Reflections on space, time and their quantum nature

Negative philosophical discoveries of Machian approaches to the problem of time

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Outline

- The problem(s) of time in Quantum Gravity and in General Relativity
- Two Machian proposals :
  - Carlo Rovelli 's physics without time
  - Julian Barbour's Platonia
- Negative philosophical discoveries (cf. London&Bauer) and philosophical insights

- The pb of T is a consequence of the application of general covariance (or better : background independence via diffeomorphism invariance) in quantum gravity, especially canonical quantum gravity.

- Since philosophical beliefs exert implicit or explicit constraints on physics and physicists, I do 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.

- My goal is to understand the impact of background independence on philosophical questions on time — especially its relation to change — and in return try to highlight physical debates on background independence in general relativity and quantum gravity by such philosophical issues.

Time in QM, QFT and GR

- Time plays a problematic role in the framework of the canonical approaches to quantum gravity. This should not come as a surprise once accepted the initial incompatibility between time in QM and Quantum Field Theory and time in GR.

Time in QM, QFT &GR

- Time in QM : the parameter t that appears in Schrödinger's equation
  - $i\hbar\partial\psi/\partial\tau=H\psi$
  - is an external and non-dynamical parameter. It is Newton's absolute time.
- In QFT, Newton's space and time are replaced by the spacetime of SR. 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
- Newton's time and Minkowski's spacetime are non dynamical

General Relativity

- In GR : spacetime is dynamical : bad formulation and bad understanding
  - No background spacetime : better.
    - «We can say that GR is the discovery that there is no spacetime at all. What Newton called “space”, and Minkowski called “spacetime”, is nothing but a dynamical object — the gravitational field — in a regime in which we neglect its dynamics» (Rovelli, 2007).

Pb of Time in CQG

- The canonical quantization method, when applied to Hamiltonian GR, leads to the Wheeler-DeWitt equation
- The Wheeler-De Witt equation states that $H\Psi = 0$. 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
- More generally, background independent attempts to QG have no time pbs in their formalism

Background independence and time evolution

- GR is a generally covariant theory, ie :
  - coordinates have no physical meaning
  - The equations of general relativity are invariant under any sort of coordinate transformations, among others, under time translation
    - background independence implemented via diffeomorphism invariance = general covariance+absence of non-dynamical background fields. (cf. Rovelli, 2004 & Giulini 2006)

Background independence and time evolution

- In GR, evolution in time is problematic because time evolution is a coordinate change and generally covariant formalism should be blind to coordinate change. (Cf. Roger Penrose, 2005).
- Hamiltonian GR, 3+1 formulation of GR, time evolution is a diffeomorphism : time does not exist

Barbour's Platonia

- Julian Barbour has a radical understanding of the WDW 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" (1994).
    - No time nor change, evolution or motion. Nothing happens, everything is (Parmenides)

Against timelessness

- Many philosophers but also physicists amongst :
  - Karel Kuchař, William Unruh, Joy Christian, Fotini Markopoulou, Olaf Dreyer or Lee Smolin

Against timelessness (Christian)

- "If, however, temporal becoming is indeed a genuinely ontological attribute of the world, then no approach to quantum gravity can afford to ignore it. After all, by quantum gravity one usually means a complete theory of nature. How can a complete theory of nature be oblivious to one of the most immediate and ubiquitous features of the world ? Worse still : if temporal becoming is a genuine feature of the world, then how can any approach to quantum gravity possibly hope to succeed while remaining in total denial of its reality ? " (Joy Christian, 2007).

Against timelessness (Markopoulou)

- « 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* […]. What is the reason to believe that time does not exist, despite our obvious experience to the contrary ? » (Fotini Markopoulou, FQXi contest, 2009).

Against timelessness (Dreyer)

- « Attempts to quantize general relativity encounters 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» (Olaf Dreyer, Fqxi contest, 2009).

Against timelessness (Kuchař)

- 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
    - *Conceptual Problems of Quantum Gravity (1991)*

Three questions

- Can there be non-temporal becoming (cf. Christian) ?
- 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)?
  - Corollary : can there be dynamics without time ? No time, no dynamics ?

