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RELATIONAL TIME

ABSTRACT. The present paper looks at a particular point of intersection between contemporary physics and metaphysics, and claims that a relatively neglected metaphysical theory could become of interest (again) thanks to the interaction between the two. In particular, the paper discusses the relational view of time, whereby time (but not, at least not necessarily, space) is reduced to a structure of relations between events. The argument takes its main cue from Barbour's recent 'Machian' perspective on physical theory. It is contended that it is possible to endorse Barbour's basic insights while not following him in his outright rejection of time as a non-existent entity. As a matter of fact, doing this makes it possible to circumvent some problems that Barbour's theory has to face, especially with respect to the explanation of temporal experience. At the same time, a scientifically credible background to the relational view of time is provided.

1. Introduction

According to substantivalists about space and/or time, space and/or time exist independently of physical objects and processes and are prior to them, as they constitute the 'stage' in which objects exist and physical processes take place. According to relationists, instead, space and/or time depend on physical objects and events: they are derivative on, and even reducible to, relations between things. Slightly differently, according to the substantivalist an ontological catalogue of what exists as a fundamental entity includes portions of space and/or time, according to the relationist it doesn't.

Why 'space *and*/*or* time'? On the one hand, from the purely logical point of view, one's metaphysical theory of space is independent of one's metaphysical theory of time: for instance, a philosopher could be a substantivalist about time while believing that there are good reasons for adopting a relational theory of space. On the other hand, historically relationism and substantivalism have been regarded as 'package deals', whereby space and

In: Tomasz Bigaj and Christian Wüthrich (eds.), Metaphysics in Contemporary Physics (Poznań Studies in the Philosophy of the Sciences and the Humanities, vol. 103), pp. 215-236. Amsterdam/New York, NY: Rodopi, 2015.

time are to be subjected to the same metaphysical treatment. And this has happened, it seems, essentially for two reasons. A first, generally methodological, motivation is that one's basic philosophical stance should be implemented as uniformly as possible. And the arguments for either substantivalism or relationism have often seemed to apply equally to time and to space – two obviously related concepts/entities. Leibniz, for instance, based on his ideas concerning God's creation, the Principle of Economy and the Principle of Sufficient Reason, opposed substantivalism both with respect to space and with respect to time: in both cases, he argued, God would have had no reason for creating a 'container' over and above all the things existing in the universe, nor grounds for locating the universe exactly where it is in fact located within either the spatial or the temporal container.[1] There is also an important, more science-related, reason for what one may label the 'unitary' attitude with respect to the ultimate nature of space and time. It is the fact that 20*th* century physics – in particular, Einstein's Theory of Relativity – seems to have decreed that space and time are not two separate things but rather aspects of a unique, fundamental, four-dimensional entity: space-time.

It is not surprising, then, that the more or less recent philosophical discussion has been concerned with the opposition between relationism and substantivalism in general. That is, it has by and large taken for granted that, whatever the winner of the contention, the corresponding metaphysical perspective would apply to both space and time (or, better, to space-time and nothing else). Indeed, a winner might seem to have emerged clearly quite some time ago. In the 1960s and 1970s, it became a widespread opinion that the space-time manifold could, and should, be regarded as an autonomous entity, fundamental for our physics (see, e.g., Earman (1970)). In the 1980s, difficulties were raised in the form of the 'Hole Argument' (for an illustration, see Norton (2011)). But this 'only' led to the formulation of a 'sophisticated substantivalism', according to which certain space-time models should be regarded as representations of the same state of affairs (see, for example, Hoefer (1996)) – the general opinion with respect to relationism remaining generally unfavourable.

More recently, however, there have been interesting developments. Some have suggested that the metaphysical debate concerning the nature of space and time has become outdated, as it doesn't properly transfer from the classical context Newton and Leibniz worked in to contemporary physics (Rynasiewicz (1996)). Others have argued instead that not only does contemporary physics justify the continuing interest in the metaphysical

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[1] It goes without saying that this is a very rough reconstruction of Leibniz's views.

dispute concerning the nature of space and time, but it also offers important new insights. Here, obviously enough, we will side with the supporters of the relevance of the metaphysical debate. In this context, we will be concerned with two main elements of (relative) novelty: first, the ongoing re-evaluation of the relationist programme in physics (for examples, see Pooley and Brown (2002) and Pooley (2001)); secondly, the progressively more popular idea that time is only an illusion (for an overview, see Callender (2010)), which appears particularly compelling exactly in the context of the 'new relationism'. The leading thought will be, in a nutshell, that it is in fact possible to decouple the revival of the relationist programme and the closely related eliminativist stance with respect to time. And that this leads to a particular answer to the question concerning the nature of time, one affirming:

(a) The mutual independence of space and time from each other (and, consequently, between one's metaphysical views about the former and about the latter);
(b) That there might be physics-based reasons for endorsing a relational theory of time *only* (leaving it open whether space is a substance or it too should be reduced to relations between physical entities).

I believe the resulting conception, i.e., relationism about time only, deserves serious attention for two reasons. First of all, because, as already mentioned, it is a rather underdeveloped philosophical view. Secondly, because, remarkably, a lot of the arguments that have been recently provided in favour of the idea that physics tells us that time is an illusion – most notably, the arguments developed in the last 15–20 years by Julian Barbour – crucially rely upon a) relationist ideas and, as already pointed out in the past (for example, by Healey (2002) and Rickles (2006)), b) on an important ambiguity between reductionism and eliminativism. Consequently, the possibility appears worth exploring (especially from the perspective of a broadly naturalistic methodology) of providing a scientific basis to temporal relationism as an explicitly non-eliminative stance. In what follows, ~~moreover,~~ I will argue that the approach to physics delineated by Barbour constitutes a plausible basis for a respectable form of 'selective' relationism, about time but not (necessarily) about space, and make some suggestions as to how to articulate such a relationist stance.

