Comments on Sklar's "Barbour's Relationist Metric of Time"*

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Professor Sklar's paper (Sklar, 2003–4) illustrates very well the vitality of the relationalist–substantivalist debate, a debate that not so long ago was declared by some to be outmoded (Rynasiewicz, 1996). To a limited extent, in fact, the critics are right, for it is not the relationalist–substantivalist debate *per se* that is providing a rich vein of philosophical material. Rather interest is now (or should be) in a family of interpretative questions concerning space and time in physics that are related to, though not identical to, those of the traditional debate. The work of Julian Barbour has played a central role in posing many of these questions and suggesting answers. In the context of Newtonian physics—the context of Sklar's paper—it is true that Barbour offers a picture that is relationalist in the traditional sense: the rock-bottom ontology consists only of material particles; there is nothing more to space and time than the relative distances between these particles, and their relational evolution. But things are different when Barbour extends his Machian framework to general relativity and beyond. In these contexts space (though not spacetime) re-enters at a fundamental level. In the context of relativity, one of the most unorthodox features of Barbour's picture is his rejection of spacetime's fusing of space and time, and his embracing an ontology of global "Nows". This feature of his worldview should be of particular interest to philosophers who wish to defend an A-theory of time, although it should be stressed that Barbour himself has no time for a privileged present, or for the objective passage of time.

In these comments I will focus on two questions raised by Sklar. First, does Barbour and Bertotti's approach to Newtonian dynamics constitute a genuine alternative to the standard way of conceiving of the theory? Second, and this is really Sklar's principal question, if one supposes that it does constitute a genuine alternative, how is one to choose which viewpoint to adopt? Which methodological considerations bear on, and are raised by, the existence of such a choice?

In raising the first of these questions, and answering it positively, Sklar gives an exemplary non-technical review of many of the key aspects of the Barbour–Bertotti framework. I too wish to rehearse some of the details. Doing so will also allow me to highlight some of its features that are pertinent to my later discussion, but I also want to present Barbour's viewpoint in a way which points in the direction of two things Sklar mentions in passing. One is that the ultimate test for Barbour's approach is how successfully it generalizes, beyond Newtonian dynamics, to our contemporary physics. The second is the question of eliminating the 'absolute' structure that remains, namely, the absolute spatial metric of instantaneous configurations.

So let me now give my own gloss on the Barbour–Bertotti approach to Newtonian dynamics. Suppose the actual world to be a world of N point-particles interacting in such a way that, relative to some coordinate systems on space and time, the actual trajectories satisfy Newton's laws of gravitation. Suppose I give you the relative distances between the particles at

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some instant, and the *relative* rates of change of these.[1] Is this information all you need in order to be able to work out the entire sequence of sets of relative distances that constitute a history? If the only constraint is that in some spacetime coordinate system Newton's laws are true, the answer is No.[2]

There is a particularly elegant perspective from which to view this fact. One thinks of formulating possible dynamics on a series of abstract spaces. First, one considers the space QT—a space formed from two separate spaces: T, the space of Newton's absolute times, and Q the space of the possible configurations of our N particles given by their positions in some autonomous, persisting space (e.g., the relative space of an inertial frame). This is the arena for the Lagrangian formulation of Newtonian dynamics, which picks out a privileged class of curves in this space as representing dynamically possible histories. A crucial point to note is that if one is given a point in QT (i.e., a configuration with respect to space, at a time) and a direction at that point (i.e., one is also told how, with respect to space, that configuration is changing, and how quickly), one can calculate a unique Newtonian history.

But one might wonder about formulating dynamics on Q alone. What happens if one 'projects down' the possible Newtonian curves in QT, onto Q? Is a point and a direction *in* Q enough to single out a unique curve in Q? The answer is No. A point and a direction in Q only gives us a configuration and *how* it is changing relative to absolute space. It does not tell us *how quickly* it is changing (i.e., it does not give the total kinetic energy), and this can make a dramatic difference to the subsequent evolution.