Two proposals

- There are two possibilities
  - Either time is the same thing as change and if it is, it is indeed a pb 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

Rovelli's solution to the pb of time

- This solution relies on a relational understanding of space and time in GR
- Most textbooks present Einstein's 1916 theory as a theory in which spacetime is described in terms of a four-dimensional geometry curved by the presence of matter
- But there is in GR something more profound

Relational core of GR

- Rovelli (1999) : « The image of GR that has emerged from these debates is far less simple than the one on which many contemporary textbook are still based, and than the one held dear by many relativists of the generations that preceded mine - with the notable exception of very few, among whom certainly Stachel and DeWitt. GR discloses a deep relational core, which perhaps does justice to Einstein's early claim about it, and to its specific philosophical lineage. My interest in this problem started from a remarkable conference that John Stachel gave in Stockholm when I was a student.»

- « [G]eneral relativity profoundly modifies our ideas of space and time and prevents us from assuming quantitative relations (such as distance) between two given world points ab initio, [...]. As a result of general relativity we cannot define a given world point merely by (four dimensional) triangulation, that is by stating its distance from a set of four base points ; we can define it only in terms of physical events associated with the world point in question and its surroundings. Thus the notion of space-time as a scaffolding or background against which the drama of the physical process is played out becomes somewhat vague, though it does not lose its significance entirely ». Bergman &Komar (1959).

- «The gravitational field at a certain location represents nothing physically real but the gravitational field together with some other datas does» Einstein (1918)

Relational core of GR

- What is the physical meaning of the coordinates x and t ?
- There isn't one (cf. general covariance, background independence)
- Spacetime location is relational, ie,
  - 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 » Rovelli (1999).
- Or in John Stachel's (2005) words : « A typical pre-general-relativistic question takes the form : Here is a point in space and now is a moment in time (or if you prefer, here-and-now is a point in space-time). In general relativity, here and now cannot be defined before we have a chronogeometry, which presupposes that we have already solved the dynamical equations for the metric tensor field. So here and now cannot be part of the initial question.»

Physics without time

- GR 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 between dynamical variables. (cf. partial observables).
- Rovelli proposes to implement this relational understanding of evolution into quantum gravity : cf. physics without time

- 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.
  - a(b), b(c), c(d)  a(t), b(t), c(t), d(t)
- However, Rovelli argues that this equivalence between relative evolution and evolution in time is scale dependent and 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(T1), T1(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 is no good clocks at the Planck scale » Rovelli (2004).

No time, no dynamics ?

- Background independence forces us to build a novel or generalized conception of dynamics far away from the non-relativistic and ordinary intuition that tells us that dynamics is about change of localization in time

- Dynamics can not be studied and understood in the usual and classical sense, ie involving an external parameter

«Machian time is to abstracted from what change ?» (cf. E. Anderson 2012)

- Evolution is no more measured with respect to some independent variable but can be chosen among the internal degrees of freedom. This is a machian shift.

- "It is utterly beyond our power to measure the changes of things by time. Quite the contrary, time is an abstraction at which we arrive through the changes of things (Mach,1883).

    - any change (Rovelli). There is no distinction between dependent and independent variables. There is no independent time variable. What we measure are the relative evolution of variables all on the same footing. This is the moral of GR that must be taken into account in QG.

    - all change (Barbour). At the classical level, Barbour argues that some motions are better than others

        - Ptolemy and Hipparcus were using sidereal time - which is kept by the rotation of the Earth relative to the background of the stars - not solar time.

        - It was replaced at the beginning of last century by ephemeris time which does not rely on some periodic motion. It relies on the solar system and the laws of motion which we assume to be true (newtonian or with relativistics corrections). cf. Clemence (1952, 1957).

        - Generalized ephemeris time : to the whole universe. «The Universe is its own clock». Ephemeris time is deduced from the system as a whole.

        - Since the beginning of Astronomy and until now, time has never been measured. Clocks do not measure time.

Thermal Time Hypothesis (Connes&Rovelli 1994)

- The TTH has been proposed has a method to identify a time within a background independent context
- Since there is no preferred physical variable, how do we explain the fact that at our scale, a preferred variable is singled out ?
- From this physics without time based on relational evolution, how do we recover a more familiar notion of time : some kind of flow, irreversibility, ...
- Since mechanics treats all variables as equivalent, how do we identify an appropriate clock that can play the role of time for some observers ?
- The idea is that these peculiar features are not of mechanical but of thermodynamical origin. The irreversible phenomena are of statistical origin.
- To well understand all this one must distinguish mechanical time - time of the dynamics - and thermal time characterizing the unfolding of irreversible phenomena. The two notions match in classical physic but not in general relativistic context because of background independence.
  - cf. Rovelli 2009, Rovelli&Smerlak 2010, Martinetti 2011, Bojowald et al., Menicucci et al., Simon 2004, Paetz 2004.

