

Article

Change Before Time: Empirical Equivalence, Mechanics, and Structures for Dynamic Metaphysics

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Abstract

This paper argues that, within established mechanics, a change-first structure of mechanics—one that does not treat background time as fundamental—is as empirically licensed as the familiar time-first structure. Carlo Rovelli’s generally covariant framework and Wonchull Park’s initial conditions framework each provide an independent demonstration of this possibility across classical, relativistic, and quantum mechanics. Park’s Reality View Equivalence is employed as an epistemological constraint on claims of compatibility at the physics–metaphysics interface. The resulting picture of change before time yields structural resources that offer, without mandating, ways of supporting metaphysical projects that emphasize the dynamic nature of reality. Two worked examples are used to illustrate this application: first, by placing local becoming within the change-first state package, and, second, by treating entities that participate in change-first states as necessarily dynamic and thus, arguably, processual.

Keywords: time; change; interpretation; empirical equivalence; becoming; process ontology; dynamic metaphysics; philosophy of physics; problem of time; Rovelli; Park

1. Introduction

Time is the background in which change happens—or is it? In the standard metaphysical picture, change is difference in properties across time: time is primary, along with the entities in time, and change is secondary. This is reflected in—or is it a reflection of?—dynamics in physics, where a temporal dimension or 4D spacetime provides the background for dynamical evolution. Time is first, not change. The argument of this paper does not question the validity of this time-first view. Instead, it asks whether the empirical content of our best physical theories actually limits us to only this picture. Could we remain empirically anchored in established physics and nevertheless reverse the ordering, so that change is first in a viable change-first alternative? If so, what then is the structure of such change “before time”? Two physicists have argued for a definite “yes” and articulated a change-first picture of mechanics. Carlo Rovelli’s generally covariant framework and Wonchull Park’s initial conditions framework each show that background time structure is not strictly required across classical, relativistic, and quantum mechanics.

Though questions about the relation between change and time have been taken up repeatedly in both physics and philosophy, developments in general relativity and attempts at quantum gravity have brought the issue into sharper focus in recent decades from within physics via “the problem of time,” which, roughly, is the mismatch between how time is treated in quantum theory and in relativity, and the challenge of making those treatments mesh in a theory of gravity. The question here, however, is not linked to any



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candidate quantum gravity theory. Rovelli is well-known for his work on loop quantum gravity, yet the focus on his work in Case 1 is on two papers in which he argues that mechanical theory—the way physics studies and describes fundamental change—does not require an external, independent time parameter [1,2]. This formulation of mechanics is what Rovelli calls “generally covariant” and so will be referred to here as his generally covariant framework [3] (p. 45). Park’s initial conditions framework, as Case 2 is called, then shows how the change-first possibility can also be due to the underlying structure of initial conditions, reconceived as a minimally sufficient subset for the whole effect [4]. Taken together, their frameworks make it harder to treat the change-first possibility as an isolated or contingent curiosity; they show that, right now within well-established theories of mechanics (classical, relativistic, and quantum), a change-first formulation can stand on equal empirical footing with the familiar time-first formulation.

Making this empirically licensed change-first picture explicit and its resources available for metaphysical projects is the aim of this paper. Towards this end, it consolidates Rovelli’s and Park’s frameworks into a single change-first empirical platform and articulates a general epistemological constraint—developed by Park—under which time-first and change-first views stand on equal empirical footing. Sections 4 and 5 then clarify the structures of change “before time” and illustrate how such structures could support, though not mandate, metaphysical readings. Two worked examples are presented for how the change-first state could be cashed out if one seeks to advance a view of reality as fundamentally dynamic: (1) local becoming can be located within the change-first state package, rather than as an overlay of global time structure on a 4D catalogue of static states, and (2) entities that participate in change-first states must be dynamic entities and thus, arguably, processes. These are meant to be illustrative of how resources within the change-first platform can be put to metaphysical use, in much the same way that familiar time-first resources typically are—and with equal empirical standing.

2. Change-First Empirical Platform

A key fact about models of fundamental mechanics is that once a state is suitably specified—together with the fundamental equations of dynamics—the empirical content of the model is determined. This fact permits a clear test: Can one obtain a sufficient state specification without background time structure playing any indispensable role? If so, then the empirical content of the model is preserved by construction under the priority inversion between time and change in question. Background time structure, for present purposes, is a presupposed time parameter, such as a Newtonian dimension of time or a relativistic 4D spacetime structure, that is treated as fundamental rather than emergent. To pass the test, background time structure cannot play an indispensable role in defining, specifying, or ordering states—for example, by defining states as a time slice (as in “the state at $t = 0$ ”), by specifying states with velocities defined as dx/dt with t as the privileged parameter of change, or by providing the ordered arrangement of states as an independent parameter. These roles for background time structure are often taken for granted in dynamical modeling, but Rovelli and Park show how such roles can be separated from the matter of state specification and, therefore, from what is strictly required to preserve the empirical content. The t variable, if used, loses its special status as representing background time structure and, instead, represents a physical clock, which is on a level with the other dynamical entities changing relationally in the change-first picture.

2.1. Case 1: Rovelli’s Generally Covariant Framework

Ordinarily, a state is understood as a complete description of a system “at an instant,” what Rovelli refers to as an instantaneous state. In the usual time-first picture, an inde-

pendent time parameter t orders the instantaneous states: at each t , the system's state is a point in phase space, and, as t varies, this point traces out a trajectory (orbit). Rovelli, however, works within a generally covariant Hamiltonian formalism that is already well suited to relativity—and to passing the no-background-time test—because it does not privilege any particular variable as an independent parameter nor is it formulated in terms of instantaneous states. What is distinctive in his generally covariant framework is not new mathematics but a clarifying reinterpretation: he treats the extended configuration space C of partial observables as the primary arena of change and defines a relativistic state so that it no longer means how things are at one instant in time but the entire solution (orbit), which determines a pattern of correlations among partial observables.