To be clear, my aim here is not so much to discuss the merits and/or limits of Barbour's approach to physics; nor of relationism as a view on the metaphysical nature of time. Rather, the paper only aims to make two *conditional* claims. First, that *if* one has independent, a priori reasons for being a relationist about time, then s/he should also try to make his/her views credible from a naturalistic, scientifically informed perspective;

and the best way to do so is to endorse an elaboration of Barbour's views. Secondly, that *if* one has independent, scientific reasons for taking Barbour's views seriously, then one should consider interpreting those views in terms of (a particular version of) relationism, rather than antirealism, about time. In this context, what will be said specifically about space can and should be intended as a relatively independent philosophical addition. Another thing that must be made explicit is that this paper does not aim to do anything like providing a detailed solution to the so-called 'problem of time' in quantum gravity, which is at the basis of the idea that time is an illusion. Rather, it will exploit some ways of dealing with the problem that have been proposed in, or at least can be reconstructed from, the recent literature with a view to lending support to the specific metaphysical view under scrutiny.

The structure of the paper is as follows. The next section provides a – very brief! – reconstruction of the relationist view of time (and space) – and of its opposition to substantivalism – from Aristotle to modern and contemporary physics. This will be instrumental to providing some distinctions, definitions and qualifications. Section 3 explores in some detail recent arguments against the reality of time – in particular, those based on the Machian perspective developed by Barbour – and employs them for sustaining instead a realist, relational metaphysics of time (and not necessarily space too). Section 4 deals with some potential problems for the proposed metaphysical account, and Section 5 contains a concluding summary.

2. A Brief History of Relationism (About Time)

Intuitively, events take place at specific times which pre-exist as potential 'containers' of physical happenings: there might be a moment, the layman is likely to think, in which nothing happens, but that moment would still be real, *hence* temporal instants must be ontologically basic. Relationism opposes this idea, starting from the observation that talk about time is (or at any rate seems to be) exclusively talk about what happens (or may happen), and about relations between certain events and other events. As a matter of fact, relationists argue, quantification over times should not be read literally, as it is simply a convenient instrument.

At least according to its supporters, relationism is made clearly preferable by epistemological considerations. In the present case, it is unquestionable that events are less mysterious entities than times – if only because we can make direct experience of (some) events but not of any instant of time *per se*. And, of course, this epistemological aspect goes hand in hand with considerations of economy. In the present case, if I can meaningfully talk about time and things that happen in some sort of sequence while only positing the latter sequence in my ontology, there are good reasons not to postulate the existence of time as a fundamental entity as well. Here, we will not discuss this in detail but, rather, take the above considerations as *prima facie* compelling reasons for carefully exploring the prospects for relationism – primarily, of course, in the form of relationism about time.

The best known supporter of relationism is indubitably Leibniz. However, a relational view of time can be traced back to Aristotle. In the *Physics*, and in particular in Sections 10–14 of Book IV, Aristotle explicitly argues that time is distinct from, but existentially dependent on, change, that is, on relations between *numerically and qualitatively* distinct events. In particular, for Aristotle time is "a number of change with respect to the before and after" (219b 1–2): instants of time, that is, can be distinguished, counted and ordered in a series only on the basis of modifications in what exists, and of the properties that things exemplify in different 'sections' of their existence.[2] Leibniz makes a similar, but more radical, point when he says that "instants, consider'd without the things, are nothing at all; [...] they consist *only* in the successive order of things" (1704 (1956), third paper, Section 6, emphasis added).

That Leibniz is a relationist also about space is well-known. For example, he states: "I hold space to be something merely relative, as time is; [...] I hold it to be the order of coexistences, as time is an order of successions" (Ib.; 25–26). ~~T~~he motivation for this particular sort of relationism, applied to both space and time, was for Leibniz – very roughly – that both space and time as containers for physical objects and events are superfluous; and that, so understood, they would entail too many unrealised possibilities, a choice among which couldn't be grounded in any way (these are the well-known observationally indistinguishable shifted universes that Leibniz used to refute Newton and his followers).

Leibniz's relationism didn't remain unchallenged. In 1689, Newton had already formulated ~~the~~ notorious bucket experiment: if we picture a bucket suspended by a rope which starts rotating around the rope's axis, first bucket and water are at rest with respect to each other, then the bucket rotates but the water is at rest (bucket and water are in motion relative to each other), but ultimately bucket and water are mutually at rest (the water moving with the same velocity as the bucket). Since in the last phase the water's surface becomes concave but water and bucket are at rest in

[2] It is arguable that Aristotle's definition indicates that he takes time to be essentially the by-product of conscious experience. We will set this aside here.

relation to one another – which was not the case in the initial stage of mutual rest – there's something that must be explained but cannot be explained by having recourse to the relativity of the water's motion with respect to the bucket.[3] Strictly speaking, the bucket argument was intended by Newton to prove the weakness of Descartes' views of space as identical with matter and of the 'proper motion' of bodies as relative to other, *neighbouring* bodies – *not* that motion *requires* an absolute background. Exegetical matters aside, however, Newton can be legitimately regarded as the paradigmatic enemy of relationism; historically, his arguments have indeed been primarily interpreted as direct arguments in favour of substantivalism and absolute space and time. As is well known, Leibniz debated at length the force of Newton's considerations with Newton's follower Clarke. Independently of the details of this philosophical dispute, it is unquestionable that the Newtonian reflections[4] turned out to constitute formidable obstacles to relationism. In more detail, the dispute remained open for a long time, and many thinkers sided with Leibniz. Among these, Huygens, Berkeley and, most importantly, Mach between the second half of the 19th and the beginning of the 20th century. Mach's response to Newton's bucket thought-experiment, in particular, was that absolute acceleration is relative to the fixed stars, that is, to the universe as a whole. More generally, absolute space was systematically replaced by Mach with a fully relationist analogue, and the same goes for time. From the point of view of philosophical motivation, Mach (especially in his *Science of Mechanics*, 1883) started from the observation that Newton departed in a striking way from his own key methodological tenet, according to which one should not go beyond observational facts. Based on this, Mach tried instead to truly and fully implement Newton's principle, which more or less immediately led him to dispense with absolute space and time altogether. In particular, Mach tried to make do with *relative distances* only, the key idea behind the Machian relationist approach to physics. However, Mach's project was not a success. Even though people such as Reichenbach went as far as to argue that Einstein's Theory of Relativity fully vindicated the Machian perspective, hence relationism, it seems rather the case that the workability

