The Process Metaphysics of Loop Quantum Gravity

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Abstract

Dupré and Nicholson (2018) defend the metaphysical thesis that the 'living world' is not composed of things or substances, as traditionally believed, but of processes. They advocate a process – as opposed to a substance – metaphysics and ontology, which results to be more empirically adequate to what contemporary biology suggests. Their ultimate view, however, is that there are compelling reasons to believe that contemporary physics, too, strongly suggests an analogous process-based conception as to the 'physical world'. Consequently, they argue that if this were the case, then the whole nature should be understood as consisting of 'processes *all the way down*'. The aim of this paper is to provide some further reasons supporting the correctness of this view in the framework of contemporary fundamental physics. To this end, I examine the metaphysical and ontological underpinnings of Rovelli's view of loop quantum gravity. I show that it consists of a timeless yet dynamical, radically relationalist, conception ultimately based on an event and process metaphysics and ontology according to which the 'physical world' is, fundamentally, a network of interacting quantum dynamical processes. Therefore, this suggests that at least 'all the way down' to the *Planck scale*, nature appears indeed to be composed of processes rather than things or substances.

Contents

1 Introduction

In their recent 'Manifesto for a Processual Philosophy of Biology' (Nicholson and Dupré, 2018), John Dupré and Daniel Nicholson defend the metaphysical thesis that 'the world – at least as living beings are concerned – is made up not of substantial particles or things, as philosophers have overwhelmingly supposed, but of processes. It is dynamic through and through' (p. 3). Their general argument is that the traditional *substance metaphysics* and ontology that has dominated both philosophy and science since Parmenides, Plato and Aristotle, turns out to be inadequate to account for the 'living world' according to contemporary biology. Instead, they argue for a *process metaphysics* and ontology for which 'processes must be, in some sense, more fundamental than things' (p. 4). In short, using the traditional metaphysical dichotomy between being and becoming, we might say that, on their view, *becoming* (process, change, event) is prior to, and more fundamental than, *being* (substance, stasis, thing).

Dupré and Nicholson make clear that their project is a research in the metaphysics of science, understood as a 'naturalistic metaphysics', for which philosophy 'must proceed in dialogue with what science actually tells us about the world' (Nicholson and Dupré, 2018, p. 4). Indeed, although their analysis is focused on the 'living world', they ultimately believe that 'there are compelling reasons to interpret the *physical world* more generally in terms of processes as well' (pp. 4-5; my emphasis). Contemporary physics, and quantum physics in particular, they argue, seems in fact to support a process – as opposed to a 'thing', 'particle-like', substance – metaphysics. Consequently, if this would turn out to be correct, they conclude, then the whole nature should be understood as consisting of 'processes *all the way down*' (p. 13).

My aim in this paper is to provide some further reasons in support of the correctness of this view in the framework of contemporary fundamental physics and, specifically, according to Carlo Rovelli's view of loop quantum gravity (LQG) (Rovelli, 2004, 2020; Rovelli and Vidotto, 2014). Rovelli states concisely his view as follows:

> Fundamental physics turns out to work much better in the language of becoming than in the language of being. Quantum theory is about *transitions*, general relativity about *events*. Events *happen*, rather than *are*, and this we call 'becoming'. [...]. The best language for describing the universe remains a language of happening and becoming, not a language of being. Even more so when we fold quantum theory in. This is the language used in LQG. *LQG describes reality in terms of processes.* The amplitudes

> of the theory determine probabilities for processes to happen. This is a language of becoming, not being (Rovelli, 2020, p. 124).

In what follows, I would like simply to explain the metaphysical and ontological underpinnings of this process-based conception of the physical world.

2 The ontology of loop quantum gravity

To understand the ontology of LQG according to Rovelli, we have at least three ontological claims to consider:

(1) At the fundamental level (i.e. at the Planck scale), there is *no* preferred observable time variable t, or non-dynamical background spacetime;

(2) there are *no* things or objects as concrete particulars or individual objects (i.e. substance-like entities bearing properties), but only quantum *events* and *relations* between events;

(3) events, as happenings and occurrences, *are* change *simpliciter*.