The “ingredients of mechanics” in Rovelli’s framework can be taken to be solely the extended configuration space C and the relativistic Hamiltonian H , which encodes the dynamics [1] (p. 7). He shows how this pair (C, H) is sufficient to determine a mechanical system, with no background time structure required. The following schematic explains, informally, how C and H suffice to construct states and solutions in “the geometric way,” and how this construction makes each relativistic state itself a solution:

C is the extended configuration space: each point in C is a possible joint outcome of several measurable quantities, the partial observables, such as positions, field strengths, clock readings, among others. Unlike the standard configuration space, clock readings are on equal footing with all other partial observables in the extended configuration space.

Σ is a constraint surface in an extended phase space Ω built from these partial observables and their conjugate momenta. It is defined by a relativistic Hamiltonian H —a constraint that vanishes on Σ rather than generating evolution in an external time parameter—which encodes the dynamics and picks out those combinations of values that are dynamically admissible. These are then tied together into orbits—i.e., the solutions of the equations of motion.

Γ is the relativistic phase space where each point is a state defined by an orbit on Σ ; that is, a relativistic state is a solution (or, in gauge theories, a gauge equivalence class of solutions) of the equations of motion.¹

The key link is this: each point in Γ (a state) represents an orbit (solution), so a state is defined as a solution; projecting that orbit (solution) down to the extended configuration space C yields a motion in C that displays the correlations among the partial observables determined by that state. The set of these relations—and so all predictions that can be made using the theory—can be captured by an evolution equation of the system $f = 0$ (defining a surface in the combined space $C \times \Gamma$). For each state in Γ , the evolution equation $f = 0$ determines one motion in C displaying correlations among the partial observables.

This can be seen concretely with a frictionless pendulum. Take two partial observables: the angle of the pendulum α and a physical clock reading t ; the extended configuration space C is then the (t, α) plane, representing all possible pairings of angles and clock readings. Unless the pendulum is disturbed, the state remains the same and determines the correlations between the partial observables t and α as a curve, which is familiar as a sine-like oscillation in this case.² As Rovelli summarizes, “Each state in Γ determines (via $f = 0$) a motion of the system,” namely the correlations of partial observables in the extended configuration space C [2] (p. 2). This (C, Γ, f) language is broad enough to describe both general relativistic systems and those of conventional mechanics.³ In this formulation of mechanics, there is no role for instantaneous states, observables at fixed time, or evolution in time.

Thus, there is still state specification, dynamics, and prediction sufficient for mechanics, but without background time required. That this is possible “is a remarkable fact by itself,” Rovelli writes. “What is remarkable is that the formal structure of mechanics doesn’t really

treat the time variable on a different footing than other variables" [5] (p. 84). The distinction between dependent and independent partial observables, which is what gives t its special status for evolution in time, is what Rovelli calls "an accident of non-relativistic theories" [1] (p. 7). The pair (C, H) —with neither ingredient involving background time—is sufficient to determine a mechanical system. Mechanics, on this view, is not a theory of evolution in time but, as Rovelli concludes, a "theory of relations between partial observables" [1] (p. 7).

As shown in the above example with the pendulum, a time variable can be introduced by choosing one partial observable as a physical clock, but this t is just one partial observable among many and not a special background structure. This is like seeing, for instance, that the physical clock is really just a measurable quantity from a second frictionless pendulum, which makes clear that neither pendulum is "the time": whichever is chosen as the clock, there are still only the correlations between partial observables, all on equal footing, in the extended configuration space C . This leveling of the variables, including the t variable, is called for in general relativity since any clock also interacts with the gravitational field, which affects its motion and rate.

In his framework, Rovelli takes the generally covariant formalism that is needed in general relativity and generalizes it as a unifying structure of mechanics. "GR [general relativity] changes the way we understand dynamics," Rovelli writes. "The main novelty is that dynamics treats all physical variables (partial observables) on the same ground and predicts their correlations" [5] (p. 265). Rovelli shows that classical as well as quantum dynamics admit formulations consistent with this novelty; the quantum mechanical extension is left to his own treatments [2,3,5]. Rovelli's generally covariant framework can be applied wherever physical systems can be described by Hamiltonian mechanics, with standard time-parametrized mechanics appearing as a convenient special presentation of the same correlations among partial observables.

A critic of this generalization could point out that, in principle, almost any theory can be written in generally covariant form, which echoes Kretschmann's objection to Einstein's emphasis on general covariance: that it risks treating a flexible way of writing a theory as a genuine requirement of the underlying physical principles. Einstein's response, in part, was that general covariance is a simpler formalism in general relativity.⁴ What, though, could motivate applying a generally covariant formulation to conventional mechanics, where an independent time parameter is simpler?

One motivation, according to Rovelli, is that "taking a theory seriously" by extending its insight has often led to major advances [5] (p. 306). "General covariance," he argues, "is the language for describing a world without distinction between the spacetime entities and the dynamical entities" [5] (p. 56). On this view, there are not, first, spacetime entities forming a background stage and, second, dynamical entities; there are only dynamical entities, as specified by the dynamics. In this way, mechanics in the language of (C, Γ, f) —generated, as shown above, from the pair (C, H) —is a simpler structure that can underwrite both non-relativistic and relativistic mechanics. Non-relativistic mechanics can be reinterpreted in this generally covariant language and treated as a special case in which some dynamical entities—those associated with spacetime—are effectively independent of the dynamics. This does not conflict with the generally covariant picture of the world; rather, it shows how that picture provides a more general underlying framework for all of mechanics. This framework has further significance in that Rovelli extends it into loop quantum gravity, but that application is bracketed from the present discussion. The question here is focused on already established theories. Is it possible—with established physics at hand—to find independent corroboration that background time structure is not required for the structure of mechanics?

