativity), since what happens in a space-time region 2 that is separated from a space-time region 1 by a space-like interval nevertheless contributes to determining the probabilities of what happens in region 1, and *vice versa*.[4]

This conflict does not automatically imply that we have to give up one of the two principles on which the special theory of relativity is built. First of all, (1) the mentioned determination does not mean that there is a signal travelling from space-time region 2 to space-time region 1 with a velocity that is much higher than the velocity of light. There is no precisely formulated version of quantum theory that includes superluminal signals, although one can contemplate models of quantum non-locality that are built on the idea of superluminal signals, as notably Chang and Cartwright (1993, section III) do. Secondly, (2) there is a straightforward way to solve the conflict, but it comes at a high price: if one countenances backward causation, one can contemplate acknowledging a signal that travels from space-time region 2 backwards in time to the region where the past light cones of region 2 and region 1 overlap and from that region then forwards in time to region 1.[5] Apart from well-founded general reservations that one can voice against backward causation, the problem in our context is that such models are committed to closed causal loops, as Berkovitz (2008 and 2011) convincingly argues. Thirdly, (3) there is the possibility to explain quantum non-locality in terms of some sort of a common cause that is not located in the intersection of the past light cones of space-time region 1 and space-time region 2. All precisely worked out versions of quantum theory pursue this strategy (insofar as one interprets them in causal terms, again without presupposing a specific theory of causation).

If one endorses this strategy, one is not committed to any sort of direct superluminal interaction, since one searches for a common cause of the correlation between the local beables in space-time region 1 and space-time region 2 instead of explaining that correlation in terms of a direct interaction between these beables (signal travelling with superluminal velocity). Furthermore, it is not excluded that it may turn out to be possible to respect in this framework the principle according to which there is no privileged foliation of space-time into spatial hypersurfaces that are ordered in time as well.

The most promising proposal in this respect is the ontology that Bell (2004, chap. 22) puts forward for the version of quantum theory developed by Ghirardi, Rimini and Weber (1986) (GRW). According to Bell, the spontaneous localizations of the quantum mechanical wave-function in configuration space that the GRW dynamics introduces describe the local beables

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4 See notably Bell (2004, p. 172), Albert (2000), Norsen (2009) and Seevinck (2010).

5 See notably Price (1996, chap. 8 and 9), Dowe (2000, chap. 8), as well as the papers in *Studies in History and Philosophy of Modern Physics* 38 (2008), pp. 705-840.

in space-time. That is to say, whenever a spontaneous localization of the wave-function in configuration space occurs, there is a local beable centred around a point in physical space-time, and these *local beables are all there is in space-time*. Tumulka (2006) proposes to call these local beables "flashes". Thus, all that exists in space-time is a sparse distribution of flashes at space-time points.

Tumulka (2006) sets out to show that the flash ontology does not have to commit itself to more space-time structure than the special theory of relativity admits. In other words, it does not have to presuppose a privileged foliation of space-time into spatial hypersurfaces that are ordered in time.[6] As it stands, Tumulka's proposal does not include interactions. On the one hand, one can maintain that the point at issue just is whether one can account for interactions in quantum physics without presupposing a privileged foliation of space-time. On the other hand, one can retort that we do in general not have a relativistic quantum theory at our disposal that provides a precise dynamics for interactions.

Be that as it may, one can already raise reservations about the Lorentz invariance of Tumulka's proposal as it stands. If one considers space-time as a whole, this proposal can describe the distribution of flashes in space-time without presupposing a preferred foliation, and its dynamical law does not rely on there being a particular foliation of space-time. However, we have good physical and philosophical reasons for maintaining that there are concrete physical relations of entanglement instantiated in space-time.[7] That is why quantum physics is commonly regarded as being incompatible with David Lewis' famous thesis of Humean supervenience according to which there are only local matters of particular fact occurring at points in space-time.[8] Applied to the flash ontology, that is to say that insofar as there are flashes occurring at space-time points, there are correlations among these flashes existing as relations instantiated in space-time, constituting certain structures of correlated flashes.