[3] Newton also imagined a pair of globes connected by a rope and revolving about their centre of gravity. This he took to show that, despite the fact that absolute space is invisible to the senses, it is nonetheless possible to infer the quantity of absolute motion of individual bodies.

[4] Kant reinforced the substantivalist case by bringing considerations about 'chirality' to bear on the issue, and presenting them as providing further indisputable support to substantivalism. Using a famous example, Kant argued that in a space containing only a single hand, its being a right or a left hand could not be established on the basis of relational facts, but is an objective matter nonetheless.

of a completely relational physics remained doubtful to say the least. First, as mentioned, Einstein's relativity was almost unanimously taken to show that space and time form a unitary whole and cannot be considered as separate entities. And such a unitary space-time progressively came to be regarded as a basic element in the context of the theory, *to be understood as a fundamental substance*.[5] More generally, modern-day relationists ~~might be able to translate substantivalist models in relational terms, but —~~ exactly like Leibniz ~~— they~~ seem to remain in any case unable to produce a 'relationally pure' physics, where everything we need to know about physical systems can be expressed without making any reference to an objective spatio-temporal background. In other words, substantivalism about space and time came to be regarded as correct, as an absolute background, i.e., an inertial structure and a temporal metric, appear necessary for our physics to work (see, e.g., Pooley and Brown (2002, Section 4)).

However, in spite of the foregoing facts, which unquestionably give substantivalism about (space-)time some advantage, there are other elements to be taken into account, having to do with some of the most recent developments in physical theorising.

3. Contemporary Physics and Barbour's Machian Perspective

One of the fundamental tasks of contemporary physicists is that of putting quantum mechanics and General Relativity (GR) together in a theory of quantum gravity, so solving the obvious problem represented by the mutual incompatibility of the two theories when taken as they are currently formulated. Roughly speaking, there are two main approaches: some physicists give priority to quantum mechanics (superstring theories, for example, go in this direction), others regard relativity as more important, thus essentially attempting to quantize Einstein's GR. The focus here will be on the latter approach. Let us, therefore, look at it in more detail.

Canonical quantum gravity emerged in the 1950s and 1960s as a first attempt to employ the same techniques used to give a quantum formulation of electromagnetism in the case of gravity. In particular, in the late 1960s DeWitt formulated the basics of the theory by making use of previous work of Bergmann and, even earlier, Dirac. This kind of research developed in~~to~~

[5] Although, for reasons already mentioned in the introduction, not one constituted by points provided with primitive, irreducible identities that could give rise to distinct, yet indiscernible, spatio-temporal arrangements in scenarios such as those contemplated in the hole argument.

a number of different directions. In so-called ‘loop quantum gravity’, for instance, space becomes discrete, a network of finite entities (the loops). Other options include the use of so-called ‘Regge calculus’, or of cosmological ideas developed by Hartle and Hawking. All these approaches share the ‘problem of time’: very briefly, time is not *presupposed* as a background ‘container’ but rather *described* by GR, and it turns out to disappear in the context of quantum gravity, as the wave-functional that supposedly describes the evolution of the universe does not change (more on this in a moment). This has led to the idea that physics, and the physical world itself, should be regarded as *timeless*. According to Rovelli, for example, as one moves to a deeper and deeper level of reality, time as a fundamental quantity disappears: mechanics turns out to be the theory of relations between variables, not a description of how things evolve in time, the latter being regarded as a somehow ‘special’ variable. Time only emerges at a later stage, more or less as a variable singled out as preferred given the specific state of the system.[6]

But it is Julian Barbour’s views that deserve the most attention here. In work carried out in the last three decades or so, including his book (1999), Barbour translated the Machian idea of grounding the whole of physics on relations between (observable) quantities – in particular, as we have already seen, instantaneous relative distances – into the view that the only things that exist are configurations of physical systems – that is, of interrelated objects and properties; and that reference to absolute space and time can, and in fact should, be systematically interpreted in terms of relationships between different configurations. To support this view, Barbour noticed first of all that, although a bunch of particles obeying Newton’s laws and their relative distances are not enough for reconstructing the entire sequence that we would identify with a ‘history’ of the relevant physical system – that is, with a physically possible evolution of that system – only a little more is required. In particular, while only referring to the space of configurations makes one unable to describe how physical evolution takes place (i.e., to specify the total kinetic energy and the ‘orientation’ of the dynamical behavior of the relevant system), there is a family of dynamical principles formulated on configuration space alone that allows one to predict a unique curve for each point in configuration space and direction of evolution from that point. These principles correspond to the

[6] More precisely, Rovelli puts forward a ‘thermal time hypothesis’, according to which when we identify a certain physical variable as ‘time’ we only make a statement about the statistical distribution that we use to describe a physical system at the macroscopic level, ignoring the full microstate. Nothing like an ‘objective’ temporal magnitude exists.