However, the projections of curves from QT down to Q can all be obtained by a *family* of dynamical principles formulated on Q alone, where, for each point in Q and direction at that point, each such principle does predict a unique curve. These are the *Jacobi principle* formulations of the dynamics. Each principle corresponds to a system of a fixed total energy. They are geodesic principles on Q, and time does not in any way appear in their formulation: we have a metric defined on Q, and curves representing physically possible histories are simply extremals of this metric. It turns out, however, that the form of the principles is such that there is a preferred parametrization of the curves, which simplifies the equations satisfied by the curve, and which corresponds to Newton's absolute time. Hence the talk of recovering Newton's time as a unique simplifying parameter, a procedure Barbour connects with astronomers' empirical determination of ephemeris time.

At this stage it is important to note a distinction between two ways in which time might be said to be a 'simplifying parameter'. Making this distinction is crucial if one is to recognize the full significance of Barbour's adaptation of the Jacobi principle to provide a genuine elimination time (or at least of a primitive temporal metric).

Consider Newtonian dynamics formulated in generally covariant spacetime terms as in, for example, Friedman (1983). Here the equations are ugly, and one of the basic entities they govern is a field that does nothing other than encode a primitive temporal metric. But we can effect an apparent simplification by adapting our spacetime coordinates to this (and other)

[1]By giving you only the relative rates of change, I am not giving you information about how quickly the relative distances are changing with respect to time itself, but only information such as: when the distance r_{12} between particles 1 and 2 has doubled, r_{23} has reduced by a third.

[2]Whether this in itself really does count as *prima facie* evidence against relationalism leads to the question—perhaps more intricate than is commonly supposed—of the rationale for what Barbour calls *Poincaré's criterion*, (see Pooley and Brown, 2002, §4). I leave this issue to one side.

spacetime structures: the time coordinate of these special coordinates then straightforwardly encodes the ontologically fundamental temporal intervals.

There are points of comparison between the generally covariant spacetime formulation of a Newtonian theory and so called *parameterized particle dynamics*. We can consider arbitrary parameterizations of possible curves in QT, if we treat time as another dynamical (i.e. dependent) variable. So formulated the principle is *parametrization invariant*, leading to a constrained Hamiltonian theory when cast in Hamiltonian form. One might then view the *standard* formulation of analytical mechanics as involving a choice of a simplifying parameter that encodes the 'dynamical' time variable.

Note that time is not eliminated in either the case of generally covariant spacetime theories, or in the case of parameterized particles dynamics. In the generally covariant spacetime theories, time appears as an autonomous spacetime field. In parameterized theories, time sits among the alleged configuration variables, as it does in their Hamiltonian versions. In these cases identifying time with a preferred, simplifying coordinate, amounts to nothing more than choosing coordinates adapted to these particular structures.

Something very different is going on in the Jacobi principle, which can be obtained from the parameterized form of the standard dynamics by the *elimination* of the time variable.[3] The result is an action that remains parametrization invariant but time itself does not sit amongst the configuration variables: these are *just* spatial positions. Barbour's simplifying parameter simplifies the *collective* dynamics of these entities. It does indeed turn out that each particle then obeys an equation that looks like the Newtonian equation, but the interpretation of the equation that the perspective suggests is radically different.

Having considering Barbour's use of Jacobi's approach to 'eliminate' time, let us turn to his elimination of absolute space. Consider a third abstract space: Q_{RCS}, the space of *relative* configurations (each point just encodes the relative distances between our N point particles, not their positions in some container space). We can project down our preferred curves in Q to curves in Q_{RCS} and ask, again, whether a point and a direction in Q_{RCS} is sufficient to pick out one of the class of curves so obtained. The answer is again No, but now a contrast with the transition from QT to Q needs to be noted. Unlike the curves in Q, we cannot obtain the entire set of curves in Q_{RCS} from a family of dynamical principles formulated on Q_{RCS} alone. It is only those curves which correspond to a Newtonian system with zero angular momentum that can be obtained from such a principle.