However, one can retort that it is not mandatory to recognize relations of entanglement. As Bell remarked in "The theory of local beables" (1975), one can put forward an ontology of quantum physics that admits only the distribution of the local beables in space-time (see Bell 2004, p. 53) – that is, an ontology that acknowledges only the Humean mosaic of local matters of particular fact, these being the flashes in the case of the GRW flash theory. On this view, the quantum-mechanical wave-function and its temporal development according to a dynamical law (the Schrödinger equation, or the GRW equation) is a mere instrument of economical book-keeping of the distribution of the local beables (the flashes).

Nonetheless, if one takes the physical and philosophical reasons for a richer ontology that includes relations of quantum entanglement to be convincing, it is reasonable to regard these relations as being dynamically relevant. Putting the matter in causal terms (again without presupposing any specific theory of causation), that is to say in the case of the GRW flash theory that structures of correlated flashes cause the occurrence of further correlated flashes, being their common cause.[9] The wave-function and the dynamical law in which the wave-function figures describe how they do so. The wave-function thus is not a mere instrument of

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6 See Maudlin (2008 and 2011, chap. 10) for a discussion of that proposal.

7 See e.g. Esfeld (2004).

8 See e.g. Lewis (1986a, pp. ix-x). See Darby (2012) for a recent assessment of this conflict.

9 See e.g. Esfeld (2009).

economical book-keeping, but refers to something that there is in space and time over and above the distribution of the local beables. One illustration of this view is the claim that the correlated flashes under consideration include as a whole the disposition or propensity to bring about further correlated flashes.[10] In any case, these relations are not limited to time-like separated flashes, but connect space-like separated flashes. That is to say, structures consisting in correlations among space-like separated flashes are dynamically relevant for the occurrence of further correlated, space-like separated flashes (e.g. by including the disposition or propensity to bring about such correlated flashes).

It is not clear whether and how such an ontology could be spelled out by working only with the space-time structure of special relativity theory, that is, without presupposing an objective foliation of space-time. If there are correlations among space-like separated flashes and if the existence of such correlated flashes determines, via the wave-function and its dynamics, the occurrence of further correlated and space-like separated flashes, then it seems that an objective temporal order of both the initial and the subsequent correlated and space-like separated flashes is required. In general, hence, as soon as one admits relations of quantum entanglement existing in space-time and takes these relations to be dynamically relevant, it is not clear how one could achieve an ontology of quantum physics that is Lorentz invariant, even if one recognizes only sparsely distributed flashes as the local beables of one's quantum theory.

Over and above the issue of correlations existing among space-like separated flashes and their dynamical relevance, there are further problematic aspects of the flash ontology. The theory is formulated in terms of particles, assuming that there is a fixed number of particles (at least as long as quantum field theory is left aside). However, there are no particles in its ontology. There are only flashes, each flash being an event occurring at a space-time point. There are no continuous sequences of flashes that could be considered as worldlines of particles, since the distribution of flashes in space-time is sparse. There are only occasionally flashes occurring at a space-time point.

Although the distribution of flashes is sparse, let us suppose for the sake of the argument that there are enough flashes to account for macroscopic objects, not going into the reservations that Maudlin (2011, pp. 257-258) voices as regards this point. Consider what the flash ontology tells us about typical quantum mechanical experiments. In the double slit experiment with one particle at a time, according to the flash ontology, there is one flash at the source of the experiment and one flash at the screen, but nothing at all in between, apart from the macroscopic object with two slits; the question of whether the quantum system travels through one slit or through both slits does not make sense in this ontology, since there is nothing at all in the space between the source and the screen (apart from the macroscopic device with two slits). By the same token, in the EPR-Bohm experiment, there are two flashes at the source, and then one flash in each of the two wings of the experimental set-up, corresponding to the two measurement events, but again nothing at all in between.

This fact is troublesome, for the story that the GRW dynamics tells about measurement does not make sense on the flash ontology: in the EPR-Bohm experiment, that story says that the measuring device in one wing of the experiment interacts with the quantum system, so that the state of the quantum system becomes entangled with the state of the measuring

10 See the dispositionalist ontology for GRW that Dorato and Esfeld (2010) propose.

device. That entanglement is extremely rapidly reduced, for one among the enormous number of particles that make up the measuring device immediately undergoes a spontaneous localization so that all the other particles, including the quantum system, are localized as well. But this story does not make sense on the flash ontology for there is nothing with which the measurement device could interact. There is no particle that is absorbed by it, and no field or wave in physical space that stretches out to it either. In sum, there are good reasons to have reservations about the flash ontology and to be sceptical as to whether this ontology can really achieve a peaceful resolution of the conflict between quantum theory and relativity theory.

