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

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ABSTRACT

In this paper I respond to the paper "Does time differ from change? Philosophical appraisal of the problem of time in quantum gravity and in physics" by Alexis de Saint-Ours, in which, among other things, he contrasts the views of Rovelli and myself. There are three main parts in my response. First, I consider Saint-Ours's question about the relationship between time and change and whether it is possible to have the latter without the former. Second, I go into somewhat more detail about the differences between Rovelli and myself concerning the nature of relationalism. Finally, I take the opportunity to discuss how my ideas about the nature of time have changed during the last decade as a result of examination of the role played by scale in the dynamics of the universe.

In this paper, I am responding to the paper "Does time differ from change? Philosophical appraisal of the problem of time in quantum gravity and in physics" by Alexis de Saint-Ours, in which, among other things, he contrasts the views of Rovelli and myself. Since Saint-Ours's paper covers issues on which one could write whole books, I will concentrate on only those that seem to me most important. In particular, I will try to address the following issues Saint-Ours raises in this key passage, which goes to the heart of things:

> 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.

As part of the process of answering the questions that arise here, I will take the opportunity to say how my thinking about time has changed in one key respect in the last decade. Saint-Ours's comments concentrate on the differences between myself and Rovelli circa 2000, which has made me realise an update is needed. I believe my new perspective makes it possible to say something definite about Saint-Ours's issues, at least at the level of classical physics.

I think I must start with comments on geometry, trying to make things as concrete as I can. This is because, unlike all commentators (including Saint-Ours), I prefer not to use terms like general covariance and active and passive transformations. I find their meaning is often not clear. The decades-long debate about the meaning of general covariance makes the point.

We can grasp the essence of geometry through identification of the empirical basis that led to its discovery in antiquity. Nature in its bounty supplied sticks and ropes of twisted fibres with which Egyptian surveyors could measure the distances between objects fixed relative to each other on the Earth. Such measurement aids were found to remain mutually congruent unless affected by a manifest cause. Measurement of distances is based on contiguity. The physical rod is laid next to the physical interval yielding a distance r_{ab} between the ends a and b of the interval. The value of r_{ab} is an empirical fact. Suppose the distances between N fixed points in three-dimensional space are measured. Then $N(N-1)/2$ positive numbers r_{ab} are obtained. They could be arbitrary, but reveal a wonder. If $N \geq 5$, the r_{ab} satisfy algebraic relations; the r_{ab} are very special numbers.

The algebraic relations allow remarkable data compression. One can represent all the information in the r_{ab} by means of N vectors $\mathbf{r}_a$, $a=1,\dots,N$. Then $r_{ab}=|\mathbf{r}_a-\mathbf{r}_b|$, and compression from $N(N-1)/2$ to $3N$ is achieved. There is still some redundancy, because the coordinates can be changed by Euclidean translations and rotations without altering the r_{ab}. Despite the great convenience of Cartesian coordinates, there is one profound difference between them and the r_{ab} that should be noted: the latter 'proclaim their own semantics'. By this I mean the algebraic

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relations between the r_{ab}. They 'tell' us how to make the data compression. In contrast, when considered in themselves, the Cartesian coordinates, which can have arbitrary values, say nothing. They must come with human interpretation. The same applies to the minimal set of $3N-7$ 'true' physical degrees of freedom.

In the light of these comments, what then is space? Leibniz used to say "space is the order of co-existing things". When pressed by Clarke what he meant by 'order' (Alexander, 1956), Leibniz said the distances r_{ab} between the things. I replace Leibniz's aphorism by this: space is the order of co-existing *facts*. The facts are the empirically determined r_{ab}. The set of algebraic relations between them is the order. Our evolutionary history and experiences since birth have given us an intuitive grasp of the order, which we have reified like a block of ice. I think this is the origin of much confusion. Space is not a thing but an ordering principle expressed through the Euclidean group.[1] Goethe's Faust seeks to comprehend "was die Welt im Innersten zusammenhält" ("that which in its innermost core holds the world together"). The world is not held together because its parts, including us, are *in* space. We are not 'bubbles in ice'. There is no 'ice'. The order in facts like the r_{ab} is the world's holistic interconnection. The order simply is. I take it to be the basis of dynamics.

