What's the Matter with Super-Humeanism?

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Abstract

Esfeld has proposed a minimalist ontology of nature called 'super-Humeanism' that purports to accommodate quantum phenomena and avoid standard objections to neo-Humean metaphysics. I argue that Esfeld's sparse ontology has counterintuitive consequences and generates two self-undermining dilemmas concerning the nature of time and space. Contrary to Esfeld, I deny that super-Humeanism supports an ontology of microscopic particles that follow continuous trajectories through space.

1 Introduction

In this article I offer some critical reflections on Esfeld's 'super-Humean' metaphysics of physics, which combines the primitive ontology approach to quantum mechanics with ontic structuralism realism. According to Esfeld, the world of macroscopic objects is composed of microscopic particles, which are distributed according to a law of nature specified by Bohmian mechanics. This law explains the 'non-local' measurement outcomes associated with quantum experiments, such as the famous EPR experiment involving two quantum-entangled particles. Super-Humeanism offers a supervenience base for this law consisting of a changing configuration of matter points, which have no intrinsic physical properties or causal powers, but are constituted solely by the distance relations in which they stand.

While Esfeld's super-Humean ontology is elegantly simple, and avoids a standard objection to neo-Humean metaphysics from 'quidditism', I claim that it is susceptible to a 'symmetric worlds' problem, and to self-undermining dilemmas concerning both its conception of primitive change and its persistence conditions for Bohmian particles. I conclude that this primitive ontology is too sparse to offer a plausible account of nature.

2 Matter without Physical Properties

2.1 The primitive ontology approach

Super-Humeanism rejects the 'classical' conceit that physical properties, like mass and charge, are intrinsic properties of particles (or fields). This rejection is motivated in part by Schrödinger's ([1935]) description of quantum entanglement as 'the characteristic trait of quantum mechanics' that compels a 'departure from classical lines of thought'. The phenomenon of quantum entanglement troubles the classical picture of the world in two ways. First, it gives rise to 'non-separable' systems, in which the state of two quantum-entangled systems cannot be decomposed into the states of their separate parts. Second, it gives rise to 'non-local' phenomena, in which what happens at some point P in space depends not only upon what exists in the past light cone of this event, but also upon what exists at points in space which are separated from P by a space-like interval.

For example, in the famous EPR experiment involving two quantum-entangled particles emitted from a common source, one particle is measured to be 'spin-up' when another is measured simultaneously to be 'spin-down', and vice versa, however far apart the two particles are separated (Einstein et al. [1935]). The two measuring devices in this example have both been set up to register 'vertical spin' (that is, 'spin-up' or spin-down'), but the polarization angles of these devices, ϕ_A and ϕ_B, can be adjusted separately to produce a range of experimental outcomes. Significantly, quantum mechanics predicts that the statistics for this experiment will depend on the relative angle between them: $\phi_A - \phi_B$. This is something that neither particle, considered separately, is in a position to 'know', given the ban on superluminal signalling in modern physics.

Bell's theorem (Bell [1964]) is generally taken by physicists to have established that the measurement outcomes of the EPR experiment cannot be accounted for by assuming that each quantum-entangled particle carried classical values, which are local magnitudes of the system that were available to be measured separately all along. More precisely, such 'no-hidden variables theorems' imply that we cannot infer the microscopic properties possessed by a physical system from its 'local observables', and that measurements are interactions that significantly disturb its quantum state (Lazarovici et al. [2018]).

In order to offer an empirically adequate account of the non-local measurement outcomes of quantum experiments, while avoiding the notorious 'measurement problem' of quantum mechanics, super-Humeans adopt a primitive ontology approach to Bohmian mechanics (Esfeld [2014b]), which posits a finite configuration of N particles that occupy different positions, $Q = (\mathbf{Q}_1, , \mathbf{Q}_N)$, and specifies a law of motion that determines their trajectories (Dürr et al. [1992], [1997]). This law does not depend upon the particles having intrinsic properties (Esfeld et al. [2013]), but upon a universal wave function ψ, which evolves according to the Schrödinger equation. The physical state of a system of particles $q \in Q$ can be specified by a tuple pairing an effective wave function with the positions of the particles: $(q, \psi)_t$.