I wish to make four points in terms of this more abstract framework, before finally turning to the methodological issues that are raised by the choice between standard Newtonian theories and their Barbour–Bertotti analogues.

My first point concerns the way in which Barbour's elimination of the primitive temporal metric on the one hand, and his elimination of primitive inertial structure on the other, are quite independent of each other. This is reflected in the two-stage nature of the passage from QT to Q_{RCS}. We could equally well have passed first to $Q_{\mathrm{RCS}}T$ and then to Q_{RCS}. The eliminations, in addition to being independent, are also of quite different characters. And this difference, as we will see, has interpretative implications. The passing from QT to Q involved no real restriction:

[3]Hence Sklar's gloss that Jacobi's approach involves treating time "as if it were an extra dynamical variable" (2003–4, 66), while it describes a stage on the way to Jacobi's principle, is misleading if taken to apply to the final result.

for any solution in QT to the original theory, one can find a Jacobi principle that has its unique projection in Q as a solution. Correspondingly, whatever the value of the total energy E of the universe (the system to which the relational dynamics applies), one can find a timeless Jacobi-type principle to describe it.[4]

My second point concerns the key question (considered by Sklar (2003–4, 68; 72)) of whether Barbour–Bertotti theory represents a genuine alternative to Newtonian dynamics. Here the distinction between the elimination of time, and the elimination of inertial structure, means that we should consider these elements of the theory separately. Despite the remark just made under point 1, it does seem that Jacobi's principle can be given a properly timeless interpretation. As mentioned above, there is difference between cases where time has been genuinely eliminated, and where time has simply been included as a pseudo-configuration variable. Both types of theory give rise to constrained Hamiltonian systems, but the constraints are mathematically different in each case, and Barbour's perspective suggests a very different interpretation of them. (This point would appear to be of obvious relevance to the interpretation of the constraints of canonical general relativity, where the Hamiltonian constraint is analogous to the Jacobi principle constraint, not to a constraint that arises from parametrization, a point lucidly argued for by Barbour himself (Barbour, 1994). I find it slightly surprising that the philosophical literature on the related problem of time in quantum gravity does not contain more discussion of this insight.)

Turning to the elimination of inertial structure, in the presentation above we passed from the Newtonian configuration space Q to the relational Q_{RCS}. Barbour and Bertotti's dynamical principle on Q_{RCS} might similarly be defined by starting with the standard (Jacobi) action principle on Q.[5] In particular, the geometric structure on Q_{RCS}, in terms of which the dynamical principle is framed, might be understood as induced by the geometric structure of Q. In such circumstances, and with the geometric structure of Q naturally receiving a substantivalist interpretation, the claim that one is being presented with an alternative theory might seem hard to defend. Fortunately Barbour has an account of the Q_{RCS} theory, in terms of a variational process that he calls "best matching", which makes it transparently clear that the theory is committed to nothing more than the relational quantities. Effectively the notion of best matching provides an alternative, relationalist (re)interpretation of the relevant structures of the larger space Q.[6] Sklar writes:

[4]It is true that, in the context of the original Barbour–Bertotti theory Barbour recommends the action that one obtains when $E = 0$ on the grounds of its simplicity and mathematical elegance, but observations within such a Newtonian universe could in principle rule out $E = 0$ as a possible value. It is not the case that the choice $E = 0$ is conventional, or a calculational convenience, although, for finite values of E, the absolute value will be conventional to the extent that they are dependent on the choices of units for length, mass etc.; *cf.* Sklar (2003–4, 68). Things are different when it comes to Barbour's recent scale-invariant generalizations of Barbour–Bertotti theory: see point 4, below.

[5]Belot's presentation (Belot, 1999, 2000) of a Hamiltonian theory closely connected to Barbour and Bertotti's, although without the elimination of a primitive temporal metric, follows this type of route.

[6]The need for a genuinely relationalist interpretation of the Q_{RCS} theory is considered at greater length in Pooley and Brown (2002, §§5 & 7). For Barbour's most recent, accessible account of the best-matching variational process, see Barbour (2003, §4).