Unfortunately, this understanding of 'space' has been implicit rather than explicit in my writings, as I see from Saint-Ours's comments, but I belatedly spell it out now because it makes it possible to define background independence before we even come to consider dynamics. We must first ask: what is the background from which independence is to be achieved? The background cannot be the order between the r_{ab}. If we were to attempt to jettison that, the whole world would fall apart. As Galileo said, "he that attempts natural philosophy without geometry is lost." Thus, the background is not the order that knits the world together but the coordinate axes used to define the $\mathbf{r}_a$. We must not introduce into our description of the universe anything derived from these *imagined* axes that adds foreign structure to the r_{ab}. No one will take issue with this principle. It is when we come to dynamics, considered below, that the problems begin and where the differences between me and Rovelli start to appear. Probably because I have not been explicit enough, these differences are not fully reflected in Saint-Ours's paper.

This is the point at which I need to present the assumptions I make when trying to describe the universe. One problem in comparing my ideas with Rovelli's is that we both use the word 'relational' but not in an identical sense. The universe may or may not be infinite in extent. If the latter, I do not see how we can ever have a conceptually closed description of it. This is necessary if we are to implement Mach's idea that local inertial motion is an effect of the universe as a whole. Finding that a most attractive idea, I make the hypothesis that the universe is spatially finite. I may well be wrong. Rovelli, as I understand him, keeps his options open. His understanding of relationalism is expressed in the words Saint-Ours quotes:

> The observables of general relativity are the relative (spatial and temporal) positions (contiguity) of the various dynamical entities in the theory, in relation to each other. Localization is only relational within the theory … . 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.

My worry here is twofold. First, we cannot calculate what will happen in a spatially infinite universe because we do not have a well-defined closed system. Second, I find the talk of entities and functional relationships of the kind A(B) somewhat questionable. If we model the world by point particles that we assume distinguishable and eternal, then indeed we can suppose that we observe relationships of the kind $r_{ab}(r_{ij})$, where r_{ab} and r_{ij} are two inter-particle separations. But the question still arises: how do we actually calculate these relationships? According to what law of the universe do they evolve? I will say more about this below. My doubts about Rovelli's relationalism are even more acute in field theory, in which there are no enduring entities. I do not see how to make sense of functional relations like A(B) if no enduring A or B exists.

This brings me to what I think is the real difference, not reflected in Saint-Ours's comments, between Rovelli and me. This is the need to base our theory of the dynamics of the universe on a clear notion of its instantaneous configuration. This is unproblematic in the pre-relativistic world but needs justification in the context of general relativity, which denies the possibility of defining simultaneity throughout the universe. This is a point where Rovelli and I disagree, and I grant that majority opinion at the moment is on his side. However, in shape dynamics, which will feature below and is not in conflict with any confirmed predictions of general relativity (GR), there is a notion of simultaneity that emerges rather naturally from the inner mathematics of GR, especially when considered from a relational point of view.

Up to circa 2000, my notion of an instantaneous configuration followed directly from the idea of geometry as a specific kind of order in empirical facts as discussed above. Suppose we take N particles to model an island universe. Then a configuration of it is defined by a set of r_{ab} that satisfy the algebraic relations discussed above. Each different set of r_{ab} defines a different relative configuration. I define an *instant of time* as a complete relative configuration. Such instants of time have the potential to occur in a (classical) history of the universe.[2] Another remarkable thing about geometry is that it not only defines relative configurations but also the complete set of all possible relative configurations, which I call the relative configuration space of the given N-particle universe and abbreviate RCS.[3]

The essence of non-relational classical dynamics is a law that determines a curve in the configuration space of whatever system one is considering. One has the usual Newtonian $\mathbf{r}_a(t)$, where t is the time supplied by a clock external to the system. A point that I cannot emphasise too strongly is that, at each point on the curve, the $\mathbf{r}_a$, on the number of which there is no limit, are all derived from r_{ab} knit together by geometry and pass continuously into each other along the curve. This is a vastly more important fact than the existence of the parametrisation by t on the curve. The succession of continuously changing configurations gives us the notion of the history enduring entity, which is the universe. Moreover, anything that can be objectively registered by 'observers' within the universe is completely independent of t. This is because their clocks are constituent parts of the universe, and the observable relations of all clock parts to other parts of the universe are completely unchanged by changing the labelling of the successive configurations by $t' = t'(t)$. Thus, to address one of Saint-Ours's issues, change does not require time. The real issue is what kind of law it is that we take to define the curve and also what we regard as observable.

[1] Since (spatial) Riemannian geometry is based on Euclidean geometry in the infinitesimally small, the situation is the same there too, though admittedly more complex: it is necessary to replace the Euclidean group by the three-dimensional diffeomorphism group.

[2] This is very different from Rovelli's use of the value of some arbitrary physical quantity to label time. For me, instants of time are identified *by what they are*: complete r_{ab} sets.

[3] In particle dynamics, there will be a different RCS for each set of relative masses of the particles.