Jacobi principle formulations of dynamics. In a nutshell, these formulations implement a generalised principle of least action and identify possible histories with paths in configuration space that are of extremal length with respect to a metric defined on the basis of the metric structure of three-dimensional physical space. In this way, the geodesics of the newly defined metric correspond to inertial trajectories of particles. In this context, the configurations that can follow each other in the relevant sequences of (descriptions of) physical systems are determined by what Barbour calls 'best matching' – basically, a generalisation of Pythagoras' theorem applies, and the overall differences among distinct configurations with respect to all the quantities appearing in them turn out to be systematically minimised. Starting from this, to obtain a fully Machian physics one 'just' needs one additional element: namely, an assumption concerning the angular momentum of the universe. Indeed, there is a subset of the solutions to any Newtonian theory that indicates that, *provided that* the total angular momentum of the physical system under consideration (measured with respect to its centre-of-mass inertial frame) is zero, then *relative quantities are sufficient for a complete physical theory*.[7] In view of this, Barbour concludes, relationism is eventually fully vindicated by postulating that the total angular momentum of the universe is actually zero.[8]

Relationism seems to become even more natural when one moves beyond the classical domain. Together with Bruno Bertotti, Barbour showed that, once GR is formulated as the dynamical theory of the geometrical features of space coupled with that of matter fields, it turns out to have a purely Machian nature, and thus not to require any further treatment to satisfy the relationist desiderata. More specifically, when intended in the sense of geometrodynamics on superspace (the latter being the configuration space

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[7] It also follows that isolated subsystems are correctly described by the full Newtonian theory, which straightforwardly accounts for the seeming greater naturalness of the non-relationist approach in the more realistic scenarios available to us, which clearly involve less than the entire universe.

[8] Or, maybe better, is not a well-defined quantity, as there is nothing with respect to which it can be measured. One might complain that what was just described is a very relevant assumption, and that the fact that it is necessary to make it shows that relationism is untenable, as it crucially depends on contingent features of the universe. However, it can also be argued (Belot (1999)) that what may look like a very strong, and possibly even ad hoc, assumption is in fact a decisive prediction that provides a fundamental bit of empirical support to the theory. For, granted that relationism doesn't get off the ground if the universe as a whole is not 'static' in the above sense, one can regard the latter state of affairs as a consequence of the theory rather than an assumption, and proceed to see whether or not the ensuing prediction is correct, so effectively 'testing' the Machian approach. And Belot points out that there is evidence that our universe is in fact non-rotating.

constituted by the set of 'acceptable' geometries of space[9]), GR can be regarded as the theory of relationships between 3-geometries, and the relevant configuration space is an entirely relative configuration space. In a sense, then, GR seems to contain right from the start exactly the sort of action principle that the relationist had, as it were, to actively 'plug into' classical mechanics.[10]

Lastly, and most importantly, Barbour puts quantum considerations into the picture, and argues that quantum gravity too can be formulated in terms of relative configurations. This, he argues, requires one to give priority to the time-*independent* Schrödinger equation. That is, in the case of the universe as a whole the Wheeler-DeWitt equation

$$\hat{H}|\psi\rangle = 0$$

must be used, which is naturally interpreted as conveying the information that the wave-function of the universe is constant. Thus, it looks as though one has to do with a 'frozen formalism' that mirrors the fact that *the universe does not change* – not, of course, in the relatively uninteresting sense that it should be considered as a four-dimensional 'block', already familiar from Relativity alone – but rather in the sense that, given the Hamiltonian constraint, the relevant transformations in phase space do not affect the state, the physical observables having to be invariant with respect to such transformations.

The upshot is, then, that all (physically) possible states of the universe are 'ontologically on a par', and what seems to be a sequence of states in time is instead a completely different path *in a timeless space including all the possible* '*ways the universe could be*'. In particular, Barbour endorses a 'many instants' interpretation that turns the Everettian many-worlds line of thought into the idea that all 'worlds' – he calls them 'Nows' – exist together – a sort of physically-motivated version of Lewisian modal realism. Is this view compelling? What else can be said about time, and relationism, in this framework? Can realism about time still be regarded as a viable conception? To answer these questions, we now turn to the more constructive part of the paper.

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[9] In particular, the quotient space of all Riemannian metrics defined on the 3-manifold under the action of spatial diffeomorphisms that map different spaces into one another.

[10] More precisely, under certain conditions the orthodox four-dimensional action of GR can be put in a form (the BSW form firstly formulated by Baierlein, Sharp and Wheeler (see, for instance, their (1962)) which is a particular case of the general form defined by Barbour.

4. Problems for Barbour, Definition (and Limited Defence) of an Alternative

The biggest problem for the supporter of the view that the universe is fundamentally timeless is to explain why we perceive it as evolving in time. What is Barbour's solution to this problem?

Barbour's many-instants view relies on the idea that the path connecting the various Nows is determined by best matching together with the probability distribution described by quantum mechanics. Crucially, Barbour *conjectures* that the quantum probability distribution is such that the most probable configurations, i.e., among other things, those which are most likely to be part of a trajectory *which involves human observers making experiences*, are those highly structured ones that contain 'time capsules'. The latter are physical subsystems ~~encoding~~ information that our brains process as if it were information about Newtonian trajectories across canonical time.

According to Barbour, then, one should be an 'error theorist' about time: whenever we have the perception that something shifted from being possible to being actual, and from being present to having been present, we are in fact elaborating in our brains peculiar kinds of information that are, in actual fact, non-temporally 'written' in the physical configuration(s) in which we happen to find ourselves. To use well-known labels, Barbour follows McTaggart in accepting the existence of an objective but non-temporal structure in the physical domain (something like McTaggart's C-series) which grounds the relations of being 'earlier than', 'simultaneous with' and 'later than' holding between events (McTaggart's B-series) in virtue of a decisive contribution coming from the human mind, which is the only place where a fundamental distinction between future, present and past (the A-series) can be found. Crucially, though, while McTaggart's C-series is an objective ordering, a sequence of elements that follow one another in some sense, Barbour's 'Platonia' is instead like a completed puzzle, all the pieces 'given together at once'. In light of this, it should appear clear that the idea of a time capsule and the assumption that quantum probabilities are peaked around appropriately structured Nows are essential in Barbour's framework.