2.2. Case 2: Park's Initial Conditions Framework

Park begins his analysis with standard second-order equations of mechanics, where evolution in an independent time parameter epitomizes the view of time as the background in which dynamical variables evolve. While it is standard to think of initial conditions as an instantaneous state at $t = t_0$, Park's initial conditions framework does not require an "initial" time; instead, a minimally sufficient subset for the whole effect can define the so-called "initial" conditions.

In second-order dynamical models, determining a solution requires suitable initial conditions: positions and velocities (or suitable change information such as conjugate momenta). This structure is built into second-order differential equations because the force that alters how a variable is changing (i.e., the acceleration, which is a second-order derivative) depends on the positional configuration of entities with their associated force parameters and on the first-order derivative, the velocity. Thus, the initial conditions at an instant, together with the second-order dynamics, suffice to determine the evolution in time.

Park points out that the familiar initial conditions can also be seen as the subset that is necessary and sufficient for the whole effect in a world exactly described by that model. He writes, "Initial conditions are a small subset within physics models where each element of the set is *necessary* since it has its own effect. Also, once initial conditions are given in physics models, no additional effect can be added since the set is already *sufficient* for the whole effect" [4] (pp. 17–18). Acceleration, for example, is not included in this set since its effects are already fixed by the initial conditions of force elements. To indicate initial conditions taken as this minimally sufficient subset for the whole effect, Park refers to this subset as essential reality.

Essential reality is made up of "things"—bodies, particles, fields, or whatever the dynamical entities may be—with their force elements and their position and velocity, all of which evolve according to the fundamental dynamics. On this view, the equations of motion simply encode the way the dynamical entities in essential reality co-change, and essential reality—as the minimally sufficient subset—remains as such throughout the dynamics that unfold within it. Velocity is understood as a ratio of comparative changing between dynamical entities in essential reality.

One can reintroduce a time variable by choosing one of the comparatively changing things in essential reality as a clock, so that all the comparative changing ratios are given in terms of this standard. This will make it look as though "everything else" in essential reality changes in comparison with this t variable, but t no longer has the meaning of a background time structure: the t variable is only a physical clock, one of many comparatively changing things in essential reality with nothing special in its status.⁵ Importantly, this is also how the initial condition of velocity can be treated: not as a derivative with respect to a background time, but as a ratio of comparative changing with a physical clock. Essential reality thus has all the ingredients for mechanics, but no background time structure.

In treating initial conditions as essential reality, Park has taken initial conditions—even in the standard second-order differential context—and shown how, on this view, they are no longer defined by an "initial" time. In this way, Park takes seriously the role of initial conditions as the minimally sufficient subset for the whole effect; that is his version of a change-first state. Once that interpretation is in place, it follows that this structure of mechanics is sufficient for determining solutions, without background time structure playing any indispensable role.

Whenever a model—whether non-relativistic or relativistic—admits an initial-conditions formulation, those initial conditions play their role as a minimally sufficient subset. A familiar worry, especially in relativistic mechanics, is that including an observer's frame

of reference, as is needed for essential reality, would privilege that frame and so conflict with relativity. As already noted, however, essential reality is not defined as a time slice according to some particular observer but as a minimally sufficient subset. Any observer's essential reality is sufficient for the whole 4D spacetime solution and, further, fixes every other observer's essential reality and associated 4D spacetime description. The sufficiency of any observer's essential reality for all the empirical content of the model is therefore intact, even in the relativistic case. Section 3.3 will return to this point, drawing on Park's Reality View Equivalence for further clarification.

In summary, Park began his framework in the familiar time-first setting of fundamental second-order dynamics and their initial conditions, but he shows that a change-first picture is available wherever a fundamental dynamical model admits an initial-conditions formulation. Thus, his initial conditions framework extends to quantum mechanics, but those developments are left to his original work [4]. On this view of mechanics, there are only the dynamical entities of essential reality with their relative position and relative co-changing. This reformulation of mechanics arises from reconceiving the structure of conventional mechanics in a simpler way—without the need for an additional formal toolkit to express it. Park's initial conditions framework is thereby the second “yes” to the test, completing two independent demonstrations that can stand together and apply wherever a Hamiltonian or an initial-conditions formulation is available across classical, relativistic, and quantum mechanics.

3. Methodology and Equivalence

What enabled Rovelli and Park to manage the priority inversion in question was not new mathematics or new theories. Rovelli's approach starts with treating the general covariance of general relativity as indicating the structure for all of mechanics. Park's approach begins by treating the minimally sufficient subset—namely, initial conditions—as an underlying structure already present in fundamental dynamical models. Despite these differences, each challenged standard views about redundancy—especially gauge redundancy—and shifted the interpretive load of mechanical theory onto partial observables and initial conditions, respectively. These are quantities they treated as physical, where others had tended to regard them as merely operational or even as representational, gauge-dependent excess. Partial observables and initial conditions were, accordingly, available to Rovelli and Park when considering alternatives to the structure of time-first mechanics. Seeing the how—not just the what—brings their shared approach into focus, despite their differences, and leads to Park's epistemological constraint for empirically equivalent views of what is physically real.

3.1. Gauge Redundancy and Interpretive Options

A common principle in gauge theory is that only gauge-invariant content is physical, because gauge-dependent quantities do not represent distinct physical possibilities. The extended configuration space C , with its gauge-dependent partial observables, had typically been treated as a bookkeeping device and mere formalism, leaving the generally covariant Hamiltonian formalism without a clear interpretation for physical change. When written in fully covariant form, the Hamiltonian constraints generate orbits on Σ as gauge transformations, and thus the dynamics appears “frozen” if one tries to interpret it as independent evolution in a gauge parameter. Rovelli, however, argues that this merely shows that the dynamics is not expressed as evolution in a single parameter [3] (p. 44). Instead, he shifts the physical interpretation of dynamics to relations between partial observables in the extended configuration space C as the primary arena for mechanics. According to Rovelli, when the structure of mechanics is sufficiently general for both non-relativistic and rela-

tivistic mechanics, partial observables are “the main quantities mechanics deals with” [1] (p. 6). Rovelli introduced the term partial observables to distinguish them from complete observables—gauge-invariant quantities whose values are predicted by the theory—while still treating gauge-dependent partial observables as physically meaningful observables.