> It is sometimes argued by defenders of Barbour and Bertotti that their demonstration that the theory can be derived from a new action principle framed entirely in relationist terms adds to the believability of the theory. (2003–4, 72)

I would prefer to put the point this way. The fact that the solutions of Barbour–Bertotti theory can be obtained from a theory of a type which can be shown to be motivated by, and understandable in terms of, relationalist first principles is a *prerequisite* for being able to take the theory seriously as a genuine alternative to standard (substantivalist) Newtonian dynamics. However, that such a demonstration is possible does not by itself favour the relationalist theory over the standard one; it just means that we do face a genuine choice between the two.

My third point concerns the generalization of Barbour–Bertotti theory to general relativity. Our discussion in terms of configuration spaces facilitates this story. Corresponding to the point-particle configuration spaces Q and $Q_{\rm RCS}$, there arise in the investigation of canonical general relativity two, much larger, configuration spaces: $\mathrm{Riem}(M)$, the space of all Riemannian metrics on some 3-dimensional manifold M of fixed topology, and $\mathrm{Riem}(M)/\mathrm{Diff}(M)$—or 'superspace'—, the space one gets from $\mathrm{Riem}(M)$ by quotienting by the group of diffeomorphisms on M. A geodesic principle on $\mathrm{Riem}(M)/\mathrm{Diff}(M)$ would appear to be the analogue of the timeless, relational theory on $Q_{\rm RCS}$. It turns out that general relativity itself can be cast, without real modification, as just such a theory. To transform the standard action of general relativity into such a form, one does not have to impose an analogue of the constraint that the angular momentum of the point-particle universe is zero; general relativity *already* implements best matching.[7] To put the point the other way around: general relativity is *not* the analogue of a full Newtonian Jacobi theory on Q. Any such theory on $\mathrm{Riem}(M)$ would be an (odd) generalization of general relativity.[8] All of this concerns inertial structure. What of the elimination of time? Different values of the total energy E in distinct Newtonian Jacobi principles turn out to be the analogues of different values of the cosmological constant. So here again, it turns out that the standard formulation of general relativity (i.e., those for which the cosmological constant *is* regarded as a fundamental constant) can already be interpreted as doing away with a primitive temporal metric when cast in the appropriate form.

My final point concerns the 'absolute' structure that remains in the Barbour–Bertotti theory: the instantaneous inter-particle distances. It is worth pointing out that such distances hardly contravene the spirit of traditional relationalism. However, perhaps they can be threatened by a version of the Leibnizian shift arguments that (erroneously in my view) might be taken provide the philosophical motivation for a relationalist alternative to standard physics. For consider the universe doubling in size overnight while preserving all of the *ratios* of the relative distances. How would such a change be detectable? Does regarding such differences as

[7] It is worth stressing that such a formulation of general relativity nonetheless constitutes a more restricted theory than the standard 4-dimensional spacetime formulation. Clearly it will have only globally hyperbolic spacetimes as solutions. Further, in the choice of M, we have fixed the spatial topology.

[8] Some of these points a further explored in Pooley (2001), where it is also argued that the theory is not relationalist because the points of $\mathrm{Riem}(M)/\mathrm{Diff}(M)$ are naturally interpreted as intrinsic specifications of the geometry of empty, substantival space.

meaningful saddle us with distinct possible worlds, differing from each other only by an overall scale factor, that violate the principles of sufficient reason and the identity of indiscernibles?[9]

The answer is No: empirically we can determine whether a given distance has increased or decreased from one moment of time to the next. However, this determination is mediated by theory, just as our ability to determine whether a body is absolutely accelerating is. And Barbour has considered a generalization of the original Barbour–Bertotti theory to a scale-invariant theory that does away with primitive comparisons of distance at different times (see Barbour, 2003). One considers the space Q_0 which encodes only the ratios of the relative distances between particles. By generalizing the notion of best matching, geodesic principles on this space can be found which correspond to dynamical theories for which, while comparisons of distances in different places *at a time* are primitively meaningful, comparisons of distances at different times are not. However, just as the original best matching of the Barbour–Bertotti theory allows the construction of emergent inertial frames (as its reproducing a subset of the solutions of a Newtonian theory entails it must), so the generalized best matching of scale-invariant theories allows for a dynamically determined comparison of distances at different times.