While of course naturalists should be ready to endorse (in fact, should actively seek) an error theory of this sort whenever they find that one of our commonsense and/or philosophical presuppositions is put into question by our best science, the problem here is that it is not entirely clear that the error theory provided in the present case is ~~satisfactory,~~ There are two reasons for this claim, one having to do with explanatory strength and the other with the physical basis of the proposal. Starting from the first point, it could be argued that the sort of Leibnizian 'temporal monadism' endorsed by Barbour – whereby time reduces entirely to the internal structure of the individual configurations – "does a fair job of capturing the central features of the *experience* of time" (Ismael (2002, p. 326)). Ismael grounds this assertion on the fact that a lot of our everyday experience involving the past is indeed based on 'mementos', i.e., physical signs in the present that get the mechanisms of temporality started in our heads. However, Ismael herself acknowledges the problem that something being a record of something else presupposes the sort of causal relations that Barbour rules out, and thus it remains unclear exactly what makes an instantaneous configuration of the universe a time capsule, i.e., what mechanism is responsible for there being mementos in our experience. Developing a suggestion made in passing by Baron, Evans and Miller (2010, p. 53), one may add to this the following consideration: our temporal experience is primarily experience of change, but to be experience of change, such experience must itself change, as it cannot but consist of a 'diachronic process of interpretation', as it were, of the available data by our brains. Even more generally, we perceive our experience as a process and as itself changing, and this again seems to *presuppose* something like a temporal dimension and, possibly, to consequently open the way for a vicious regress analogous to that employed by McTaggart to demonstrate the unreality of time – but now directed to Barbour's error theory. If the foregoing is correct, it follows that Barbour's ~~error theory~~ is unworkable: our temporal experience might well be illusory, but to be so it has to have certain 'dynamic' features that Barbour's picture doesn't seem to be able to reconstruct – exactly because it denies that physical reality is objectively ordered along *some* dimension.[11]

As for the second problem with Barbour's error-theoretic reconstruction of temporal experience, it can be stated quite briefly: Barbour never formulates a truly convincing argument in support of his claim that (some) solutions to the Wheeler-DeWitt equation give high probability to configurations containing time capsules – which is clearly crucial for his peculiar

[11] Analogous worries are raised by Healey (2002), who emphasises the fact that physical theorising essentially relies on observations and experiments that, it would seem, necessarily occur in time. Related to this, Baron, Evans and Miller also argue that Barbour's view threatens to lead to temporal solipsism as, according to it, we are confined to single points in configuration space and can never access other configurations. Time capsules, that is, only give us the (wrong) impression of being able to collect information about several distinct physical configurations. This criticism, however, seems to be off the mark, as it is exactly Barbour's intention to replace our traditional, commonsense understanding of our perceptual (in particular, temporal) experience. On the other hand, it is true that the acceptance of solipsism represents a non-negligible cost for those accepting Barbour's views.

explanation of the 'psycho-physical parallelism' holding with respect to time and temporal experience. It is at least unclear whether this is compensated by the overall strength of the theory or, to the contrary, makes the proposed reconstruction of the psychological side of the issue irredeemably ad hoc because based on a mere conjecture.

In light of the above, one may start to think that, if at all possible, one should be a relationist (in particular, about time) rather than accepting Barbour's antirealism about time. That is, try to preserve the Machian perspective construed by Barbour without also accepting Barbour's eliminativist views, so avoiding the need for a consistent error-theory of temporal experience altogether. After all, it is an obvious, yet important, philosophical fact that relationism is a form of reductionism, but not all forms of reductionism amount to full-blown eliminativism.[12] At this point, then, it is necessary, first, to say more about what time could look like from a non-eliminativist viewpoint in the context of a Barbour-like quantum gravity. In connection to this, secondly, more should be said about the differentiated treatment of space and time that we have indicated as at least a conceptual possibility. There is a lot to be said of course, and, as mentioned earlier, we will not pretend to have a final solution (this would not only be overambitious, but also beyond the aims of this paper, which is only intended as a general overview of a particular area of interplay between traditional metaphysics and contemporary physics, with the addition of one or two more specific suggestions for further research).

Let us begin by looking again at the origin of the timelessness of quantum gravity, i.e., the Wheeler-DeWitt equation. While it is true that the route followed by Wheeler and DeWitt for quantizing GR with specific initial 'constraints' are normally taken to lead to a manifestly time-independent equation, this 'only' entails that the t variable does not refer to a fundamental physical magnitude. But of course this leads to eliminativism about time in the metaphysical sense only if one assumes that, if it is real, time must be a fundamental entity – which is exactly what the non-eliminativist relationist denies. Thus, one should explore the possibility of either

[12] Compare with Healey's (2002, p. 303) idea of replacing the 'Parmenidean' timeless view with the 'Lockean' view that time is a secondary quality. To be absolutely clear, the point being made is not that one should buy Barbour's views as a package and add the label 'real!' to them. Rather, the ideal aim is i) to re-establish the objectivity of the sequence of 'stages' that Barbour's 'temporal monadism' had eliminated (so replacing, as it were, the completed puzzle whose pieces do not and cannot communicate with each other with an ordered deck of cards which get uncovered one by one, the figure of each one of which depending on that on the previous one); ii) say more about the relevant relational structure, so recovering at least a minimal notion of physical time.

recovering time in some way from the available degrees of freedom (the 'internal time' approach) or 'imposing' it from outside as an additional element (the 'external time' approach). Either way, what one obtains is, essentially, the view that i) the intrinsic sequential ordering typical, say, of McTaggart C-series should be also attributed to the Machian relationist universe; and, additionally and crucially, ~~that~~ ii) contrary to what McTaggart and Barbour would say, that objective structure is itself intrinsically temporal.[13] How can this be done?