Likewise, initial conditions appear in every college physics textbook but have tended to be seen as too closely tied to gauge-dependent measurements and coordinates to be of real physical or theoretical significance. Park uses reasoning about effects to reconsider the status of initial conditions and to treat them as identifying what has its own effect, in contrast to redundantly representing an already adequately specified whole effect. In this sense, presenting the entire history predicted by a model is redundant, or what Park calls non-essential, given the initial-conditions structure within the model itself [4].

While the underlying formalism certainly admits multiple gauge-related presentations for partial observables and initial conditions, this does not preclude other reasons for treating them as physically meaningful aspects of model structure [7–9]. Rovelli argues that gauge-dependent quantities, such as partial observables, function as physically meaningful “handles” on how systems couple, and their gauge redundancies do not disqualify them from physical interpretation. In Park’s case, an observer’s essential reality directly reflects the relational character of initial conditions, which necessarily involve relative positions and relative velocities.

3.2. Sufficiency for Change-First Mechanics

Both frameworks thus identify sufficient “ingredients” for state specification and solution, without state meaning a state defined in time or dynamics meaning evolution in time. Despite many differences in their approaches, the similarities are evident in a high-level summary of what suffices for their change-first mechanics:

- Rovelli shows that the ingredients sufficient for mechanics can be simply the pair (C, H) : the partial observables in the extended configuration space C together with the relativistic Hamiltonian H , which encodes the dynamics.
- Park shows that the ingredients sufficient for mechanics can be simply essential reality: the initial conditions of “things” (e.g., bodies, particles, fields, or whatever may be the dynamical entities) with their force elements behaving according to the dynamics.

3.3. Park’s Reality View Equivalence

Park treats the sufficiency of essential reality as an example of a more general constraint on physical interpretations—that is, reality views—that are compatible with a dynamical model. For example, so long as views of what is physically real in the model include the full initial conditions for an observer-experimenter, there is no distinguishable difference that an experimenter could encounter as a result of holding such views in a world exactly described by a deterministic model, leaving indeterministic cases to Park’s original work [4].

Consider a simple experiment in Newton’s world, exactly described by Newtonian mechanics, involving a moving ball in space. Compare two reality views: (1) only the ball’s position at a moment is physically real; (2) both the ball’s position and velocity as comparative changing at a moment are physically real, that is, a view that holds only essential reality is real. An experimenter could tell the difference between these two views because, when attempting “the same” experiment under both views, the experimenter (inadvertently) sets up different initial velocities with different outcomes as a result. Now compare the second reality view (2), which takes only essential reality as reality, and a third view (3) that is the usual 4D spacetime view, where quantities at other moments are also real. An experimenter in Newton’s world would encounter no distinguishable difference

whichever of these two views was held, since both adequately inform the experimental setup and deliver exactly the same results for measurement outcomes.

In such a world, there would be no empirical basis for declaring one of them “the correct reality view.” This is what Park calls *Reality View Equivalence*: When experiments cannot tell the difference between two situations, they are considered effectively equivalent, and Reality View Equivalence extends this so that “two situations” can include setting up, running, and measuring experiments under two different reality views.⁶ If experiments cannot tell the difference, as was the case between the two situations of holding a reality view of essential reality or of 4D spacetime, the two reality views are said to be equivalent. Returning to the discussion of essential reality and relativity, the same constraint and thought-experiment show that, for an observer-experimenter, experiments cannot distinguish between the following reality views: one that includes only the observer’s own essential reality, another that adds other observers’ essential reality, and another that adds even the entire 4D spacetime.⁷

Though the above examples already compare—and find equivalent—reality views that do or do not have background time structure, a further example can clarify the time-first or change-first reality views as related to clocks [4] (pp. 60–61). Consider a light clock under two interpretations, or reality views: it can be set up and run under a time-first reality view, where there is background time structure for which it provides a measure, or it can be set up and run under a change-first reality view, where it is one comparatively changing thing in essential reality, related only to other comparatively changing things. An observer-experimenter holding either of these views would encounter no distinguishable difference in repeating this simple experiment, whether in the Newtonian regime or the general relativity regime. Since our best models capture what experiments have shown to happen in that regime of applicability, Reality View Equivalence returns to this experimental basis to test the effect of holding one reality view or another through its effects on experiments. The time-first and change-first reality views of a clock make different commitments about what is physically real, but they are equivalent in that there is no experimental basis—and so, arguably, no basis in physics as an empirical endeavor—for saying that they differ in any physical effect.

Constraints of this kind can help make room for alternatives, especially when long-standing views dominate the interpretive landscape. Park puts it this way: “It shows us viable options for simpler views” [4] (p. 22). As Rovelli writes, “The best guide is provided by the theories of the world that have proven empirically effective, and therefore summarize the knowledge we have about Nature” [12] (p. 9). Further, “Until our theoretical and experimental investigations tell us otherwise, I think that what is important is to put the alternatives clearly on the table, and extensively discuss their rationale and consistency” [12] (p. 1). Park’s Reality View Equivalence provides a general rationale for taking suitable change-first alternatives as seriously as the time-first standard.

4. Dynamical Structures in the Change-First Empirical Platform

With these change-first frameworks on the table as empirically equivalent to the time-first standard, this discussion turns to the question of what is change if it does not happen in time. This section describes the dynamical structures available in such a change-first picture; these same structures are the resources provided by the change-first empirical platform that can later serve as the basis for metaphysical readings.