Let us ask the analogous question to those asked above. Take some Newtonian-type Barbour–Bertotti theory defined on Q_{RCS} and project its solutions down onto Q_0. If the projected curves are to be found as the solutions of some geodesic principle on Q_0, are there constraints placed on the original theory, and on its solutions? The answer, as might have been expected, is Yes. Of particular interest to us here is the fact that the total energy of the system must be zero, and the potentials of all the forces must be homogeneous of degree -2. This appears to be in conflict with those Newtonian-type theories that have enjoyed empirical success, none of which involve force potentials that are homogeneous of degree -2.[10] However, Barbour shows how any such theory, including those with non-zero values of total energy, can be obtained as an *approximation* from the right choice of scale-invariant theory, which will reproduce the original Newtonian potentials together with an epoch-dependent cosmological force.

It turns out that the scale-invariant, or conformal generalization of best matching is of particular interest in the context of general relativistic theories (Anderson et al., 2003). The general relativistic analogue has the potential to reintroduce a preferred foliation of spacetime at a fundamental level, a foliation that has already long been recognized to be mathematically significant because it makes the initial value problem of general relativity significantly more tractable. The framework also suggests generalizations to theories which would differ empirically

[9] Actually, these two cases should distinguished. One might believe that primitive trans-*temporal* comparisons of distance are physically meaningful, and hence sanction the use of Q_{RCS}, but deny that trans-*world* comparisons are meaningful, and hence deny that two worlds could differ only by an overall scale factor. For this reason it would seem to be a mistake to take the use of Q_{RCS}, which is required if one is committed to the primitive comparability trans-temporal distances, to indicate a commitment to the corresponding trans-world differences (similar points, in a different are context, are made in Pooley, forthcoming). In the theories discussed below the trans-temporal comparison of distance is given up, but primitive trans-temporal comparison of *angle* remains meaningful. It seems that any theory formulated in terms of a geodesic principle on a configuration space will be committed to the primitive comparability of *some* trans-temporal quantities.

[10] In contrast, the constraint imposed on the form of the potentials by Barbour and Bertotti's original best matching—that the potentials be functions just of the relative distances—was not in conflict with empirical evidence.

from general relativity in crucial respects. I suggest that all of this has an important bearing on Sklar's question concerning the choice between the original Barbour–Bertotti theory and the standard Newtonian theory. For it points to a way in which a choice between them can transcend the interpretation of the particular solutions that they have in common. Surely theory choice is partly determined by the more general framework in which the theories are embedded, and by which avenues of fruitful research they suggest. While empirically indistinguishable with respect to certain solutions, *neither* Barbour–Bertotti theory nor standard Newtonian theory is ultimately empirical adequate. The fact that they generalize in very different directions leaves open the possibility that it may be future theoretical developments that ultimate reveal which is 'closer to the truth.'

I now turn to some of the specific methodological questions raised by the question of which of Barbour–Bertotti or standard Newtonian dynamics would be preferable *if* our universe really were a Newtonian universe of zero angular momentum. Three subissues raised by Sklar strike me as particularly interesting: (1) Whether Barbour's theory is to be preferred because it does not suffer from deficiencies suffered by the standard Newtonian theory. Sklar answers that the standard theory can have the deficiencies removed and so this leads to one of the issues that flows from the cosmological nature of Barbour's theory: (2) if neither theory is *inherently objectionable* (the Newtonian deficiencies can be overcome), how do we choose between them *given that it cannot be based on empirical evidence*? (3) Finally, there is the issue of the relation of 'isolated' subsystems of the universe to the universe as a whole: what does the theory say is the 'influence' of the latter on the former? I will say a little about each of these in turn.