The view I would like to put forward (once again, only as a suggestion for future work) is a sort of 'hybrid approach' between the internal time option and the external time alternative. The idea is that the observables that act as the relata of temporal relations are all the fundamental properties of physical systems; and that the relations that connect these relata with each other are nothing but Barbour's 'best matching' relations – which consequently end up coinciding with the canonical 'earlier than' and 'later than' relations.[14] An obvious objection is that this only amounts to naïve relationism, as a physically-respectable formulation of the view requires the related quantities to be gauge invariant, which they haven't been shown to be yet. A response to this objection can be given in the terms recently suggested by Barbour himself together with Koslowski and Mercati (2013). According to these authors, in the context of so-called 'Shape Dynamics' (a theory of gravity that implements Mach's principle, and in which the spacetime picture is replaced by a picture of evolving spatial conformal geometry) it is possible to define a variable τ with the desired features in terms of the overall expansion of the universe D. In particular, $\tau = D/D_0$

[13] Notice that the crucial assumption that the Machian has to make concerning the 'staticity' of the universe as whole can also be made in a non-eliminativist setting, regarding it as a constraint on the possible evolution of physical systems ordered in a linear series rather than a description of something that is true of them when they are all considered together (perhaps cosmology can provide a non-teleological elucidation of such a constraint). For one, Butterfield (2002) explicitly agrees with this separation of Barbour's relationism from his antirealism about time: "Barbour's views are by no means a package deal [... and his] denial of time, and speculations about quantum theory and quantum gravity [...can be] left on the shelf" (Ib.; 291). In particular, Butterfield explicitly notices that that based on eliminativism with respect to time is only one possible interpretation of the Wheeler-DeWitt equation.

[14] For each and every configuration in the overall relevant space there will exist either only one other configuration (or, at most, only one type of configurations) that 'follows' it as its best match, which naturally corresponds to a deterministic temporal evolution; or more (types of) configurations that, in different ways, match the initial configuration equally well, which is naturally interpreted in terms of non-deterministic, or at any rate 'chancy', temporal evolution. In any case, best matching intended as a relation holding between different physical configurations ordered in an objective sequences (rather than coexisting in a timeless 'Platonia') seems sufficient to reconstruct a canonical temporal sequence.

(with D_0 being the value of D at the point chosen to begin evolution), and $\partial f / \partial \tau = D_0\{H, f\}$ (with f being the relevant shape variable); and τ turns out to be a monotonic and dimensionless independent variable whose growth is determined "by all physical degrees of freedom working together." Importantly, in the words of Barbour, Koslowski and Mercati, the "variable τ appears as an internal time, but it is an external evolution parameter in the scale-invariant dimensionless description." Of course much more can and should be said, but this seems a promising avenue for the non-eliminativist relationist about time who intends to follow Barbour's suggestion the development of a Machian physics and a working theory of quantum gravity.[15]

Having said this, let us move on to our second crucial question. Why draw on Barbour's relationism in order to be relationists about time only? Well, first of all let me remind the reader that the fundamental claim of this paper is that one can be a Machian relationist without accepting the idea that time is a mere illusion, while leaving it completely open what the metaphysical status of space is. Thus, the position being put forward is best intended as neutral with respect to space, and equally liable to be developed in the sense of a) a full-blown relationism about both time and space, and of b) a 'mixed' view whereby spatial substantivalism goes together with temporal relationism.

However, there are reasons for not regarding (a) above as the obvious choice, and indeed for regarding (b) as a serious alternative. As Pooley (2002) argues, and Rickles (2006) approvingly reports, Barbour's claims with respect to GR might be best interpreted in terms of substantivalism about space. In particular, Barbour's treatment of GR might be said to demand that the relative configurations taken to be fundamental be relational

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[15] The ground for the work just mentioned was at least partly prepared by James W. York. In David Brown and York (1989), for instance, it is suggested that the usual action principle of General Relativity is analogous to Jacobi's form of the principle of stationary action, and that elaborating on this analogy one can arrive at a time-dependent Wheeler-DeWitt equation in which the role of physical time is played by the four-volume of space-time. On this note, at least two other recent works must be mentioned. Gryb and Thebault have recently elaborated upon the idea of a 'York ontology' and a 'York time variable' which is the canonical conjugate to the spatial volume. In their (2012), they argue more extensively that, once General Relativity is translated into the terms of shape dynamics as suggested by Barbour, modulo certain formal extensions of the theory a non-standard procedure of quantization can be implemented that leads to a dynamical theory of quantum gravity which retains a canonical temporal structure (while, however, not reintroducing an absolute, non-relational notion of duration). Lastly, on a different note, Okon and Sudarsky (2014) suggest that objective collapse models could usefully contribute to the solution of the problem of time by selecting a privileged frame of reference.

specifications of the properties of space (matter fields need not be present in all cases); and that this entails that such a Machian rendering of the theory in fact *requires* a substantival treatment of space.[16] Without entering a detailed discussion of whether this claim is correct, we can certainly say here that, if Pooley and Rickles are at least remotely on the right track, it immediately follows that ~~it is *a fortiori* fair to say that~~ the Barbour-inspired relationalist about time *may have good reasons* to ~~be, at the same time,~~ a substantivalist about space (and, obviously enough, ~~even more~~ reasons to refrain from saying anything about space). Whatever one decides, the fundamental point is that it is *physics itself* that shows that space and time ~~are not~~ on a par, in terms of conceptual, formal and ontological standing, within Barbour's perspective. In particular, not only does this follow from the general fact that Barbour is an antirealist about time but not about space, together with the considerations just reported concerning substrantivalism about space possibly being the best interpretation of what Barbour says about GR. It also follows from the fact that ADM formulation of general relativity[17] which Barbour employs is based on the idea that the dynamics of the theory does not concern four-dimensional distances in a 4D block, but rather distances in three-dimensional space-like surfaces. This makes it possible (although, of course, not necessary!) to treat the diffeomorphism constraints and the Hamiltonian constraints of the theory differently, following a suggestion made, for instance, by Kuchar (1993).