Bohmians explain the non-separability of quantum systems, and the non-local measurement outcomes of the EPR experiment, by embracing a form of holism in which the trajectories of all particles are choreographed by the Bohmian law of motion. Fixing the polarization angle of the apparatus in one wing of the EPR experiment influences the trajectory of the particle in the other wing via the wave function, which induces a velocity profile $v^{\psi}(t)$ for all of the particles, including those particles composing the two measuring devices, which accounts for their correlated measurement outcomes. While the positions of a system of particles cannot be measured without simultaneously disturbing their wave function, an ontology of particles is defended by appealing to the 'discrete' nature of the phenomena that scientists observe in experiments (Esfeld and Deckert [2017], p. 5). According to Bohmians, 'all measurements come down to position measurements' (Lazarovici et al. [2018], p. 1). Since the 'classical value' Q of the global configuration of particles cannot be measured, Bohmian mechanics is empirically equivalent to standard quantum mechanics.

In a Bohmian world, the pointers of our measuring devices are patterns of particles which instantiate this law. However, while the wave function is supposed to be merely a feature of how Bohmians represent the dynamics of quantum systems (Solé [2013]), the universal wave function ψ at time t does not supervene upon the global particle configuration Q at time t. The wave function thus represents some matter of fact over and above the particle positions at t, and scientific realists who adopt a primitive ontology approach to Bohmian mechanics must specify an adequate supervenience base for the Bohmian law of motion that accounts for the truth of quantum mechanics.

2.2 Super-Humean matter points

Super-Humeanism combines the primitive ontology approach to quantum mechanics with ontic structural realism to produce a minimalist ontology defined by two axioms:

1. There are distance relations that individuate simple objects, namely, matter points.

2. These matter points are permanent, with the distances between them changing.

The primitive ontology consists of the matter points. The ontic structure consists of the distance relations. The matter points do not exist over and above this structure, since there is nothing more to being a matter point than its standing in certain distance relations. However, the world is not made of relations without relata. Rather, these matter points are the fundamental objects that instantiate this ontic structure. In this model, macroscopic objects, like measuring devices, are individuated by their microscopic matter points, while matter points are holistically individuated by the distance relations in which they stand.

In order to explain how physical systems made of matter points change, for the sake of empirical adequacy, Esfeld is compelled to expand the supervenience base. Since distance relations are supposed to establish the order of what coexists in nature, he takes up Leibniz's relationalist definition of space. Since these distance relations constitute particles that change their positions, he follows Leibniz in conceiving time as the order of that change. Esfeld must therefore sort his supervenience base into an infinite number of time-slices by imposing a linear ordering, in which each time-slice contains a complete assignment of distance relations between all of the matter-points that exist at that time. To give a direction to this linear ordering, which explains why one time-slice should follow another, he must also include a primitive arrow of change.

Since super-Humeans follow the Mill–Ramsey–Lewis account of laws, they consider the Bohmian law of motion (or something like it) to be a universal law of nature only insofar as it is an axiom in the 'best system' that balances strength and simplicity in deriving the facts about how matter points are distributed for all time. However, since scientific practices are typically aimed at investigating interactions that take place within isolated physical systems, they must find other ways of representing how systems change. Super-Humeans treat the physical properties of systems, like mass and charge, in the same way that classical neo-Humeans treat powers: such properties are conceptual decorations, rather than objective features of nature, which may feature as part of a 'best system' account that offers a simple and informative way to represent change (Esfeld [2014a]).

3 Objections to Super-Humeanism

Super-Humeanism offers a simple account of non-local quantum phenomena in terms of a holistic law of nature, which supervenes upon and is wholly made true by a linearly ordered set of time-slices composed of matter points. By eliminating all of the causally redundant and unknowable qualities that featured in the neo-Humean metaphysics of Lewis, Esfeld's minimal ontology avoids a common objection to neo-Humeanism from 'quidditism'. Nonetheless, super-Humeanism creates some problems of its own.

For instance, Lazarovici ([2018]) has argued that it is an empirically inadequate account with a 'starving ontology', on the grounds that 'distance relations' fail to offer a plausible foundation of space and time. However, Lazarovici ([2018], p. 82) recognizes that super-Humeans who are committed to parsimony are unlikely to be moved by such objections, and briefly raises the question of whether super-Humeanism might also suffer from internal conceptual problems due its conception of matter. I explore this worry here by posing three metaphysical objections to super-Humeanism.