4.1. Relational Co-Change Structure

The change-first picture is one of physical quantities: partial observables in Rovelli’s framework or the position and comparative changing of interacting force elements in Park’s

essential reality. Within this picture of change, there is no abstract parameter—and thus no relations other than those among physical quantities. Because there is no background time for a lone physical variable to relate to (often hidden as abstract, assumed relata), change cannot be “one quantity changing in time.” In other words, velocity cannot be merely one entity’s velocity without reference to another entity, which is Galilean relativity restated in this context. Thus, change necessarily involves at least two physical entities changing in relation to each other—with implications for the meaning of “entities” in this picture as well.⁸ A choice of clock does not alter this relational structure of change but is an example of it: a clock is merely part of this same structure of two (or more) physical entities standing in a relational co-change structure with respect to each other.

4.2. Change-First State Package: Self-Sufficient Unfolding

What is change in Rovelli’s framework? The ingredients of mechanics can be just (C, H) , yet it takes his entire generally covariant framework to sufficiently specify a state in relativistic phase space Γ , which is defined as a solution (or gauge equivalence class of solutions). The interpretation as change, however, happens in the solution’s projection as a motion in the extended configuration space C . In this picture, change is represented by this motion in C that shows the correlations among partial observables.

One caveat to this picture of change is that extracting and presenting only Rovelli’s generally covariant framework in this way may make his notion of change look more observer-independent than a fuller view of his physics would justify, since Rovelli advances strongly observer-relative interpretations, exemplified by his relational quantum mechanics [11,13,14]. To see how Rovelli’s framework already contains the structures needed for a local, directed unfolding of change, we can take a clock—merely one of the partial observables—and an observer’s frame of reference, understood as a standpoint tied to some system that can be interpreted physically and permitted by the theory’s own structure. The clock parameterizes the motion in C , so that the correlations can be read off as locally directed change from any joint values at which the observer’s clock reads $t = t_0$. Structurally, there is still no privileged frame nor an independent time parameter, so all partial observables remain on equal footing; this is merely a use of a clock and an observer’s frame of reference within Rovelli’s framework and its relational structures, not a modification of those structures or addition to them.

In Park’s framework, the change-first picture is simply that of essential reality for an observer since any observer’s essential reality is sufficient for the whole effect. Essential reality is populated by force elements with their initial conditions—their positional configuration relative to each other and their comparative changing relative to each other. In this picture, change is this comparative changing in essential reality; further, this comparative changing and the positions of force elements together fix the forces and thereby the unfolding co-variation in essential reality.

So far, these pictures of change before time have served to summarize and clarify the change-first state structure in both Rovelli’s and Park’s frameworks. Both change-first states are internally sufficient for the solution: in Rovelli’s framework, state is defined as the full solution; in Park’s framework, state is defined as the essential reality that is sufficient for the whole effect, with the presentation of the solution as non-essential and the dynamics unfolding within essential reality. In Park’s case, the change-first state is already self-sufficient for the unfolding of what comes next because essential reality includes an observer’s frame of reference. As noted above, Rovelli’s change-first state also yields, in its usage with an observer’s frame of reference, a local direction of unfolding toward what comes next in its relational picture of change. For the purposes of the discussion to follow, this similar structure—present with the above usage of Rovelli’s relativistic state—will

be referred to as the *change-first state package*. With this label, the differences between Park's and Rovelli's change-first states are not blurred, even when emphasizing what they share: namely that this change-first state package is self-sufficient for the unfolding of what's next.⁹

What, then, is change before time? Change no longer has a background against which entities change "in time." Instead, change is inseparable from dynamical entities that are necessarily in relational co-change with each other. Evolution happens not in time but as the self-sufficient unfolding of a change-first state package. Change-first mechanics thus describes a world where change is merely happening among dynamical entities and thereby offers a simpler picture of change.¹⁰

4.3. The Smallest Complete Package: The Integrand Picture

There is a further opportunity afforded by the change-first picture to consider the dynamical structure that is intrinsic to a single instant. Possibilities for treating an instant as intrinsically changing have typically been developed within time-first views, which makes non-contradictory, physics-compatible accounts difficult.¹¹ Within essential reality, however, Park proposes that a ratio of comparative changing can be intrinsic to an instant of relational co-changing structure between physical entities [4] (pp. 66–67). (This is not, of course, an instant in time; the term is used here to denote an instant of co-occurrence within an observer's frame of reference.) Park's rotating disc illustrates this possibility using geometric structure: points on the outer rim and at half the radius stand in a comparative-changing ratio of 2 within one rotating structure, without appeal to two distinct instants.

Formally, such comparative changing intrinsic to an instant can be defined as an integrand: that which gives the next distance when paired with a clock-change. Whereas the derivative in its definition necessarily calls upon neighborhoods of values, the integrand represents a quantity entirely at an instant. In fact, when solving differential equations of dynamics, velocity does not enter as a derivative: velocity, taken as an integrand, is integrated to give position; position and velocity determine the force; and integrating the force gives the next velocity.¹²

This additive, cumulative character is a familiar experience of change—walking across a room, drawing a line, or hearing a melody. It mirrors the way change occurs as the integrand accrues in an integration process; only afterward can it be perceived or measured as changes marked by differences over a finite interval. Though the empirical change-first platform does not depend on this integrand picture, it is an optional structure made available within the change-first picture: a way of allowing an instant itself to hold change, as comparative changing intrinsic to that instant, and thereby carry the full change-first state package. This is the change-first state package at its most minimal interpretation since, on this view, it is intrinsic to an instant.

4.4. The Trio of Time, Change, and Entities

This discussion has deliberately stayed at the level of model formulation and its requirements for mechanics.¹³ In time-first formulations, time builds change: background time structure orders instantaneous states of entities, and change is just differences across that ordered series. In this picture, there is not much for change "to do," so to speak. The change-first alternative—presented here as the change-first empirical platform that unifies Rovelli's and Park's frameworks—inverts that building relation: change builds time. A change-first state package is self-sufficient for the unfolding of what's next and necessarily involves relational co-change structure among its dynamical entities. Change that is inseparable from these dynamical entities "does it all," so to speak.