The first claim corresponds to Rovelli's well known, though often misunderstood, claim that, fundamentally, 'time does not exist' (Rovelli, 2016). The apparent disappearance of time or spacetime is one of the most challenging implications of basically all main approaches to quantum gravity; yet, as we shall see, according to LQG it is in some sense a natural consequence of the requirement of *background independence* inherited from general relativity (GR). Background independence is the idea that there is no absolute, fixed, non-dynamical spacetime, and thus no preferred time coordinate, against which and with respect to which change, and thus the dynamics of physical systems, unfolds, as instead is the case with all non-general-relativistic physics (Belot, 2011; Smolin, 2006). Indeed, in non-general-relativistic theories, the dynamics of physical systems is defined in terms of the evolution of states and the relevant physical variables *in function of* an external time parameter – as in classical mechanics and standard quantum mechanics (QM), or a non-dynamical background spacetime – as in special relativity and standard quantum field theory (QFT). Therefore, Rovelli's claim that, fundamentally, 'there is no time', that 'time does not exist', and thus that in some sense the world is timeless or non-spatiotemporal, is to be understood primarily as a consequence of the assumption of background independence as one of the fundamental principles of modern physics after GR. The non-existence of time or spacetime at the Planck scale, however, does not mean that it cannot exist, generally speaking, at

macroscopic scales. The so-called 'emergence' of time or spacetime at the classical limit is indeed one of the main technical and conceptual problems of virtually all approaches to quantum gravity (see, e.g., Huggett et al., 2013, 2020; Oriti, 2014, 2018). Rovelli's view is that we should maintain a *multi-layered* and context-based conception of space, time and spacetime, which, in the case of time, extends from its apparent absence in fundamental physics to our common experience of time related to cognitive and neurobiological processes, passing through GR, thermodynamics, statistical mechanics, and so on. On this view, then, the notion of time becomes relevant only for coarse-grained *approximations* of physical reality (Rovelli, 2020).

Rovelli's second ontological claim means that the physical world according to LQG is not composed of 'things' or 'substances' persisting in time and undergoing property changes; neither, of course, that the world itself is a sort of 'thing' or 'substance' as the 'totality' of all existing things. As we shall see, LQG suggests instead that the physical world consists of nothing but *interacting quantum dynamical entities* (precisely, quantum fields), *including spacetime*, and, ultimately, events and *processes* in interaction to each other. This means that LQG holds a relational quantum field, as opposed to particle, ontology, ultimately based on an event and process, as opposed to object or substance, ontology. Thus, LQG is realist about events and processes and, conversely, anti-realist, and fundamentally eliminativist, about things, objects, substances. Note that Rovelli's understanding of the notion of *relation* between events, does *not* properly concern the traditional substantivalism or absolutism vs. relationalism debate about space, time and spacetime. For Rovelli, such debate essentially reduces to a merely verbal issue, after GR (Rovelli, 2004). As we shall see, his view instead consists of a much more radical conception – that I will thus call *radical relationalism* – as to the very relational nature of *dynamics*, that is to say, how physics describes the processes occurring in the *physical interactions* between physical systems and how it accounts for their *relative* dynamical evolution. In this sense, Rovelli's radical relationalism concerns how to interpret and even reformulate modern physics in order to address the problem of quantum gravity of how to describe the background-independent quantum dynamics of spacetime.

Finally, Rovelli's third claim as to the nature of events means that an event is not conceived of in traditional philosophical terms as a process of change happening or occurring to something over time (since, to restate, fundamentally, there are no things and there is no time); it is change or process as such. This ontological claim is extremely important, for it is precisely what Rovelli means by '*becoming*': *becoming is change as happening of events* (see, e.g., Rovelli, 2018a, 2020). Although I will not address this aspect, I believe that

this understanding of becoming may have implications for contemporary debates in the metaphysics of time. For instance, Rovelli's view suggests that neither the standard A-theory of time of a 'change *of* time' as 'passage of time' or 'temporal becoming' (i.e. the 'becoming' present of the future and past of the present) nor the standard B-theory of time of 'change *in* time' as 'temporal difference' (i.e. change of some thing or object having different properties at different times) turn out to be relevant at the fundamental level, for, again, there are no things or objects and there is no time with respect to which events happen. A further point worth to mention is that Rovelli's view of becoming does not mean that the happening of events is a sort of 'coming into being' of events *at a spacetime position (x, t)*, as it is standard in relativity theories. This understanding is inadequate at the fundamental level, too, first, because the background independence of LQG excludes in principle any embedding in some underlying spacetime structure, and, second, because the expected quantum features of spacetime render the very notion of position no longer well-defined. Consequently, events cannot be thought of as to happen neither *in* space nor *in* time. Thus, on Rovelli's view, fundamentally, becoming is neither spatial nor temporal, it is the non-spatiotemporal process of the happening of events.