- The thermal time hypothesis (Rovelli 2009) : " In nature, there is no preferred physical time variable t. There are no equilibrium states preferred a priori. Rather, all variables are equivalent; we can find the system in an arbitrary state ρ; if the system is in a state ρ, then a preferred variable is singled out by the state of the system. This variable is what we call time. The statistical states determines which variables is the physical time."

- The TTH also comes also from the algebra of observables of the physical system under investigation. Cf. Martinetti (2011)

- Many of you are very familiar with all of this.
- What more can be said ?
- Physicists are searching for a background independent theory of QG
- What are the philosophical consequences of background independence on time ?

Negative Philosophical discoveries

- London&Bauer 1939 (in Wheeler&Zurek, 1982, PUP)

> Physics insofar as it is an empirical science cannot enter into such problems in all their generality. It is satisfied to use philosophical concepts *sufficient* for its needs; but on occasion it can recognize that some of the concepts that once served it have become *quite unnecessary*, that they contain elements that are useless and even incorrect, actual obstacles to progress. One can doubt the possibility of establishing philosophical truths by the methods of physics, but it is surely not outside the competence of physicists to demonstrate that *certain statements which pretend to have a philosophical validity do not*. And sometimes these "negative" philosophical discoveries by physicists are no less important, no less revolutionary for philosophy than the discoveries of recognized philosophers.

- commented by Maurice Merleau-Ponty (La Nature)
  - One could also talk of relativistic constraints on a metaphysics of time (cf. Peter W. Evans)

The negative philosophical discoveries of GR

- What are the consequences of background independence on time ?
  - Things change and evolve but they don't change in time :
    - Time is not the container of change (nor evolution or becoming)
    - It is not either a dimension along which everything flows

The negative philosophical discoveries of GR

- This is remarkable because there is a long tradition in Philosophy in which time is understood as the universal container of change or the dimension along which everything flows. The expression «in time» can be found in :
  - Plotinus (Enneads III 7), St Augustine (Confessions XI, 24), Aristotle (Physics IV).
    - Every change or motion could stop, time would still flow ; strong version of substantival time
    - Time, analogous to space, is the homogenous medium that bathes everything

In ~~time~~

- In the XXth century, The french philosopher Desanti even explains that the task of phenomenology is to forget the ordinary meaning of the proposition «in time» : time is not a place, a scene or a medium. We must forget the ordinary meaning of the preposition «in» when we talk about time

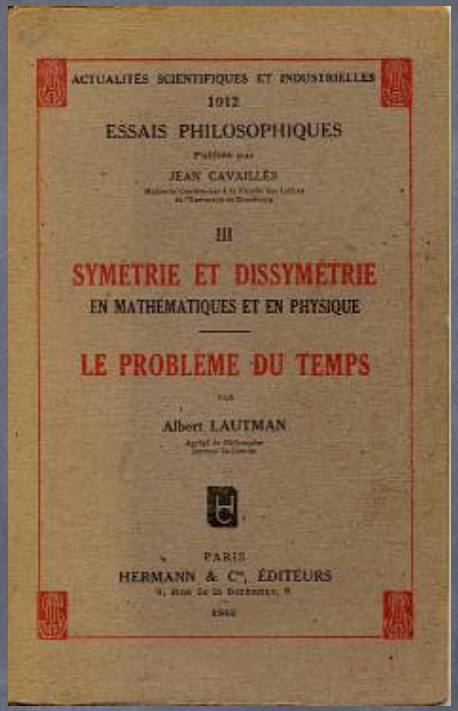
  - « le sens ordinaire de la préposition “dans” que nous utilisons spontanément lorsque nous parlons de notre expérience du temps. C’est même cet usage, tellement ancien, qui devrait faire l’objet de notre examen. Vraiment il serait étrange que ce que nous avons appris à nommer “temps” puisse contenir quoi que ce soit. Et cependant nous disons sans inquiétude : “C’est dans le temps que tout se passe.” Or, ce qui se passe “dans” le temps n’y demeure pas comme en un lieu. »