3.1 Symmetric worlds

My first objection concerns an implausible modal commitment that follows from its structuralist conception of matter. I shall argue that it leads to the contradiction that distinct particles in symmetric configurations are in fact identical. This argument turns on the claim that, if super-Humeanism is true, then it is metaphysically impossible that two distinct particles could be constituted by the same set of distance relations. In other words, super-Humeanism is committed to the principle of constituent identity:

> Super-Humean principle of constituent identity (PCI): If Particle 1 is constituted by the same set of distance relations as Particle 2, then Particles 1 and 2 are identical.

However, the principle of constituent identity entails a controversial principle:

> Leibniz's principle of the identity of indiscernibles (PII): If object O_1 has a property if and only if object O_2 does too, then O_1 and O_2 are identical.

This claim is not to be confused with Leibniz's law, which is often referred to as the principle of the indiscernibility of identicals. According to this law, where there are instances of incompatible properties, there must correspondingly be distinct objects. (PII) is both logically independent of Leibniz's law and more controversial: the sparser one's theory of constituents, the easier it is for objects to be indiscernible, and hence the easier it is to satisfy the identity condition imposed by (PII). In a sparse ontology, there are fewer properties that can explain the fact of an objective resemblance between two or more things, or the fact of their objective distinctness.

A super-Humean cannot appeal to intrinsic physical properties, since super-Humeanism admits only ontic structure within its supervenience base. However, its supervenience base is extremely sparse, since the only perfectly natural constituents it admits are distance relations. Super-Humeanism thus depends upon the following form of the principle of the identity of indiscernibles:

> Super-Humean Principle of the Identity of Indiscernibles (SPII): If object O_1 stands in a distance relation to some object O_i if and only if object O_2 does too, then O_1 is identical to O_2.

However, this principle leads to implausible results that come at a theoretical cost. This objection can be made more forcefully by means of the following argument:

(i) Suppose there are three non-identical particles, 1, 2, and 3, separated by distances d_{12}, d_{13} and d_{23}, and suppose they trace a locus such that $d_{12} = d_{23}$.

(ii) If super-Humeanism is true, then Particle 1 is identical to the matter point constituted by the relations $\{d_{12}, d_{13}\}$, and Particle 3 is identical to the matter point constituted by the relations $\{d_{23}, d_{13}\}$.

(iii) Therefore, super-Humeanism implies Particle 1 is identical to Particle 3 (by (i) and (ii)).

(iv) Therefore, super-Humeanism is false (by (i) and (iii)).

The second premise is simply a restatement of that form of the principle of the indiscernibility of identicals to which super-Humeans are unavoidably committed (SPII). The argument hangs, then, by the first premise, which may be rephrased as the modal claim that it is possible for there to be two non-identical particles that stand in the same distance relations.

I make this claim on the basis that we can conceive possible scenarios in which there are two particles that stand in the same distance relations. In fact, physicists frequently do so in considering textbook examples, such as the cases of spatially homogeneous and isotropic cosmological models, in which all of the particles, by the above reasoning, would be identical to each other (Wüthrich [2009]). The relevance of this claim to my argument depends upon the commonly held assumption that the conceivability of some state of affairs offers evidence for its possibility, albeit only a defeasible kind of evidence.

The evidence required for the first premise is easy to come by. For example, consider a world in which Particles 1 and 3 are making a circular orbit of the same radius around Particle 2. In such a world, the distance between Particles 1 and 2 is identical to the distance between Particles 2 and 3, hence $d_{12} = d_{23}$. While this scenario is perfectly conceivable, and such a system can be modelled straightforwardly using quantum mechanics, super-Humeanism entails that there is no possible world in which it could ever be realized. It cannot be realized because the supervenience base in a super-Humean world is too sparse to individuate Particles 1 and 3. This counts as evidence for the first premise, in support of the conclusion that super-Humeanism is false.

Such scenarios are commonly referred to as 'Max Black' worlds, which are possible worlds that contain indiscernible objects that we have reason nonetheless to consider distinct (Black [1952]). In Black's original example, we are asked to imagine a world with two distinct but qualitatively indiscernible spheres that stand one mile apart. In fact, the number of Max Black worlds that can be offered in evidence against super-Humeanism may be multiplied *ad infinitum* by conceiving any number of symmetric configurations of particles in which many of the particles stand in identical sets of distance relations.