This brief account of the ontology of LQG obviously raises countless questions, but let me state what, in my view, are its most far-reaching metaphysical and ontological implications. First, the world appears to be fundamentally non-spatiotemporal (i.e., there is no classical spacetime); it is timeless or atemporal; yet, crucially, it is *not* changeless or static (i.e. non-dynamical). Thus, there is no time, but there is change. This point, in my view, has been largely underestimated if not entirely misunderstood in the philosophical literature. Rovelli's view has been often, erroneously, associated to some form of Parmenidean view (see, e.g., Belot and Earman, 2001; Healey, 2002; Huggett et al., 2013), such as that, for instance, advocated by Julian Barbour (1999). On Barbour's view, indeed, the disappearance of time involves that of change, so that, as he puts it, 'the quantum universe is *static*. Nothing happens; there is being but not becoming. The flow of time and motion are illusions' (Barbour, 2009, p. 2). Rovelli's view is diametrically the opposite. He explicitly insists that from the claim that, fundamentally, there is no time, it does not follow that nothing changes or happens (see, e.g., Rovelli, 2016, 2014). On the contrary, despite being atemporal, the world is definitely dynamic, *not* static. Moreover, since there are no things or substances but only events, on Rovelli's view there is in fact nothing but change as happening of events (Rovelli, 2018a, pp. 85-86); and since this is what he means by 'becoming', his view entails the idea of a timeless or *atemporal becoming*. This leads to the second, and in fact major, metaphysical and ontological

implication: LQG suggests a radical rejection of any *substance metaphysics* in favour of a *process metaphysics* for which *becoming* is more fundamental than *being*.

But how to make sense of an atemporal becoming; that is, a 'world without time' in which however there are changes, processes, events? Furthermore, how to make sense of a world of ceaseless *becoming*, of nothing but interacting processes and happening of events, without any substantial *being*? To try to answer these questions we need, first, to understand the *radical relationalism* at the core of fundamental physics. This will allow us, second, to understand the radical '*process turn*' that LQG ultimately suggests.

3 The radical relationalism of contemporary fundamental physics

According to Rovelli, to understand the relationalism of modern and contemporary fundamental physics, we need to comprehend, first, the profound physical meaning of GR, second, its connection to quantum theory, and, finally, what such a connection involves for a quantum theory of gravity, and, specifically, for LQG. Let me consider then these points in turn.

3.1 The relationalism of general relativity

The core idea of GR, Rovelli argues, is that 'there are only dynamical physical entities' (Rovelli, 2006, p. 30). The main implication of the background dependence of all non-general-relativistic physics was the presupposition of an ontological distinction between space and time or spacetime, on the one hand, and the dynamical entities (particles and fields), on the other. The ontology of the physical world, that is, consisted of an absolute, fixed, non-dynamical background space and time or spacetime in which particles and fields moved and interacted. The background independence of GR is the understanding that 'there is no distinction between non-dynamical background and dynamical physical variables' (Rovelli, 2007, p. 1310). That means that if we remove the dynamical entities in non-general-relativistic physics, what remains is space and time or spacetime. If we do the same in GR, what remains is nothing (Rovelli, 2004, p. 9). The ultimate reason for this is that in GR, Rovelli states, 'spacetime and the gravitational field are the same entity' (ibid.).