Since physics developed in a time-first context, there are many special features attributed to time: temporal order (without direction), temporal flow (with direction), temporal metrics, and so on. When these are not attributed to a background time structure, it is more evident that they can be built from dynamical entities, as the following examples briefly illustrate. Partial time ordering via light cones and the associated causal structure can be seen as a way of organizing patterns already present in the empirical content of relativistic dynamics. Since the change-first picture preserves that same empirical content, those patterns are still present to be organized as “temporal order.” Further, what is usually called “time’s arrow”—fixing the way that counts as the direction of evolution—is typically supplied by entropy as a thermodynamic consideration, which can be equivalently accounted for in a change-first way: in a statistical system, more change among dynamical entities will lead to a more probable state, which is consistent with a higher entropy state.¹⁴ Regarding temporal metrics, the common choice in the literature on general relativity is that it is “spacetime” that has dynamical properties; an equivalent expression of the same physics is that, if the dynamical entities (i.e., gravitational field) are taken away, there is no spacetime—which is the expression that Rovelli adopts [5] (pp. 53, 55).

As these examples suggest, there may be different building-type relations for different features “of time,” which, when no longer attributed to background time structure, can be recognized more easily as diverse and distinct. Rovelli lists ten notions of time, for instance [5] (p. 60). Complicating the discussion further, temporal terminology tends to imply the time-first view, and so a careful clarification of temporal notions in the change-first context must be left for future work.

The simple conclusion, however, is that time built from change is not “special” in the way background time structure is. Rovelli writes, “The structure of mechanics is the formalization of what we have understood about the physical structure of the world. Therefore, we can say that the physical (more precisely, mechanical) structure of the world is quite blind to the fact that there is anything ‘special’ about the variable t ” [5] (p. 84). As an example of a situation where dropping the “special” features of time can be advantageous, Park writes: “If one were to study a new effect of time, for example, it would be clearer in this [essential reality] view that one would study the behavior of a clock (as Einstein did by replacing time with clock in developing relativity) since time effects are fully given by the behavior of clocks. In the 4D spacetime view, dimensional time is assumed before clocks, so this is less obvious” [4] (p. 61).

A change-first structure of mechanics provides a way to see change, entities, and even time itself with fewer prior commitments to time-first notions. For the physicist or philosopher who wants to probe limiting assumptions while staying firmly anchored in established physics, it offers alternatives that can widen one’s thinking and may prove more effective and fruitful for a given question at issue.

5. Putting the Change-First Resources to Metaphysical Use: An Illustration

So far, this discussion has been about models, their structures and interpretations, and their building relations—not about metaphysical readings of them. The careful and methodologically honest answer to what, if anything, the change-first empirical platform and its structures might have to do with the nature of reality is that they are not necessarily more correct than a time-first view of reality, in which there is background time structure and change is built from static states in time. Rovelli’s and Park’s frameworks show only that the empirical content of mechanical theories can be preserved with structures of mechanics that do not require background time, so a change-first view is as empirically licensed as a time-first view of reality.

Rather than a limitation, however, this equivalent empirical standing can be used to make room for alternatives that might otherwise be crowded out by a dominant interpretation at the physics–metaphysics interface. Rovelli notes, for example, that many physicists and philosophers made claims that relativity means that all events are equally existent, so that a static reification of 4D spacetime structure became a dominant view; he counters that Einstein’s equations are descriptions of unfolding change, writing, “This is possible. There is real becoming in the universe. Things happen” [19] (p. 4). In contexts like this where dynamic change-first alternatives confront a static time-first standard, Reality View Equivalence demarcates where claims of incompatibility with physics are justified empirically and where they instead overstep into interpretations that may be contested.

It would likewise be a disservice to overstep toward a dynamic metaphysics by treating the structures of the change-first picture as what physics says is so. The building relations summarized in Section 4.4, for example, can be given a metaphysical reading, following Bennett, as arguments about relative fundamentality: between time and change, which is the more fundamental “builder” and which the less fundamental “built”? [20] In a strictly empirical sense, established physics must fall silent on this question. The upshot is that change-first structures can be treated as seriously since they are as empirically licensed by established physics—without caveats or contingencies—as time-first structures.

Proceeding further is therefore a matter of criteria beyond empirical equivalence, and there are many such criteria, from structural parsimony to experiential fit. Park, for example, appeals to criteria he groups under “effective” as reasons why essential reality, or *nowflow* in Park’s more colloquial usage, offers “a simpler view of reality that’s both consistent with physics and helpful in living” [4] (p. 79). If, guided by such further criteria, one judges a dynamic metaphysics better than a static one, the structures of the change-first empirical platform are available to be put to use. With full acknowledgement that these dynamical structures are resources rather than mandates, how might one go about using these empirically licensed change-first resources?

In these illustrative examples, there will, of course, be overlap with existing philosophical developments, notably those of Rovelli and Park. The point is not to sidestep the richness of those developments, but to show how the bare structural resources of the change-first empirical platform can be cashed out in a variety of ways. Among philosophers developing Rovelli’s relational quantum mechanics and loop quantum gravity along metaphysical lines, the relational structure of change and entities has already received substantial attention, and its stripped-down presentation here as part of a change-first structure offers additional support.¹⁵ For present purposes, I will sketch a metaphysical reading of the change-first state package, and of what it takes to be an entity within it, in order to support claims about real becoming and fundamental processes.

5.1. *Becoming in the Change-First State Package*

The question of becoming in metaphysics concerns whether things genuinely happen—whether reality in some sense unfolds. On most views, becoming is inseparable from change: to say that there is becoming is to say that there is an unfolding pattern of change, rather than a wholly static arrangement of facts. Debates about becoming often run together with debates about the objectivity of tense, but, following work that treats these as separable issues, the present discussion can set questions about A- and B-theories aside and focus on local becoming as it is describable in relativistic physics models [24–26]. For those who view becoming as a real and dynamic feature of nature, a key question is how such local becoming can be based on structures that our best physical theories already license.