If one admits local beables that are continuous in space-time (that is, do not leave gaps between them, space-time may be discrete), then, as things stand, one is in any case committed to an objective foliation of space-time into spatial hypersurfaces that are ordered in time (although we can in principle not know that foliation). Apart from the GRW flash ontology, there are two other precise proposals for local beables of quantum physics, namely Ghirardi's proposal for a mass density ontology developing according to the GRW equation (Ghirardi et al. 1995, Monton 2004) and Bohm's quantum theory in terms of particles moving on definite trajectories in space-time (going back to Bohm 1952). Both these proposals are committed to a privileged foliation of space-time.[11]

Nonetheless, even if one is committed to settling for *a* particular foliation of space-time, one can rescue the principle according to which *all* foliations are equivalent by maintaining that what exists depends on a particular foliation, and that what exists is not unequivocal (nothing simply exists), but depends on the specification of a particular foliation of space-time.[12] This claim is on a par with the anti-realist claim according to which what exists is relative to an observer in the sense of a conscious subject, a language, a discourse, a conceptual scheme, etc. The problem with all these proposals is that they presuppose that the observer, the language, the discourse, the conceptual scheme, or the foliations of space-time for that matter all do exist without their existence being relative to anything.[13]

In sum, if one does not endorse the flash ontology and goes for a quantum theory that admits local beables that are continuous in space-time, then, as things stand, it seems that one cannot reasonably avoid the commitment to accepting that there is a preferred foliation of space-time, although we cannot know which one that preferred foliation is. This then is the basis on which one can make a case for presentism in quantum physics: if there is an objective foliation of space-time into spatial hypersurfaces that are ordered in time, then one can maintain that these hypersurfaces come into and go out of existence so that only one such hypersurface exists. Note that admitting an objective foliation of space-time is only a necessary and not a sufficient condition for endorsing presentism as characterized at the beginning of this paper: an eternalist can also recognize an objective foliation of space-time and then maintain that *all* the temporally ordered spatial hypersurfaces simply exist. But the eternalist has no motivation to be keen on recognizing an objective foliation of space-time, thereby provoking a conflict with special and general relativity theory, whereas the presentist has to face that conflict and can draw on quantum non-locality in order to argue that special and general relativity theory do not tell the full story about what there is in space-time.

11 See Maudlin (2008) for an explanation of why this is so.

12 See Fleming (1996) and Myrvold (2002 and 2003). See also the view of Fine (2005) mentioned in note 2.

13 See Heil (2003, in particular chap. 1.1) against any such relativism.

Nonetheless, the presentist then has to develop further arguments to justify the step from there being an objective foliation of space-time to the commitment to presentism.

Let us briefly consider in concrete terms how the case for presentism can be made by going into Bohmian mechanics, the contemporary dominant variant of Bohm's theory that is also the most elaborate version of a quantum theory with local beables.[14] Following Bohmian mechanics, the local beables are particle positions. These particle positions develop in time according to a law that is known as the guiding equation:

(1) $$\frac{dQ}{dt} = v^{\Psi_t}(Q)$$

In this equation, Q stands for the configuration of N particles in three-dimensional, physical space at a time t, and Ψ_t is the quantum mechanical wave-function of this particle configuration at t. The wave-function itself develops in time according to the Schrödinger equation. Its role in Bohmian mechanics is to fix the velocity v of the particles at t given their position Q at t. In short, the guiding equation (1) takes as input the particle positions at t and yields as output the velocities of the particles at t by means of the wave-function of the particle configuration. To be precise, the guiding equation takes as input the positions of *all* the particles in the universe at t, and the wave-function figuring in it accordingly is the universal wave-function of the configuration of all the particles in the universe at t. That is how Bohmian mechanics accounts for quantum non-locality, namely by making the temporal development of the position of any particle, its velocity, dependent on strictly speaking the position of all the other particles in the universe. (Nonetheless, Bohmian mechanics is operational, for it is possible to derive effective wave-functions that describe sub-systems of the universe by abstracting from the rest of the universe). Bohmian mechanics thereby admits relations of quantum entanglement in the form of correlations among space-like separated particles that are dynamically relevant (cf. the remark about the flash ontology above).