This means that, against the pre-general-relativistic ontological assumption of a background space and time or spacetime independent of particles and fields, GR removes such an assumption by describing gravity, and thus spacetime, in

field-theoretical terms (Rovelli, 2020). Note that Rovelli thoroughly follows here Einstein, who, in a famous passage writes:

> In accordance with classical mechanics and according to the special theory of relativity, space (space-time) has an existence independent of matter and field. [...]. On the basis of the general theory of relativity, on the other hand, space as opposed to "what fills space", [...], has no separate existence. [...]. If we imagine the gravitational field, i.e. the functions g_{ik}, to be removed, there does not remain a space of the type (1) [i.e. Minkowski space], but absolutely *nothing*. (Einstein, 1954, pp. 175-176)

Consequently, spacetime does not only lose any distinct ontological status, but, more importantly, being physically indiscernible from the gravitational field, it turns out to be a *dynamical entity* among the others. Therefore, Rovelli argues, according to GR there are only 'dynamical fields in interactions with one another' (Rovelli, 2007, p. 1312). The physical world consists uniquely of *interacting dynamical entities, including spacetime.*

According to Rovelli, this is the profound *relationalism* of GR. Since there are only dynamical entities, including spacetime, there is no preferred physical (i.e. observable) time variable t in the dynamics of GR. All physical variables are instead on a par with the others. Therefore, physics does no longer describe 'the evolution of the variables *in time*', but 'the *relative* evolution of the variables' (Rovelli, 2014, p. 751). In other words, physics does not account of change in relation to time, but the relative change of dynamical entities *in relation to each other.*

3.2 The relationalism of quantum theory

Rovelli believes that the relationalism of GR has a connection with the relationalism of quantum theory. This is the primary motivation for his proposal of an alternative interpretation of QM, called *relational quantum mechanics* (RQM) (Rovelli, 1996, 2005; Dorato, 2015, 2016; Van Fraassen, 2010). In contrast to wave function realism (Ney and Albert, 2013), but more generally to all realist interpretations of QM according to which the wave function (the quantum state) $|\psi\rangle$ of a physical system is an actual and fundamental physical object, RQM holds that the wave function has no physical reality, but is a mere book-keeping device to compute probabilities of possible measurement outcomes. RQM instead advocates an event ontology according to which 'the actual elements of reality' are *quantum events* (Rovelli, 2004, p. 214). A quantum event is what happens in the *physical interaction*

between systems, and corresponds to the values taken by the physical variables (i.e., the observables) in the interaction process. For instance, the quantum event of a system S interacting with another system O, is the value q taken by a variable Q (such as position or momentum) of S in the interaction between the two systems. This event is what is physically real, not the quantum state $|\psi\rangle$. On Rovelli's view, the reality of a particle, for instance, lies 'in the events where it reveals itself, interacting with its surrounding, not in the abstract probability amplitude for such events' (Rovelli, 2004, p. 214). Therefore, while being antirealist as to the wave function, RQM is realist as to quantum events (Rovelli, 2018b, p. 9). Consequently, the ontology of the physical world consists of 'relational quantum events happening at interactions between physical systems' (ibid., p. 7).

This is the core relationalism of RQM. Quantum events and quantum states are meaningful only in relation to each other (Rovelli, 2004, p. 220). This means that the values of the physical variables do not designate absolute states or properties of a system at a given time, but the *relation* (interaction) of a system with another system. Consequently, in quantum mechanics '*all* physical variables are relational' (Rovelli, 1996, p. 6) since 'the actual value of *all* physical quantities of *any* system is only meaningful in relation to another system' (Rovelli, 2018b, p. 6). Therefore, the idea of an observer-independent state of a physical system is entirely rejected. Quantum theory does not describe the evolution of states (the wave function) and observables in time, as assumed by the standard Schrödinger picture, but, according to the Heisenberg picture, relations or correlations between observables; that is, how 'physical systems *affect one another* when they interact' (Rovelli, 2004, p. 215). It is worth noting that, according to Rovelli, the Heisenberg picture, in contrast to Schrödinger's, does not only provide a better understanding of QM, but is also crucial in the formulation of quantum gravity. 'The Heisenberg and Schrödinger pictures', he writes, 'are equivalent if there is a normal time evolution in the theory, but in the absence of a normal notion of time evolution, the Heisenberg picture remains viable, and the Schrödinger picture becomes meaningless. In quantum gravity, only the Heisenberg picture makes sense' (Rovelli, 2001, p. 113). As a result, the relationalism of GR for which the physical world is made up uniquely of interacting dynamical fields converges with the relationalism of QM for which 'the physical world can be described as a network of interacting components' (Rovelli, 2004, p. 216).

