Studies in History and Philosophy of Modern Physics 52 (2015) 48–54

Contents lists available at ScienceDirect

Studies in History and Philosophy of Modern Physics

journal homepage: www.elsevier.com/locate/shpsb

Does time differ from change? Philosophical appraisal of the problem of time in quantum gravity and in physics

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ARTICLE INFO

Article history:
Received 16 December 2013
Received in revised form
10 March 2015
Accepted 15 March 2015
Available online 27 October 2015

To my father

Keywords:
Time
Change
Barbour
Rovelli
Bergson
Lautman

ABSTRACT

After reviewing the problem of time in Quantum Gravity, I compare from a philosophical perspective, both Carlo Rovelli's and Julian Barbour's (before Shape Dynamics) understanding of time in Quantum Gravity and in dynamics in general, trying to show that those two relational understandings of time differ. Rovelli argues that there is change without time and that time can be abstracted from any change whereas Barbour claims that some motions are better than others for constituting duration standards and that time is to be abstracted from all change in the universe. I conclude by a few remarks on Bergson's criticism of physics in the light of those debates trying to show that both Rovelli and Barbour give surrationalist (as Bachelard understood it) answers to the critique of spatialized time in Physics.

1. The problem of time in quantum gravity

The problem of time is a consequence of the application of general covariance (or better: background independence via active diffeomorphism invariance) in canonical Quantum Gravity. Since philosophical beliefs exert implicit or explicit constraints on physics and physicists, I believe that a proper understanding of the application of background independence to time has to come to terms with the philosophical debate over time and change.

Time plays a problematic role in the framework of the canonical approaches to Quantum Gravity. This should not come as a surprise once we acknowledge the initial incompatibility between time in Quantum Mechanics and Quantum Field Theory and time in General Relativity. In Quantum Mechanics, the parameter t that appears in Schrödinger's equation is an external and non-dynamical parameter. It is Newton's absolute time.[1] In Quantum Field Theory, Newton's absolute space and time are replaced by the spacetime of Special Relativity. Minkowski's spacetime does not interact with the fields under consideration. It remains a background entity on which one describes the quantum behavior of the field. It is a rigid stage for the dynamics of fields and matter. Contrary to General Relativity, Newton's time and space and Minkowski's spacetime are non dynamical.[2]

Historically, the canonical quantization method, when applied to Hamiltonian General Relativity, gave birth to the Wheeler-DeWitt equation. This equation is a dynamical equation where no parameter t appears on the right side, as it is the case, for example, in Schrödinger's equation. It is the main dynamical equation of the theory but it does not take into account evolution in time[3].

1.1. Background independence and time evolution

General Relativity is a generally covariant theory; coordinates have no physical meaning.[4] The equations of General Relativity are invariant under any sort of coordinate transformations, among

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[1] Newton's time is an absolute background in which the temporal order (topology) and the duration (metric) between events is defined independently of the changes in the material universe (cf. Gryb & Thébault, 2014).

[2] See for example Stachel (in Ashtekar, 2005), Macias & Quevedo (2007) and Kiefer (2007).

[3] More generally, background independent attempts to formulate Quantum Gravity have “no time problems” in their formalism, (cf. Anderson (2013a).

[4] Background independence is stronger than general covariance which often fails to be non-trivial and is implemented via active diffeomorphism invariance which ties together general covariance and the absence of non-dynamical background fields. (cf. Rovelli, 2004; Giulini, 2007).

http://dx.doi.org/10.1016/j.shpsb.2015.03.010
1355-2198/

others, under time translation. In General Relativity, evolution in time is problematic because time evolution is a coordinate change and generally covariant formalism should be blind to coordinate change.[5] It seems like, if time evolution is a diffeomorphism, time does not exist.[6]

Back in the 90's, Julian Barbour[7] proposed a radical understanding of the Wheeler-DeWitt equation: at the Planck scale, there is no change and no time:

> "I suggest that quantum gravity is static and simply gives relative probabilities for all the different possible three-dimensional configurations the universe could have.[8]"

No time nor change, evolution nor motion. Nothing happens, everything is. Many philosophers but also physicists have rejected this timelessness of quantum gravity.[9] The reason for this refusal is quite obvious in this dialog between Kuchař and DeWitt:

> "DeWitt: you want a "time". You want to see something evolve. Kuchař: I do not *want* to see things evolving. I *see* things evolving and I want to *explain* why I see them evolving.[10]"

Can there be non-temporal becoming ? Is the evidence all around us in nature the evidence for time or for change (cf. Markopoulou & Dreyer)? Do we need time to understand and describe, change, evolution or becoming (cf. Kuchař)? Can there be dynamics without time?

Either time is the same thing as change and if it is, it is indeed a problem to have a dynamical equation without time. Or time is not the same thing as change and at least on the conceptual level, it is not incoherent to have change without time.