That is also how Bohmian mechanics accommodates presentism: this theory commits us to accepting the particles' positions at t and the wave-function at t. The ontological status of the wave-function is a controversial matter: the wave-function is a mathematical object defined on configuration space. The controversy about its status is beyond the scope of this paper. Suffice it here to mention that one can regard this mathematical object as representing a holistic and dispositional property of all the particles taken together that determines their form of motion by determining their velocity – in other words, that determines the temporal development of the particle configuration.[15] What is crucial for the purpose of this paper is that on whatever reading of Bohmian mechanics, this theory is committed only to entities that exist at a given point of time. The theory describes the temporal development of these entities, but in doing so it does not require a commitment to entities that exist at more than a point in time.

Bohmian mechanics therefore accommodates presentism even more easily than Newtonian classical mechanics: Bohmian mechanics is a first order theory, whereas Newtonian mechanics is a second order theory. That is to say, Bohmian mechanics accepts only the position of the particles as primitive and derives their change of position in time (i.e., their

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14 See the papers in Dürr, Goldstein and Zanghì (2012) as well as Dürr and Teufel (2009) for a textbook presentation.

15 See Belot (2012, pp. 77-80) and Esfeld et al. (2012).

velocity) by means of the wave-function. Newtonian mechanics, by contrast, accepts both the position and the velocity of the particles as primitive and derives the change of velocity in time (i.e., the acceleration of the particles) by means of their inertial mass and external forces. However, acknowledging velocity as primitive implies that one endorses as primitive a quantity that is strictly speaking not defined at a point in time, but only for an arbitrarily small interval. By contrast, both the position of particles and their wave-function are well-defined at a point in time.

Let us note a few points in order to assess this result: (1) On the one hand, we have found no argument that goes as far as claiming that a certain version of quantum theory entails presentism. The result is only that some versions of quantum mechanics are compatible with presentism. At most, one can say that these versions accommodate presentism, as illustrated by considering Bohmian mechanics. (2) On the other hand, in order to make a case for quantum theory excluding presentism – in the same sense as the special and the general theory of relativity exclude presentism –, one would as a necessary (but not sufficient) condition have to develop an account of quantum non-locality that does not presuppose an objective foliation of space-time. Such an account has not been worked out hitherto, and there are important reservations against the account that comes closest to fulfilling this condition (Tumulka's further development of Bell's flash ontology). Therefore, the case of presentism is open from the physical point of view.

(3) As mentioned above, moving from quantum mechanics to quantum field theory does not change that matter, since quantum non-locality as given by the violation of Bell's theorem concerns quantum field theory in the same way as quantum mechanics. Furthermore, it seems premature to take the search for a quantum theory of gravity into account in this context. Monton (2006) maintains that there may be a prospect for a quantum theory of gravity that is based on an objective foliation of space-time, but Wüthrich (2010) objects that none of the more advanced approaches to quantum gravity admit a privileged foliation of space-time. This debate seems premature, since as a prerequisite for a sensible discussion of the relationship between quantum non-locality and relativity physics, one has to elaborate on what one takes to be the local beables of the quantum theory in question, and none of the more advanced approaches to quantum gravity has as yet spelled out the local beables to which it is committed. Moreover, some of these approaches suggest that space-time does not belong to the ontology of fundamental physics, but emerges from non-spatio-temporal elements of reality. However, this conception of emergence is left entirely vague. As Lam and Esfeld (2012) have shown, none of the precise notions of emergence is applicable in this case.

(4) Even if one subscribes to presentism on the basis of an account of quantum non-locality in terms of a privileged foliation of space-time, there is no empirical conflict with special or general relativity, since the principle of the equivalence of all inertial reference frames and the principle of the equivalence of all foliations of space-time do not have empirical consequences. All empirical phenomena can be formulated in one reference frame or foliation, whichever one chooses (and whichever happens to be the objective one, if there is an objective one). Furthermore, presentism is compatible with the central tenet of general relativity theory according to which space-time is itself dynamical instead of being a background structure. Even if there is a privileged foliation of space-time, the spatial and temporal distance between events may depend on their physical properties such as their mass. Moreover, in this context, one is not committed to going back to endorse anything like an

ether that serves as the privileged inertial frame. On the contrary, one can maintain that the distribution of mass in the universe fixes the objective foliation of space-time.