3.3 Quantum spacetime

This point of convergence between GR and QM suggests a decisive implication, which lies at the basis of LQG. Since according to GR spacetime, or the gravitational field, is a dynamical object, and since according to QM all dynamical objects possess quantum properties (discreteness, indeterminism, relationalism), it follows that 'spacetime is a quantum object' (Rovelli, 2001, p. 110). In other words, LQG predicts the existence of a *quantum spacetime* at the fundamental level. This is expected to be composed of elementary 'quanta of space', that is, intuitively, 'grains' or 'atoms of space', as quanta of the gravitational field, the quantum interactions of which determine the dynamical evolution of spacetime (Rovelli, 2004, 2016; Rovelli and Vidotto, 2014).

This understanding of quantum spacetime presents some similarities with standard QFT, but also an important difference. The 'quanta of space' in LQG are thought of as quantum excitations of the gravitational field analogously as how QFT describes photons as quantum excitations of the electromagnetic field and particles of ordinary matter as quanta of Dirac fields. However, because of the background independence and relationalism of GR and QM according to Rovelli's relational interpretation, in LQG spacetime is not a background against which the dynamical evolution of particles and fields is defined, as it is still the case in QFT, in which usually one assumes a fixed, non-dynamical spacetime geometry such as Minkowski space. In this sense, Rovelli insists that the challenge of quantum gravity is 'to understand what is a general-relativistic QFT, or a background-independent QFT' (Rovelli, 2004, p. 7).

Therefore, quantum spacetime is neither conceived of as an embedding for events and processes nor as embedded *in* space and evolving *in* time. The 'quanta of space' are not quantum excitations *in* space, but *of* space (Rovelli, 2004, p. 264), since they *are* space itself, or rather, as Rovelli states, 'the spatiality of the world consists of the web of their interactions' (Rovelli, 2018a, p. 108), while the dynamical evolution of the network of these interactions *is* spacetime. This description corresponds in LQG to the spin network and spin foam formalism (Rovelli, 2004). Intuitively, the main idea, as Rovelli puts it, is the following:

> Space is a spin network whose nodes represent its elementary grains, and whose links describe their proximity relations. Spacetime is generated by processes in which these spin networks transform into one another, and these processes are described by sums over spinfoams. A spinfoam represents a history of a spin network [...]. (Rovelli, 2016, pp. 166-167)

So, while spin networks define the quantum geometry of spacetime, spin foams

encode its quantum dynamics, as transition amplitudes for processes, that is, as probabilities for events happening in interactions (Rovelli and Vidotto, 2014; Rovelli, 2020; Perez, 2013).

In sum, the relationalism at the basis of fundamental physics lets emerge that the ontology of the physical world according to LQG consists of, fundamentally, a background-independent network of interacting quantum dynamical fields (Rovelli and Vidotto, 2014), and, ultimately, of quantum *events* occurring in physical interaction processes (Rovelli, 2016, 2018a). This leads us to what in my view is the most challenging metaphysical implication of LQG.

4 The process metaphysics of loop quantum gravity

LQG suggests that we should think of the physical world as fundamentally timeless or atemporal yet ceaselessly changing; as a dynamical world of interactions, events, processes in relation to each other. But what is actually at stake? The key point is that, according to contemporary fundamental physics, Rovelli argues, 'the best grammar for thinking about the world is that of change, not of permanence. *Not of being, but of becoming*' (Rovelli, 2018a, p. 86; my emphasis). In other words, the ultimate metaphysical implication of LQG is that an ever-changing world without time, uniquely made up of events and relations involving physical interactions, is a world of nothing but *processes*, without anything properly *being* and persisting changeless through time.