In view of the above, it seems that we are now in a position to make at least the conditional claim that *if* one regards relationism about time (and perhaps *only* about time) as compelling, then such a view can be shown to be perfectly compatible with (some parts of) contemporary physics; and to even be supported by (a specific interpretation of) the latter, developed along the lines suggested by Barbour in his work in support of the Machian approach to physical theory. Obviously enough, it should not be forgotten that Barbour's vision is not mainstream, and indeed his proposal is incompatible with both standard GR and other, perhaps better developed,

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[16] Of course, for reasons that we have already mentioned at the beginning of the paper, if this were the case substantivalism would then have to be made 'sophisticated' enough not to attribute haecceities to space(-time) points. This opens the way for the criticism, raised for instance by Belot and Earman (2001, pp. 248–249), that there is no third way between traditional substantivalism and relationism, and thus one should be a relationist about space too. Without entering into the details, this is exactly the position that Pooley attacks in his abovementioned (2002), and I agree that 'mild' substantivalism about space is in fact a ~~plausible~~ option.

[17] That is, the Hamiltonian formulation of GR proposed and developed from 1959 onwards by American physicists Arnowitt, Deser and Misner.

approaches to quantum gravity. Nonetheless, that something counts as a conceptual possibility which is not straightforwardly ruled out by science is already an important fact from the philosophical viewpoint, at least in a broadly naturalistic context. Moreover, it should be acknowledged that, when it comes to assessing and choosing theories and hypotheses at the intersection between science and philosophy, no straightforward algorithm is present – let alone a direct derivation from scientific 'data' – and a careful consideration of different factors should instead be carried out. In this sense, one's independent, and more philosophical, reasons for being a relationist in general, and about time in particular, might outbalance the disadvantages of the chosen approach from the purely physical viewpoint. For sure, whatever one's personal views on these matters may be, only a cautious assessment based on a preliminary identification of the various options can lead to progress.

Having said this, let us now conclude by considering three other potential objection to Barbour's Machian perspective and/or its proposed reinterpretation in terms of realist relationism about time.

As we have seen, the geometrodynamic formulation of GR turned out to be the Machian version of the theory that Barbour was looking for, and in it the metric based on best matching between configurations makes it possible to ground the dynamics exclusively on relative dimensional configurations. This, however, has been taken (e.g., by Pooley (2001; Sec. 3.2)) to lead to a problem of indeterminism. The idea is, essentially, that there are many different sequences of configurations of the desired type (i.e., satisfying the least action principle in geometrodynamics) that can be 'extracted' from the canonical four-dimensional relativistic space. But such sequences constitute observationally indistinguishable 'histories'. Moreover, two sequences can be identical up to a point and radically differ afterwards and, consequently, the specification of an initial sequence appears insufficient for predicting the rest of the evolution of that sequence. A form of indeterminism thus emerges, analogous to that emerging in the context of the hole argument. This suggests that the traditional four-dimensional formulation of GR should, after all, be preferred to its Machian reformulation as the only framework that guarantees the needed uniqueness of configuration-sequences. However, the surplus degree of freedom might be disposed of by formulating the theory on so-called conformal superspace allows one to identify families of sequences in such a way that, ~~in effect~~, a unique curve in relative configuration space is individuated in the relevant cases in any general relativistic space-time. This suggestion (see, for instance, the work by Barbour and Ó Murchadha (2010)) is still under study but it does seem to have the potential to eliminate the difficulty just pointed at. One might point out that, since the above amounts to adopting Leibniz-equivalence for spatial configurations, it naturally suggests relationism about space too, not only time. This might be the case but, first, it does not affect our claim that relationism about time only is at least a philosophical possibility which is in no way explicitly refuted by our best physics. Moreover, the sophisticated substantivalist, especially if s/he agrees with Pooley's abovementioned claims about the need to interpret space in substantival terms in the context of Barbour's reconstruction of GR, can point out an analogy with the debate concerning the hole argument, and insist that the claimed equivalence has no obvious metaphysical consequences.[18]

On a more general note, it could be objected that both geometrodynamics and the Wheeler-DeWitt equation are very questionable: the former was popular from the mid 1960s to the early 1980s, but has now been replaced by physicists with more sophisticated programmes such as, for example, loop quantum gravity; the latter has always been difficult to interpret and make sense of, even at the purely mathematical level. Couldn't these facts be sufficient for keeping away from approaches to the interpretation of physics that require one to put one's emphasis exactly on geometrodynamics and on the Wheeler-DeWitt equation? As may be expected, the reply is that this objection misses the key point: namely, that certain approaches to quantum gravity are being pursued because they have turned out to lead to some progress, and that since progress was based in this case on the use of geometrodynamics and the Wheeler-DeWitt equation, this is sufficient for re-establishing the respectability of the latter two elements. Indeed, as pointed out, for example, by Brown (1996, p. 197), quantum gravity is problematic in itself, and *every* attempt and approach in that context has its own difficulties. Given this, one could contend that – even admitting the difficulties he has to face – Barbour provides a new motivation and a new interpretation ~~to~~ the geometrodynamical programme (although, arguably, this does not yet put geometrodynamics on an equal footing with respect to the extant alternatives) and a new way of dealing with the Wheeler-DeWitt equation.[19]

Another relevant issue, although of a rather different, more purely metaphysical nature, has to do with temporal vacua. While, strictly speaking,

[18] After all, if this were not the case, relationism would have been nearly-unanimously preferred to substantivalism already in the case of the traditional hole argument, which clearly not been the case.