To put the matter in other words, given the fact that there is a conflict between quantum theory and relativity theory and given that, as things stand, the only precisely worked out proposal for a peaceful resolution of this conflict meets with serious reservations, one can resolve this conflict by giving up the relativistic principle of there being no objective foliation of space-time without facing empirical consequences. But one cannot resolve this conflict by giving up quantum non-locality, since quantum non-locality in the sense defined at the beginning of this section is an empirical fact.

(5) Even if there is a privileged foliation of space-time, all the versions of quantum theory that are committed to such a privileged foliation imply that we can not know which one is the objective foliation of space-time. Callender (2008) formulates on this basis a coordination problem between the unknowable privileged foliation of space-time to which some versions of quantum theory such as Bohmian mechanics are committed and presentism as based on common sense, more precisely as based on the experience of a particular foliation of space-time. Nothing guarantees according to Callender (2008) that these foliations coincide. However, it is doubtful whether there is the experience of one particular *global* foliation of space-time in common sense, given the limited scope of common sense experience and given in particular the fact that the velocities with which we are familiar in common sense are very small in comparison to the velocity of light.

One can with reason maintain that the point at issue in the support that presentism can draw from common sense is temporal becoming: the block universe view (eternalism), to which one is committed if one accepts the principle of the equivalence of all foliations or inertial reference frames, rules out temporal becoming, since everything that there is in space and time simply exists. One can argue that (a) common sense and in particular our experience of ourselves as acting beings in the world are based on the view that our future gradually comes into existence and that (b) it is this commitment to temporal becoming that drives the common sense support for presentism. Consequently, in order to do justice to common sense, an ontology that admits temporal becoming is required. But it is of no importance which one is the privileged foliation of space-time and whether or not we have an epistemic access to that privileged foliation.

Furthermore, subscribing to presentism on the basis of recognizing an objective foliation of space-time in the ontology of physics makes room *only* for accommodating temporal becoming in the ontology, thus fulfilling what one may take to be one requirement in the theory of human agency. However, if one maintains that agency implies free will and that furthermore free will is incompatible with determinism, one can draw no support from physics. The dynamics of Bohmian mechanics is deterministic. The dynamics of the GRW theory is indeterministic, but includes probabilities that are completely fixed by physical variables alone – no agent that stands outside the laws of physics could manipulate the GRW probabilities. Thus, endorsing presentism based on an objective foliation of space-time is no means to alleviate the conflict between physical laws and free will, if one assumes that there is such a conflict.

In sum, one can compare the argument for an objective foliation of space-time from quantum non-locality to Newton's famous bucket argument. Newton postulates more space-time structure than is observable, namely absolute space and motion with respect to absolute space. By means of the famous bucket argument, he argues that we have to endorse absolute space in order to accommodate rotation, since rotation cannot be considered as relative motion. He gives a precise account of how rotation can be conceived as motion in absolute space. We have to recognize absolute space although doing so contradicts the well-established metaphysical principle of the identity of indiscernibles; but the denial of this principle does not lead to a conflict with empirical results, whereas rotation is a form of observable motion that has to be accounted for.[16]

By the same token, one can argue that in the context of today's physics, we have to postulate more space-time structure than is observable, namely an objective foliation of space-time, in order to accommodate quantum non-locality as manifested in the EPR-Bohm experiment. Once one endorses an objective foliation of space-time, there are full and precise accounts of quantum non-locality in space-time available (Bohm's theory, as well as the GRW mass density ontology in the framework of a collapse dynamics). We have to recognize an objective foliation of space-time although doing so contradicts one of the theoretical principles on which the special and the general theory of relativity are founded; but the denial of this principle does not lead to a conflict with empirical results, whereas quantum non-locality is an empirical fact that has to be accounted for.