According to Sklar, the traditional substantivalist understanding of Newtonian theory suffers from defects in that it commits us to physically meaningful quantities that are in principle empirically beyond reach. The shift from Newtonian space to Galilean spacetime gets rid of some of these (absolute velocities), but some remain; in particular, temporal shifts, and spatial shifts of the entire material universe with respect to space and time are supposed to give us distinct universes which are nonetheless empirically indistinguishable. Sklar proposes that we consider a 'sanitized' Newtonian theory that deals with the temporal shifts in Barbour's way (i.e., via the Jacobi method), and then deals with the latter by introducing quantities of absolute acceleration as primitive monadic predicates. (These properties, originally countenanced in Sklar (1974) are dubbed 'sklarations' by Huggett, who develops the idea in Huggett (1999).)

I am against this approach on two counts. First, it seems that one might wish to consider a similar question about a choice between a Newtonian theory (sanitized so as to avoid temporal shift problems, but still involving a primitive notion of temporal distance between instants) that allows the universe to have any possible energy, with a Barbour-style but non-relational theory that only allows the universe to have one energy, does not involve a primitive temporal metric, but does involve primitive inertial structure.

Second, I do not think that the standard substantivalist account does suffer from the alleged defects. The difference between universes involving the entire material universe shifted with respect to spacetime (whether spatially or temporally) are of a different kind to those differences between two old-style Newtonian universes which differ in terms of the absolute velocity of the material universe with respect to absolute space. Both types of difference are unobservable, but the former, and not the latter, are merely *haecceitistic* differences: differences only over which entities in the worlds instantiate which properties, not differences over which properties are instantiated. I believe it is coherent just to deny that there can be such differences. And that the denial of such differences is perfectly compatible with the standard formulations of the theory.[11] If such differences *are* allowed then they arise in any theory. By eliminating spacetime points, models of Barbour–Bertotti theory cannot differ in terms of which points instantiate which properties, but they *can* differ in terms of which particles have which properties: the properties of two particles can be swapped to yield two distinct, possible but qualitative identical worlds.[12] I also believe that the postulation of primitive monadic accelerations brings with it some particularly undesirable consequences, as we will shortly see.

So if we sanitize Newtonian theory the sophisticated substantivalist's way, which should we choose: Barbour–Bertotti theory or the standard theory? As Sklar stresses, we cannot do what is standardly done: look for cases where their empirical predictions differ. Their predictions *do* differ, but only, *ex hypothesi*, in other possible worlds.

The most obvious difference between the theories is that according to standard Newtonian dynamics the vanishing of the universe's angular momentum is a contingent fact, but according to Barbour–Bertotti theory, it is a lawlike prediction. Should this count in favour of the Barbour–Bertotti theory (*cf.* Sklar, 2003–4, 71; 73–4)? Here Sklar makes two interesting comparisons. The first is with the role that a low-entropy initial condition plays in the reconciliation of time-symmetric statistical mechanics with time-asymmetric thermodynamics. Do such initial conditions, that are in some sense extremely improbable, stand in need of an explanation, as many have felt they do? And if the answer is Yes, does this reflect badly on standard Newtonian mechanics? Here it is worth mentioning that it is perhaps not clear that zero angular momentum is unlikely from the perspective of Newtonian mechanics. Frank Arntzenius has suggested that standard Newtonian mechanics predicts that there will be no observable universal rotation because as $N \to \infty$, the measure of the set of random distributions of N particles with discernible angular momentum goes to zero. But if we suppose that Barbour–Bertotti theory *does* explain, while Newtonian theory does *not* explain, the zero angular momentum of the universe, then we need not address whether *in general* such conditions stand in need of explanation. All we need ask is, when we *do* have a choice between a theory that does (genuinely) explain and one that does not, which is preferable?

Sklar's second comparison involves the inflationary explanation of the 'improbable' cosmological spatial near-flatness of our universe. Might the Newtonian not be able to postulate some *mechanism* that analogously results in near zero angular momentum? Perhaps. But any such mechanism would surely break the empirical equivalence between Barbour–Bertotti theory and the Newtonian theory. For example, it might be expected to leave a distinctive signature, much as different inflationary models predict different fluctuations of the cosmic microwave background.