[19] It shouldn't be forgotten, in this connection, that progress with respect to the Wheeler-DeWitt equation has been made: some (e.g., Smolin (2001)) claim to have found solutions to it, ~~and~~ the existence of such solutions is central, for example, in both loop quantum gravity and the path-integral approach to quantum gravity.

this is not a problem a philosopher of physics needs to be worried about, it becomes relevant when one attempts, at a more general level, to put together the strongest possible combination of a coherent metaphysical view and a workable interpretation of the relevant physics. Since this is exactly the level of discourse that the present paper ~~was~~ intended to be at, we will discuss the temporal vacua objection to relationism about time, albeit briefly, before closing. This will, at the very least, be instrumental to illustrating the 'other side' of the metaphysics-physics interplay as well.

With the aim of putting the originally Aristotelian conviction that time implies change into question, Shoemaker (1969) (see also LePoidevin (1991, pp. 94–98)) considered a world consisting of three disjoint regions each one of which completely 'freezes' and remains changeless for a precise period of time at regular intervals. These intervals are different for the three regions, so as to entail a) that freezes in each region can be observed (or, better, indirectly reconstructed based on the available evidence) by the inhabitants of the other regions, who can then inform the inhabitants of the relevant region of what happened to their part of the world; and b) that some freezes can occur simultaneously in the three regions. Shoemaker argues that a) lends support to the idea that the global freezes suggested by b) are not only possible but also something that is reasonable to expect and regard as real given the available data. Of course, this means that in Shoemaker's imaginary world a global freeze does not imply that time stops (for, local freezes do not entail this, and global freezes are entirely anal~~a~~gous to local ones), and this seems to count against relationism. For, clearly, in such a world there are no changes, no relations between different events in terms of which the passing of time can be analysed, and yet – we just concluded – time does pass. Now, the mere conceptual possibility of temporal vacua ~~has~~ certainly be~~en~~ taken to add to the force of the substantivalist perspective on time. But there are answers available to the relationist. Against the temporal vacua objection, first of all, some (among others, Newton-Smith (1980; pp. 42–47) and Butterfield (1984)) suggested a reformulation of relationism in modal terms, so that time is said to pass between two distinct instants t_a and t_b if and only if there is either an actual *or a possible* event occurring at an instant t_n in between t_a and t_b. Others argued instead that, upon scrutiny, it can be maintained that in fact "we are unable to conceive of a world about which it is clearly reasonable to claim that time passes but no events occur" and, thus, despite appearances to the contrary Shoemaker fails to prove his point (Warmbrõd (2004, p. 282)). Last but not least, I take it that it is also possible to claim that change is in fact not required for real passage of time in the relationist framework, as sequences of *merely numerically distinct* events are sufficient. After all, the identity conditions of events do not analytically entail qualitative novelty and/or qualitative uniqueness, and if time is reducible to relations, why should it matter whether or not the relata of such relations are qualitatively distinct? If this is correct, the relationist can contend, contra Shoemaker, that time can in fact pass without change.[20] When this happens, s/he will add, for every thing that appears to persist 'frozen' in the relevant interval there in fact is a sequence of several events that are exactly similar qualitatively and yet non-identical.[21] This appears to be compatible, quite importantly, with the idea of grounding temporal succession on best matching and the evolution of physical observables along the lines suggested above. For on Barbour's construal it seems to be an open possibility that an instantaneous configurations best matches an absolutely indiscernible one (which, on the present proposal, plays the role of its temporal successor).

5. Conclusions

~~In spite of the dominant trends in the literature~~, there seems to be some relatively unexplored space for manoeuvre at a particular point of the thin, and sometimes blurred, boundary between science and metaphysics. In particular, at the intersection between the related but distinct debates between relationism vs. substantivalism and '3+1' space and time vs. four-dimensional space-time. The present essay has attempted to identify this area of potential philosophical research, illustrate some of its features and put forward some suggestions. In particular, some recent work on the implementation of a Leibnizian-Machian relationist perspective to contemporary physics has been exploited with a view to recommending both a separation – at the metaphysical and physical level – of space and time, and a defence of relationism with respect to the latter only (remaining instead neutral with respect to space, if not suggesting substantivalism about it). Julian Barbour's recent work has been analysed in special detail, and his Machian perspective preserved while rejecting his anti-realism with respect to time. Besides being instrumental to a defence of a specific, intuitively more plausible, metaphysical perspective where time is not eliminated altogether, this has been presented as advisable on

[20] An obvious consequence of this is, clearly, that relationism should *not* be formulated as the view that time is reducible to change, but rather as the view that temporal relations are reducible to physical relations between objects and properties, independently of whether or not the latter, as relata of the relevant relations, are qualitatively different from each other.

[21] Interestingly, independent metaphysical arguments in favour of the primitive identity of events have been provided: see, in particular, Diekemper (2009).

independent grounds, having to do with the strength of Barbour's account when it comes to making sense of our perception of time. Turning the 'flat and frozen' relational structure identified by Barbour into a genuine sequence and enriching it with further features, it has been argued, allows one to avoid antirealism about time while also augmenting the theory's explanatory power – most notably, with respect to temporal experience. The discussion aimed to nothing more than a first, quite general illustration of certain philosophically relevant facts and possibilities. Nonetheless, its outcomes appear sufficient for confirming the fruitfulness of the interplay between contemporary science, especially physics, and metaphysics, and to suggest that the relatively neglected option of relationism about time deserves more careful examination in the future (~~P~~erhaps in connection with the other fundamental opposition in the metaphysics of time, namely, that between presentism and eternalism – or, more generally, A-theories and B-theories of time).

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