This generalization of my argument against super-Humeanism is analogous to Hawthorne's criticisms of causal structuralism (Hawthorne [2001]), in which he distinguishes two forms of structuralism. According to the strong form (as I shall call it), two things are identical if they play identical roles in a structure, where the roles that they play are defined abstractly without reference to the identities of things in the structure. According to the weak form, the roles that they play are defined concretely in terms of relations to relata whose identities are independent of their roles. Hawthorne's criticisms are directed toward the strong form of causal structuralism, in which a natural property is supposed to have an individual essence consisting of nothing over and above its 'causal profile'. This view is troubled by intra-world duplications of causal profiles resulting from the possibility of symmetric structures. However, Hawthorne notes that a weak form of causal structuralism can be defined that avoids this trouble, in which the necessary and sufficient conditions for being a particular property are specified in terms of its relations to other properties, while properties have identities independently of their causal roles. For the weak form to be viable, a property must have a quiddity that exists over and above its causal profile.

Similarly, super-Humeanism advances a strong form of structuralism, in which a particle has an individual essence consisting of nothing over and above its 'distance profile' (so to speak). This view is troubled by intra-world duplications of distance profiles resulting from the possibility of symmetric configurations. A weak form of structuralism, in this case, would be one in which the matter points have identities over and above the structure of distance relations they instantiate. For this view to be viable, each particle would require an haecceity that exists over and above its distance profile.

This parallel move, however, is unavailable to super-Humeans, since it would require the abandonment of ontic structural realism. If the featureless particles of Bohmian mechanics have an identity over and above their distance relations, they cannot be constituted solely by distance relations. If each of the matter points which instantiate these relations has an haecceity, this configuration is not an ontic structure. Yet if the Bohmian particles are constituted neither by properties nor relations, and they have no haecceities over and above the distance relations in which they stand, it is unclear how they are supposed to exist as distinct objects at all.

An alternatively strategy is to appeal to the 'weak discernibility' of particles in symmetric configurations. Two objects may be said to be weakly discernible if they stand in some irreflexive relation (Quine [1976]). Saunders ([2003], [2006]) has argued that, while we should retain the principle of identity of indiscernibles, it is sufficient that physical particles should be weakly discernible in order for them to count as distinct objects. A distance relation is an example of such a relation: the two spheres in Black's original example, for instance, are weakly discernible, since each object is one mile from the other, but is not one mile from itself. The examples used by Saunders to illustrate his claim are drawn from quantum mechanics: two particles in the singlet state (Equation 1) may be considered weakly discernible, insofar as each particle 'spins' in the opposite direction to the other, but not in the opposite direction to itself. These particles are fermions, which are anti-correlated with respect to their spin. However, there are also quantum-entangled states involving bosons, which are positively correlated with respect to their spin. These particles are not weakly discernible.

However, Hawley ([2006]) has argued that the claim that objects are distinct just in case they are weakly discernible is unmotivated. Noting that Saunders is effectively using (PII) to settle the 'inverse special composition question' and decide when quantum-entangled systems may be considered to have basic constituents, Hawley observes that an appeal to weak discernibility is merely an appeal to the fact that positing basic constituents is not forbidden by (PII). To argue that we should actually posit basic constituents in such cases is to invoke a supplementary principle: we should posit the existence of basic constituents whenever this is not forbidden by (PII).

Hawley offers three objections to adopting this supplementary principle. First, it seems arbitrary to regard the relation of being-of-the-opposite-spin as a 'better or worse claim to ontological basicness' than the relation of being-of-the-same-spin. On such a basis, Saunders claims that fermions are distinct objects but bosons are not. Second, it leads to arbitrary divisions within physical systems. For example, a system with four units of charge, according to this principle, could be partitioned into two basic constituents, where the first has a single unit of charge, and the second has three units. Third, maintaining both (PII) and the supplementary principle involves holding conflicting motivations: (PII) favours mereological simplicity over complexity, by restricting our ontology to the minimum requirements of Leibniz's law, whereas the supplementary principle prefers mereological complexity over simplicity, whenever we can get away with it.

While Leibniz's law requires us to recognize the non-identity of physical systems that instantiate incompatible properties, Hawley notes that apparent heterogeneity might correspond to modifications of a single entity instead. In the eyes of an ontological monist, the original Max Black world might be viewed as a single object that is spatially disconnected. Likewise, the universe might be viewed as something which, at some moment of time, just happens to be positively-charged-here-and-negatively-charged-there. Alternatively, since Leibniz's law is logically independent of (PII), we might favour a model in which the particles in a quantum-entangled system are posited as putative elements. Such a move would amount to admitting particles with haecceities and rejecting the role of distance relations as basic constituents. Thus the super-Humean, in confronting the problem of symmetric worlds, is presented with a trilemma:

> The Symmetric Worlds Trilemma: Either (i) posit particles with haecceities, or (ii) attribute distinct particle configurations to different modifications of a single object, or (iii) deny the existence of symmetric configurations.