1.2. *Physics without time: a view on Carlo Rovelli's solution*

This solution relies on a relational understanding of space and time in which the lesson of General Relativity is understood as the disappearance of spacetime as an entity of its own replaced by a dynamical object, the gravitational field. Since General Relativity is the understanding that spacetime and the gravitational field are the same entity, Carlo Rovelli argues that there is no spacetime but just the gravitational field. This reinforces his relational philosophy in which physical entities are made of particles and fields and not particles and fields living on a background. There is no background. In this relational view, one has to accept that we don't live *in* space and that we don't evolve *in* time either:

> "In classical GR, there is no meaning to *R*(t). There is no meaning to the value of the radius of the universe at some coordinate time *t*. What is meaningful is, say, the radius R′ of the universe when a given supernovae explodes. This quantity R′ is well defined, and—in principle—we can ask for its value in quantum gravity. The observables of general relativity are the relative (spatial and temporal) positions (contiguity) of the various dynamical entities in the theory, in relation to one another. Localization is only relational within the theory. This is the relational core of general relativity; almost a homage to its Leibnizian lineage.[11]"

What is in General Relativity the physical meaning of the coordinates *x* and *t*? There isn't one. Spacetime location is relational in a sense that objects do not move with respect to spacetime, they move, evolve and change in relation to one another. There is no time along which dynamics develops as there is no space in which dynamics takes place:

> "Thus, a general relativistic theory does not deal with values of dynamical quantities at given spacetime points: it deals with values of dynamical quantities at "where" 's and "when" 's determined by other dynamical quantities.[12]"

General Relativity predicts correlation between dynamical observables but not physical variables with respect to a preferred time *t*. Change is not described in terms of evolution in time but in terms of relative evolution or correlations between dynamical variables[13] chosen amongst the degrees of freedom.[14] Rovelli proposes the implementation of this relational understanding of evolution in quantum gravity and physics in general, what he calls "physics without time". The interesting point with this formalism is that it does not give you the false impression that you measure time. In other words, this formalism is very coherent with what you find in the practical measure "of time". Indeed our everyday measures "of time" are always correlations of dynamical variables.

Evolution in classical mechanics also deals with dynamical variables with respect to other dynamical variables but when one compares this set of variables, one can easily verify that these observations fit with evolution in *t*. However, Carlo Rovelli argues that this equivalence between relative evolution and evolution in time is dropped at the Planck scale:

> "In particular, it gives us confidence that to assume the existence of the unobservable physical quantity *t* is a useful and reasonable thing to do. Simply: the usefulness of this assumption is lost in quantum gravity. The theory allows us to calculate the relations between observable quantities, such as A(B), B(C), $A(T_1)$, T_1(A), …, which is what we see. But it does not give us the evolution of these observable quantities in terms of an observable *t*, as Newton's theory and special relativity do. In a sense, this simply means that there are no good clocks at the Planck scale.[15]"

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[5] Cf. Penrose, 2004.

[6] Pons, Salisbury & Shepley (1997), argues that in the canonical formulation of General Relativiy, there is a clear distinction between time evolution and diffeomorphism symmetry.

[7] This article focuses on Barbour's work before Shape Dynamics. This new theory of gravity that was developed in the last years by Barbour and his collaborators (Niall Ó Murchadha, Edward Anderson, Henrique Gomes, Sean Gryb, Tim Koslowski and Flavio Mercati) is a reformulation of General Relativity in which the relativity of simultaneity is replaced by the relativity of size (conformal invariance). This theory, that implements Mach's relational ideas to the notion of size, shows differences with General Relativity and gives new perspective on the Big-Bang, the quantization of gravity and the problem of time. Julian Barbour's response to my essay gives a beautiful overview of the theory.

[8] (Barbour, 1994a, p. 2876). But note also: "The quantum universe is *static*. Nothing happens; there is being but no becoming. The flow of time and motion are illusions." (Barbour, 2008, p. 2).

[9] "Attempts to quantize general relativity encounter an odd problem. The Hamiltonian that normally generates time evolution vanishes in the case of general relativity as a result of diffeomorphism invariance. The theory seems to be saying that time does not exist. The most obvious feature of our world, namely that *time seems to progress and that the world changes accordingly becomes a problem* in this presumably fundamental theory." (Dreyer, 2008, p. 1, my emphasis). "There are two kinds of people in quantum gravity. Those who think that timelessness is the most beautiful and deepest insight in general relativity, if not modern science, and those who simply cannot comprehend what timelessness can mean and see evidence for time in everything in nature." (Markopoulou, 2008, p. 1).

[10] Ashtekar & Stachel, 1991, p. 171.

[11] Rovelli, 1999, p. 216.

[12] Rovelli, 2007, p. 1310. In classical general relativity there is no contradiction in accepting relational evolution in the sense of Rovelli and nevertheless evolution in time. See, for example Salisbury, Pons, & Sundermeier, 2010.

[13] For example, a scalar field or a curvature scalar.

[14] Rovelli (2007) makes a distinction between:

- Partial observables: a physical quantity to which one can associate a measuring procedure leading to a number.
- Complete observables: a quantity whose value can be predicted by the theory (this definition refers to classical theory but has a quantum equivalent in which the probability distribution of the quantity can be predicted by the theory).

Relying on such a distinction, Carlo Rovelli argues that at the fundamental level, the variable *t* is on the same footing as any other partial observables.

[15] Rovelli 2004, p. 30.