Consequently, the philosopher-physicist who is not willing to admit Newtonian absolute space is committed to giving a full and precise account of rotation that does not presuppose absolute space, which neither any of Newton's contemporary critics did nor Mach accomplished.[17] By the same token, the philosopher-physicist who is not willing to admit more space-time structure than is recognized in the special and the general theory of relativity is committed to giving a full and precise account of quantum non-locality in space-time that is Lorentz-invariant. As in the case of a relational account of rotation, so in the case of a Lorentz-invariant account of quantum non-locality, this is of course not to say that such an account cannot be achieved, but only that there is a challenge to be met that should not be underestimated.

4. The deeper issue: the ontology of physical objects and the case for presentism

Classical mechanics as well as Bohmian mechanics are theories that propose an ontology of matter in motion: the fundamental physical domain consists in moving particles. The behaviour of complex objects is to be explained in terms of their composition by particles and the movement of these particles. Thus, Newton famously writes at the end of the "Opticks" (1704):

> … it seems probable to me, that God in the Beginning form'd Matter in solid, massy, hard, impenetrable, moveable Particles …; no ordinary Power being able to divide what God himself made one in the first Creation. … the Changes of corporeal Things are to be placed only in the various Separations and new Associations and motions of these permanent Particles. (Question 31, p. 400 in the edition Newton 1952)

The particles do not have spatial parts: they are located at points in space. They do not have temporal parts either: each particle is wholly existing at the point in space where it is located at a given time. It moves in the sense that the whole particle changes its position, being located at another point of space at another time. By moving the particle creates a continuous

16 See Maudlin (2012, chap. 2) for a forceful reconstruction of Newton's argument.

17 The most elaborate account today is Barbour (2002).

trajectory in space-time. The trajectory occupies a region in space-time, more precisely a worldline. The worldline has spatial as well as temporal parts, but the particle has no parts at all. Thus, employing technical philosophical vocabulary, the particle persists in time by *enduring*, that is, by wholly existing at the location where it is at a given time. A worldline, by contrast, persists by *perduring*, that is, by having spatial as well as temporal parts, so that only a proper part of it exists at any given point in space at a given time.

One can with reason maintain that endurantism implies presentism.[18] The main argument is, in brief, this one: if an object x *wholly* exists at point p_1 in space at time t_1, then it cannot *wholly* exist at point p_2 in space at time t_2 AND it being true that whatever exists in space and time, simply exists, existence not being dependent on time. If x wholly exists at p_1 and if x wholly exists at p_2, then existence depends on time in the sense that when the object exists at p_2, it *no longer* exists at p_1. The argument against solipsism – that is, in this context, the argument against only the space-time point designated as "here-now" existing – then leads us to presentism, that is, the view that a spatial hypersurface ("the present") exists, whereby the spatial hypersurfaces are ordered in time such that they continuously come into and go out of existence. If, by contrast, an object x exists at point p_1 in space at time t_1 and if the same object x exists at point p_2 in space at time t_2 AND if both t_1 and t_2 exist, then x has spatial as well as temporal parts (in short, spatio-temporal parts, like its worldline).[19] Furthermore, one can develop a similar argument to the effect that the existence of motion implies temporal becoming and thereby an ontology that ties existence to time, as does presentism: if an object x wholly exists at point p_1 at time t_1, then it can exist at point p_2 at time t_2 only by its being at p_2 at t_2 coming into existence, as its being at p_1 at t_1 goes out of existence.

An analogous reasoning applies to any ontology that is committed to the motion of something. For instance, if one replaces the commitment to particles with a commitment to waves or fields that move by occupying ever more space in time, then one can defend instead of presentism also a view that recognizes both the past and the present as existing. Such a view is known as the "growing block universe" view. It of course also implies an objective foliation of space-time into spatial hypersurfaces that are ordered in time. The view then is that fields or waves move by growing in space, as what exists grows in time.

If, by contrast, one holds that there is no objective foliation of space-time, then one is committed to the position that the whole of space-time including all there is in space and time simply exists, that is, the block universe metaphysics (unless one sympathizes with the above mentioned solipsism). The content of the block universe then consists in events in the sense of the properties that occur at space-time points. One can reconstruct what we take to be particles as continuous sequences of similar events, so called genidentical events: there are continuous regions of space-time that are distinct from their environment by there being similar properties instantiated in them. Thus, instead of starting with particles and getting worldlines from the movement of particles, one starts with regions of space-time that one can designate as worldlines due to the similarity of the properties instantiated in them and reconstruct what we take to be particles on this basis. A similar reconstruction can be applied to what we take to be waves or fields expanding in space-time. Consequently, there is nothing that moves or changes in time. But one can reconstruct what we take to be the motion or the

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18 But see Sider (2001, pp. 80-87).