I have the strong intuition that Barbour–Bertotti theory does offer a potential explanation of a universe's zero angular-momentum.[13] Why? Here, I think, the contrast with the universal energy is illuminating. Although each Jacobi principle restricts the energy of the universe to be whatever it is—the value of the universal energy is to be interpreted as a fundamental constant—there is a sense in which the value is nevertheless in no sense explained. The reason is that for

[11]This obviously needs to be defended at much greater length than I can here. I take it that many substantivalist responses to Earman and Norton's hole argument effective endorse such a 'sophisticated' substantivalism. I defend the approach in Pooley (forthcoming, §4–5) and, more thoroughly, in Pooley (in preparation*b*).

[12]To avoid worries concerning such permutations violating essentialist constraints, consider a permutation of particles which share all of their intrinsic properties such as mass and charge.

[13]This intuition is defended in Pooley and Brown (2002).

any value of energy you like, there is an equally good, distinct, theory of exactly the same type that allows just this value. Although it is a fundamental constant, it is an *arbitrary* parameter of the theory.[14] This is not the case with zero value of angular momentum. Only if the value is zero can the relationalist theory even get off the ground. The moral, rather interestingly, appears to be that lawlike predictability, or nomological necessity, *by itself* cannot be taken to explain. In this particular case, the constraint arises through an interplay between fundamental ontological categories (relationalism) and the requirement that the theory be of a certain type (that initial data consist only in configuration variables and their first derivatives). How, if at all, should this be understood to have extra explanatory power? At the very least the contrast suggests that some interesting avenues might be profitably explored.

Finally, I want to conclude with some remarks about the light the various theories shed on the relation of subsystems of the universe (and the theories they are held to obey) to and the universe as a whole (and the cosmological theory). There is a basic 'conspiracy' for an account of which we must ultimately look to our cosmological theory. Any two isolated systems, each obeying Newton's laws, are systematically related, despite their isolation. The preferred time parameters defined by their motions and Newton's laws march in step, and the two spatial reference frames defined by their motions and Newton's laws are in uniform translatory motion with respect to each other. Why? The basic, mathematical, fact is that if a total system obeys Newton's laws with respect to a particular spatial reference frame and time parameter, then isolated subsystems *of this system* will obey Newton's laws with respect to the same frame and time. However, the different cosmological theories give very different spins to this fact.

Barbour–Bertotti gives a *non-local*, holistic explanation. It is the dynamics of the universe as a whole that determines both the universal reference frame and the universal time. Consider two isolated systems A and B, separated by a vast distance. From the Barbour-Bertotti perspective, the motions of system A contribute to determining the universal frame and hence help determine those frames with respect to which system B will be seen to obey Newton's laws.

In contrast, the local spacetime theory approach gives a local 'explanation' of this coordination. The universal frames are those coordinate systems adapted to the primitive spatiotemporal structures. Their flatness accounts for the existence of such global coordinate systems, with respect to which Newton's laws take their standard, non-generally-covariant form. But now the fact that each system obeys Newton's laws separately is accounted for by the local laws constraining these material systems to be adapted in the right way to the structure fields in their locality.

What of Sklar's sanitized Newtonian theory, with its primitive monadic accelerations? It seems that in this case we add to the mystery, rather than explain it. For the coordination between the inertial frames of the two isolated systems now becomes a coordination between the sklarations instantiated by the components of the systems, a coordination that might seem to stand in need of explanation, and in tension with their status as primitive properties. Of course, the various laws that determine the coordination of the sklarations of isolated systems receive a transparent explanation if they are taken to be what they are: *accelerations* with respect to a preferred class of coordinate systems, however these coordinate systems are to be understood.

[14]Compare: does the standard model, as opposed to some hoped for unification, explain the electron/muon mass ratio?

And as we have seen, Barbour and Bertotti's relationalist dynamics, and the substantivalist interpretation of standard Newtonian dynamics, offer us two clear rival alternatives.[15]

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