Within a time-first picture, the core structural resource is a 4D catalogue of static states. Some deflationary accounts of local becoming simply leave it at that: becoming just is

that structure of events, indexed in 4D spacetime, without even a direction to that static order. Other accounts of local becoming add an objective temporal direction via temporal or causal structures laid over the state catalogue, such as light-cone structure and entropy gradients. This typically exhausts the options available within the time-first picture for placing local becoming in structures of physics—and represents the closest one can get to a dynamic account without turning to matters of the objectivity of tense. This is reflected, for instance, in Thyssen’s summary of various “degrees” of becoming; the resources for more dynamic alternatives have simply not been on the table for consideration [27].

What if the change-first state package itself is a natural place for local becoming?¹⁶ In its very structure, it is self-sufficient for what’s next. It can do something that an instantaneous state cannot: the change-first state package does the unfolding of change. This is not claiming that physics says this is so but that physics licenses this structure, which has its advantages as a candidate for real, dynamic becoming.

5.2. Resources for Processes as Dynamic Entities

Explicating what distinguishes genuinely dynamic processes from static substances merely relabeled is one of the most prominent challenges in current process metaphysics [28–30]. One recent dynamic metaphysics, developed by Zachrau, exemplifies a response to this broader challenge [31]. His theory of dynamicity takes processes to count as dynamic entities in virtue of their *forward directedness*; this forward directedness is tied to a dynamic time understood as a minimally committed temporal structure of order and direction that, on his view, stands in mutual dependence with fundamental processes. In Zachrau’s account, this is where metaphysical explanation deliberately stops. No deeper ground is offered since none is seen to be explanatorily fruitful. Once on the table, however, the change-first state package provides a way to back this stopping point with empirically licensed structure.

On this option, the forward directedness of both processes as dynamic entities and dynamic time can be read off the self-sufficient unfolding of the change-first state package. Its structure can underwrite both sides of Zachrau’s dynamicity, since at this level process and dynamic time are no longer separate ingredients but are each in virtue of the change-first state package. To be an entity in the change-first state package is to be necessary for the forward-directed, self-sufficient unfolding of it—and to be necessarily in relational co-change structures. It would follow that the entities participating in the change-first state package are necessarily dynamic entities and, thus, fundamental processes according to Zachrau’s criteria of dynamicity.

There is an additional option for those interested in a metaphysics of both becoming and processes right at the edge of dynamic unfolding: both could be placed in a minimally sufficient change-first state package due to Park’s optional integrand picture wherein comparative changing is intrinsic to an instant. The usual concern is that “only an instant” means returning to a static instant with static entities, thus countering the process philosopher’s project or else falling into contradictions.¹⁷ Though it is uncommon to consider processes as non-temporally extended, this may be due to a forced sense of dichotomy between occurrents and continuants, as Zachrau argues [31] (p. 155). The integrand picture offers the option of a change-first state intrinsic to an instant that (i) includes comparative changing as the integrand, which could be considered a non-extended process, and (ii) is the minimal whole package that generates the extended (finite) process through an integration-like dynamic structure.¹⁸ Its being is sufficient for that doing, right where local becoming is happening.

To summarize the range of options available, this most minimal change-first state package could support non-extended processes wholly at the edge of becoming, which

may have its appeal and its drawbacks, since a process is widely considered to require a temporally extended whole. The broader option is that the change-first state package supports just that dynamicity in virtue of which it is meaningful to call an entity a process. These change-first resources could also simply be left on the table since their empirical licensing does not compel their use in metaphysical projects—other criteria must guide that choice.

5.3. Change and Entities Before Time

There have long been ample resources for the time-first view that have attracted metaphysical readings. The intention here is to invite analogous readings of the corresponding resources within the change-first picture. Other metaphysical projects could draw on the change-first resources in different ways; the examples of local becoming and processes offered here are simply illustrative ways of putting those resources to use. The opening question was whether we are empirically forced to treat time as the background in which change happens. The empirical change-first platform shows that we are not. The change-first alternatives offered by Rovelli and Park hold an empirical license equivalent to that of the standard time-first picture. Taken together, they reinforce the structure of a change-first state package that is self-sufficient for what's next, and that necessarily involves relational change structure among its physical entities. Time—where it appears—comes after such change as a convenient way of labeling and organizing those relations. It is, in this sense, a picture of change before time, as well as entities before time, letting us see options that time may have previously obscured.

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Notes

- ¹ Rovelli also calls this a *Heisenberg state* because in the Heisenberg picture of quantum mechanics, a state is not a state at a time but a time-independent object that determines the entire evolution of the observables. This captures the idea of state as the full solution, which Rovelli extends to a generally covariant context [1] (p. 6).
- ² In the pendulum case, for instance, one familiar presentation of the evolution equation is $f(\alpha, t; A, \phi) = \alpha - A \sin(\omega t + \phi) = 0$, which says that there is a function f that relates (A, ϕ) as coordinates for the relativistic states in Γ to (α, t) as partial observables in C —and so provides an example with the familiar meanings of amplitude A and phase shift ϕ .
- ³ For the full presymplectic Hamiltonian construction of (C, Γ, f) , see [1,2], and Chapter 3 in [5].
- ⁴ For a clear exposition of Kretschmann's objection—that general covariance is a merely formal feature any spacetime theory can be given—and of Einstein's response, see Section 5 of [6].
- ⁵ This is the same physical interpretation of the t variable as Rovelli's account of choosing a partial observable as a clock. Park offers the example of a light clock as a comparatively changing thing, with units of distance traveled chosen to give the same values as conventional seconds, and contrasts this view with the 4D spacetime view of quantifying the duration of dimensional time by using a clock: "Since the two views of the light clock can be numerically identical and equivalent for all effects in physics, it is the interpretation of the clock that differs between these two views" [4] (p. 60).
- ⁶ For example, locally no experiment can distinguish between a uniformly accelerating frame and a uniform gravitational field, as in Einstein's equivalence principle. In that spirit, Park follows the insight that, if situations are indistinguishable via experiment, they are equivalent. What is novel in his treatment of equivalence is that it tracks the effect of holding a reality view on experiment in a manner that is also experimentally demonstrable, as shown by the examples above.
- ⁷ In Park's summary: "In other words, each observer has its own essential reality. Since any one observer's essential reality determines all other observers' essential reality, an observer's essential reality can be considered the observation of whole