- We must forget it because time is not a medium

- Each in his own way, philosophers like Bergson or even Heidegger critized time in physics because they were opposed to this conception of time as a medium

- And precisely, the negative philosophical discovery of GR is that time is not such a medium

Lautman



- Albert Lautman, French philosopher, 1908-1944. His contribution to the philosophy of mathematics at his time and to the philosophy of time is still today unrecognized.
  - Essai sur les notions de structure et d'existence en mathématiques (1938)
  - Essai sur l'unité des sciences mathématiques
  - Symétrie et dissymétrie en mathématiques et en physique
  - Les Mathématiques, les idées et le réel physique

Lautman

- In an essay on the problem of time, published in 1946, he explains the necessity to distinguish in physics the time-parameter from the time-coordinate. Let us consider the following three statements :

- 1. Time flows in one and only direction 2. Objects persist through time 3. Dynamical variables evolve according to time. There is variation according to time.

- The first two statements refer to time as a dimension whereas the third refers to time as a parameter. Can we identify the parameter of evolution, which one finds in the laws of nature, to time understood as an entity by itself ? Lautman even explains that the parametrization could in principle be done with any other independent variable !

- However, does this time-parameter naturally leads us to the concept of time-dimension, as for example in Newton's theory ? Classical physics was naturally led to see the same entity in the time-parameter as in the time- dimension. But because of background independence, this implicit identification is lost in GR.

- And Rovelli's idea of no good clocks at the Planck scale can be interpreted as «pure variation».

Ambiguities between time and change

- What do we mean when we talk about time ? This idea of global change or what can make sense of change ?
- at the ordinary level : It is common to say that things change in time but also that time flows. Is time the scene of what changes or the essence of change ?
- at the philosophical level : Against Kant that differentiates time and change, Hegel claims that time is nothing more than change or becoming

Ambivalence between time and change

- at the level of physics :
  - the measure of change and change itself
  - Or mechanical time and thermodynamical time
  - Time of the dynamics and irreversibility (entropy)

- But in some ways, mechanical time contradicts irreversibility because it is based and even constructed on periodicity, repetition and return : cycle of the seasons, earth's rotation, light pulse, etc.
- Mechanical time denies irreversibility and at the mean time it is used to measure change
- Cf. Rémy Lestienne et Hervé Barreau

The overrun of this ambivalence in quantum gravity ?

- In GR and a fortiori in QG : no mechanical time because no background metric
- But one can construct a Thermal time that grasps irreversibility
  - Both of these two features might overrun this ambivalence

Time is real (Smolin)

- One last thing, amongst those who refuse the «timelessness» of RG and QG, Bergson is often requested by those who think that «time is real» and has to appear in some way in the formalism of QG (Smolin, Christian, etc.)
- Not so paradoxically, I think that the timelessness of QG as it appears in the Rovelli program is much closer to some of Bergson's intuition.

- People misunderstood what Bergson meant when he said that time is real
- What Bergson criticized is the attempt to understand becoming via time-dimension or time conceived as a homogenous medium. Change has no need of a support
  - « le changement n'a pas besoin d'un support »

Bergson

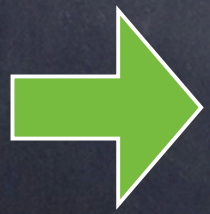
- Bergson's concern is not about time. It is about change. He criticizes physics (Newton) or some philosophers (Kant) because they are trying to understand change through some rigid and external parameter.
- When he claims in his unfortunate book (1922) on special relativity that Einstein - with minkowski spacetime - has invented a new way of spatialising time, he is right, he is not saying something very different that the fact that minkowski spacetime is a fixed stage on which one examine behavior of fields and matter.

Bergson

- He also criticized this idea that time could be conceived as an independent variable

Bergson (1907)

- « Let us conclude, then, that our science is not only distinguished from ancient science in this, that it seeks laws, nor even in this, that its laws set forth relations between magnitudes: we must add that the magnitude to which we wish to be able to relate all others is time, and that modern science must be defined pre-eminently by its aspiration to take time as an independent variable »



The «no time» physics

- Mechanical time is inappropriate to understand change's essential feature, irreversibility. Somehow, the disappearance of mechanical time within a free background context and the TTH fits perfectly in a Bergsonian context
- Time is no more considered as an independent variable, as a dimension or as a medium
- This overruns the ambivalence between time and change that one finds in physics as well as in philosophy

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