This is the radical *process metaphysics* underlying LQG. In a decisive passage, Rovelli writes:

> We can think of the world as made up of *things*. Of *substance*. Of *entities*. Of something that *is*; that persists. Or we can think of it as made up of *events*. Of *happenings*. Of *processes*. Of something that *occurs*. Something that does not last, which is continuous transforming, that does not persist in time. The destruction of the notion of time in fundamental physics is the crumbling of the first of these two perspectives, not of the second. It is the realization of the ubiquity of impermanence, not of stasis in a motionless time. (Rovelli, 2018a, pp. 86-87; translation modified)

It is interesting to note that here Rovelli closely links to Smolin, despite their otherwise notoriously different views. Indeed, Smolin agrees that if the world were composed of objects, then

> the primary description of something would be how it is, and change in it would be secondary. Change would be nothing but alterations in how something is. But relativity and quantum theory each tell us that this is not how the world is. They tell us [...] that our world is a history of processes. Motion and change are primary. Nothing is, except in a very approximate and temporary sense. [...]. So, to speak the language of the new physics we must learn a vocabulary in which process is more important than, and prior to, stasis. (Smolin, 2001, p. 53)

Rovelli and Smolin's argument is of crucial philosophical importance, for they are not claiming that every 'thing' or 'object' is subject to property changes over time. Indeed, this would not only imply a violation of the background independence of LQG, but, more importantly, it would entail a form of Aristotelian conception of change as accidental determination of an individual substance ('something that *is*'), and thus a commitment to the metaphysical view that change depends on the category of substance.

Let me briefly clarify this important point. For Aristotle, whenever there is change there must be some 'thing', as substance, that changes, or whose properties change. Since the notion of substance (*ousia*) is the primary meaning of being, it is ontologically prior to, and more fundamental than, any change and, indeed, any other way of being. As Jonathan Schaffer has recently suggested, a substance may be seen as a fundamental '*unit of being*' (Schaffer, 2009, p. 351). Consequently, if there were no substances, there would be no change at all, because literally nothing would *be* (Aristotle, 1984a, *Cat.* 5, 2b6b–6c). Therefore, for there to be change there is to be a 'primary substance' as substratum (*hypokeimenon*) of change, which in turn has to persist unchanged – 'one and the same', Aristotle qualifies – through time (Aristotle, 1984a, *Cat.* 5, 4a10–21). Identity and persistence through temporal change are indeed the most distinctive features of substance. Given its ontological priority the notion of substance has a further fundamental explanatory primacy. Understanding what something is (*ti esti*), ultimately means understanding what 'primary substance' or *being* it is, that is to say, its *essence* (*to ti ên einai*) (Aristotle, 1984b, *Metaph.* Z 3, 1028b34–36; Z 7, 1032b1–2).

The argument by Rovelli and Smolin is therefore a radical rejection of such substance metaphysics. Their ontological claim is that, fundamentally, there is change, but no 'thing' that changes. In other words, change is all what there is, for 'things', including spacetime, *are* change, process, or becoming as such; they are events, not 'something that *is*' (i.e. a substance). 'An event', Smolin

suggests, 'may be thought of as the smallest part of a process, a smallest *unit of change*' (Smolin, 2001, p. 53; my emphasis). As we have seen, for Rovelli, the physical world is a network of interacting systems in which what is real are only relative quantum events occurring in physical interactions. Quantum spacetime is itself an event, since, as any quantum event, the 'quanta of space', Rovelli writes, 'exist only as terms of ceaseless interactions' (Rovelli, 2018a, p. 108; translation modified). Consequently, spacetime is itself a *process* (Rovelli and Vidotto, 2014, p. 52); it is the process of the local interactions between 'quanta of space', and 'this interacting', Rovelli crucially states, '*is* the happening of the world' (Rovelli, 2018a, p. 108; translation modified). In other words, the physical world is no substantial 'thing' or object 'that *is*' at all, but process, becoming, event (p. 88). *The physical world is nothing but a 'network of quantum processes'* (Rovelli, 2020, p. 129; my emphasis).

Ultimately, it is the very category of *substance*, and thus the notions of independent being, individual thing, substratum, essence, persisting identical through temporal change, that is completely refuted in favour of the category of *process*. Moreover, since it is the notion of substance to disappear altogether, it is its presumed explanatory power that vanishes as well. Rovelli makes this point explicitly: 'we understand the world by studying change, not by studying things', for physics concerns 'how *events happen*, not how things *are*'; in other words, 'we understand the world in its becoming, not in its being' (Rovelli, 2018a, pp. 89, 91, 92). Therefore, LQG suggests a process metaphysics and ontology of the physical world which holds the primacy of becoming over being, and thus lend support to the thesis that nature should be understood as consisting of 'processes *all the way down*'.

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