reality" [4] (p. 49). This is a central point of Park's *Essential Reality & Time*, which does not argue that essential reality is "the" reality, but that it is a more minimal reality view equivalent to the 4D spacetime view. Since any essential reality is sufficient for determining any other essential reality, there is no breakdown into solipsism in this account; rather, each is fully sufficient for the whole effect, which includes translations into another observer's essential reality. For relevant discussions on this topic, see [10,11].

8 In this relational picture of change, gauge redundancy reflects the fact that the observables, such as velocity, are not properties of isolated systems but relational quantities between them. As Rovelli puts it, "Gauge invariance is not just mathematical redundancy; it is an indication of the relational character of fundamental observables in physics. These do not refer to properties of a single entity. They refer to relational properties between entities: relative velocity, relative localization, relative orientation in internal space, and so on" [9] (p. 7).

9 Rovelli shows that instantaneous states and relativistic states are in one-to-one correspondence once a time $t = t_0$ is given [2]. By a similar argument and under this same condition that also yields the change-first state package, there is likewise a one-to-one mapping between Rovelli's change-first state (the relativistic state) and Park's change-first state (essential reality); they stand in bijection with each other. Unlike the contrast between instantaneous and relativistic states, however, where the physical interpretation differs, these two change-first states also share important similarities in their physical interpretation, as described above.

10 It is striking that a similar change-first picture emerges from two approaches that differ significantly in their methods and starting points. However, the change-first picture developed here is not the only departure from the time-first standard. For example, Barbour proposes a reformulation of mechanics that rejects the time-first standard yet treats a timeless collection of static spatial configurations as prior to change [15]. A separate task is to explore the possibilities offered by various quantum gravity theories and to analyze their treatments of time and change. For a summary and discussion of the main "timeless" approaches to quantum gravity—including Rovelli's loop quantum gravity, Barbour's version of canonical quantum gravity, and causal set theory—see [16] (pp. 95–108).

11 For discussions of instantaneous velocity intrinsic to an instant, and of its associated difficulties, see [17,18].

12 Notationally, Park is proposing that the ratio of comparative changing (v) can be defined as the integrand in $v dt = dx$, instead of the usual definition of velocity as the derivative $v = dx/dt$. Although both formalisms give the same value for v , the derivative necessitates more than one instant in its definition, whereas the integrand does not. Velocity defined as $v dt = dx$ is precisely the ratio of comparative changing with a clock at an instant that, when multiplied by a differential of clock-change (dt), gives the next distance (dx). With the position (x) and velocity (v) of force elements at one instant, the next velocity is $d(mv) = f(x, v) dt$.

13 Sections 2–4 try to avoid talk of what is "fundamental," since both philosophers and physicists may mean different relations by it. Park and Rovelli do not frame their views of change in the philosophical vocabulary of what is "fundamental to," "grounding," or "primitive." The aim here is to make the change-first structures available as resources for the broadest range of metaphysical readings by keeping the physics–metaphysics interface as clear as possible.

14 According to Park's account, essential reality's sufficiency for what is next provides a more-change direction that tends toward a more probable state, which is consistent with a higher entropy state. For Rovelli's way of describing how a statistical state can determine an emergent temporal flow in a generally covariant setting, see his thermal time hypothesis, summarized in [12] and in Section 3.4 of [5].

15 Vidotto develops and generalizes Rovelli's relational picture, arguing that the ontology of relations and interaction events suggested by relational quantum mechanics in fact underlies contemporary fundamental physics more broadly [21]. In developing a notion of process compatible with Rovelli's loop quantum gravity, Margoni explicitly proposes that processes are what happens among systems when they interact and argues that, in frameworks without background time structure, "processes concern the identity that entities obtain within the broader sets of relations in which they stand," rather than being activities evolving through time [22] (p. 1). Calamari also interprets Rovelli's loop quantum gravity as supporting a process metaphysics and ontology "all the way down" to quantum dynamical processes [23].

16 Since we are restricting attention to local becoming, this involves a use of an observer's frame of reference with Rovelli's relativistic state, which is already accounted for by the change-first state package; see Section 4.2. Alternatively, one could treat the structures of Rovelli's and Park's frameworks separately and let this convergence emerge naturally in local applications relative to an observer's frame of reference.

17 See, for example, Galton's interest in—and then retraction of—the dynamic instant: "In earlier work, I flirted with the idea of a *dynamic instant*, that is, an instant in which actual change or motion is present. Only so, it seemed, could the idea of processes as continuants gain any purchase. ... The problem is that, although mathematicians can define the velocity of a moving object at an instant, using the differential calculus, this definition makes the instantaneous velocity dependent on the positions occupied by the object at times other than the instant in question, which means that it cannot be regarded as a property of the instant in question per se" [32] (p. 176).

- ¹⁸ The integration-like “process” is one example of what Zachrau calls *dynamic structure* to draw attention to dynamic accounts of structures and relations: “While the overarching paradigm still is Process Philosophy, I want to label such special positions ‘metaphysics of dynamic structures’. On such views, processes are not cast into preshaped moulds but rather woven into a fabric where thread and fabric are coming into being as processes” [33] (p. 122).

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