19 See e.g. Dorato (2012). Cf. also Benovsky (2009).

change of something on the basis of the variation of events in space-time, that is, on the basis of the variation of the properties that occur at points in space-time.[20]

One may be inclined to take the view that relativity physics simply settles this issue in favour of the ontology of the block universe with events as its content and forces us to reconstruct everything that a physical theory takes itself to be committed to on this basis. However, the metaphysical debate about endurantism vs. perdurantism and, accordingly, an ontology of substances such as particles (or waves or fields expanding in space) vs. an ontology of events remains open. One can with reason say that it does not remain open because metaphysicians tend to ignore physics or are wedded to common sense. One can raise at least two objections against settling for the block universe metaphysics that are based on physics in general and that are independent of the above mentioned issue of quantum physics (quantum non-locality) vs. relativity physics.

The first objection concerns the experimental evidence for any physical theory: that evidence consists in general in particles and their motion, more precisely, in evidence for changes in the state of motion of particles. To mention just two examples, the evidence for quantum field theory derives from various sorts of particle detection measurements. Furthermore, the evidence for the curvature of space-time posed by general relativity theory consists in the first place in tidal effects on the motion of particles.

The second objection concerns the question of what the properties are that the events located at space-time points instantiate which constitute the basic ontology according to the block universe metaphysics. If one asks what the properties are that make up a particle that moves in space and time, one mentions properties such as mass and charge. If one asks for a physical characterization of what these properties are, then one gets a reply of the type that these are dispositions to change the state of motion of particles as spelled out by the laws in which these properties figure – mass as a disposition that leads to acceleration of particles in the form of universal attraction, charge as a disposition that leads to a certain form of attraction or repulsion of charged particles via the creation of a field, etc. In short, the characteristic properties of particles are described in terms of how these properties change the state of motion of particles.

However, if there are no particles and if there is no motion, but a variation of the properties instantiated at space-time points with all these properties simply existing in a block universe, then one cannot use such characterizations in replying to the question of what the properties are that occur at space-time points in a block universe. In other words, one then has to elaborate on another reply to the question of what properties such as mass and charge are (if one wishes to retain these properties in one's ontology). There is one reply worked out in the literature that is based on the fact that one can develop an ontology of general relativity theory that identifies gravity with the metrical field and that, furthermore, takes the metrical field to consist in geometrical properties of space-time points (more precisely, space-time regions that can be pointlike, that is, arbitrarily small). The original programme of geometrodynamics of John A. Wheeler from the 1950s and 1960s is the ambitious project of reducing all physical

20 See e.g. Lewis (1986b, pp. 202-204), Heller (1992), Sider (2001, chap. 4.6). See Benovsky (2006, first part) for an excellent overview of the debate.

properties to geometrical properties of space-time points or regions.[21] However, that programme failed and was subsequently abandoned by Wheeler.[22]

Nonetheless, the failure of a specific programme does not imply that it is impossible to develop a reply to the above mentioned question. But as things stand, the only route open to elaborate on such a reply is of the type that Wheeler envisaged, namely the reduction of all physical properties to some sort of geometrical – or, more generally speaking, mathematical – properties (as given in geometrical, algebraic, or group theoretical characterizations, etc.). The general worry that one can raise against any such project is the old anti-Pythagorean and empiricist one that consists in saying that the essence of physical existence is missed by identifying it with mathematical existence. This, of course, is a debate that reaches far beyond the scope of this paper. But it shows that the issue of presentism concerns much more than just the question of an ontology that suits relativity physics well. And it shows that the case of presentism is open, both from the metaphysical point of view (as argued in this section) as well as from the physical point of view (as argued in the preceding section).

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21 See Wheeler (1962a, in particular pp. XI-XII, 8-87, 129-130, 225-236). For a brief overview, see Wheeler (1962b). For a philosophical characterization, see Graves (1971, ch. 4-5, in particular pp. 236, 312-318).

22 See Misner, Thorne and Wheeler (1973, § 44.3-4, in particular p. 1205).

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