Since super-Humeans cannot appeal to particles with haecceities without rejecting ontic structural realism, and since strict ontological monism is incompatible with the primitive ontology approach to quantum mechanics, they must take the third horn of the dilemma, and deny that symmetric configurations of particles could exist in any possible world. They must maintain this doubtful posture in spite of the fact that the dynamical equations of physical theories admit symmetrical solutions, and the particles comprising a super-Humean world would have an eternity in which to explore their configuration space. This prohibition must extend to solutions in which the configuration of particles is momentarily symmetric at certain times, or risk affirming the bizarre possibility of a 'peekaboo' cosmos whose particle configuration vanishes at certain times.

The symmetric worlds problem for super-Humeanism has its roots in what Keränen ([2001]) introduced as 'the identity problem' in the philosophy of mathematics. On the one hand, symmetries are supposed to be a guide to the ontic structures, insofar as it is the structures of two rival theories with different ideologies but isomorphic structures that are taken to be ontic by structural realists. Such theories are acknowledged to be true by structural realists only 'up to an isomorphism'. On the other hand, the ontic structures are also supposed to individuate the objects in the ontology, insofar as ontic structuralists are not eliminativists about objects. For super-Humeans, the ontic structure consists solely of distance relations, and the objects are the particles referred to by Bohmian mechanics. However, as Keränen points out, such structures cannot both be symmetrical and individuating.

Esfeld is aware that symmetric configurations present a difficulty for his metaphysical model, but thinks super-Humeans should bite the bullet and deny that symmetries are a guide to the ontic structures. This stance may be supported by two claims. First, super-Humeans might claim to be only in the business of describing the actual world. Second, super-Humeans might simply deny that symmetric configurations of its particles are in fact conceivable.

With respect to the first move, super-Humeans might seek to justify the exclusion of entirely symmetric worlds by observing that the actual world is obviously not symmetrical (at least, as far as we can tell), and by pointing out that all physical theories have surplus mathematical structure (Esfeld and Deckert [2017], p. 69). For example, the solution to the Klein–Gordon equation is the difference between a 'retarded' and an 'advanced' Green's function, but the advanced Green's function is typically discarded for problems involving time. According to super-Humeans, we should likewise regard symmetric solutions to the dynamical equations of physical theories as 'mathematical surplus', which have no bearing on what the world is like.

Nonetheless, the rejection of a solution to an equation of motion typically concurs with our modal intuitions, while our modal intuitions usually concur in finding symmetric solutions to be possible. For example, cosmologists who have contemplated the famous Friedmann-Lemaître-Robertson-Walker solutions to Einstein's field equations during the course of their careers, which describe homogeneous and isotropic spacetimes, have apparently considered them possible.[1] Moreover, in effectively banning symmetric configurations from the past or future, the super-Humean is not merely describing the world as we find it—'Just the facts, ma'am', like any law-abiding Humean—but prescribing how particles should behave in all possible worlds with the same laws. Ironically, in seeking to produce an account of nature that is more Humean than neo-Humeanism, Esfeld has committed himself to a strong modal claim.

A committed super-Humean, then, is likely to challenge the uniformity of the evidence of our modal intuitions. Whereas philosophers like Wüthrich may take the metaphysical possibility of symmetrical configurations for granted, super-Humeans may claim to be unable to conceive perfectly symmetric configurations, along with philosophers like Hacking ([1975]) and Belot ([2001]). More precisely, such philosophers claim that we have no reason to think that this is the correct description of what it is that we imagine, when we suppose ourselves to be imagining symmetric worlds. Super-Humeans will thus maintain that there is no possible world that must be described in a way that is incompatible with (PII).

[1]Concerning problems with spacetime structuralism, see (Wüthrich [2009]).

Nonetheless, the super-Humean refusal to take symmetry as a guide to the ontic structures comes at the cost of isolating their primitive ontology from any input from the empirical sciences, leaving super-Humeans with ontological parsimony or simplicity as their only metaphysical guide. This is the cause of Lazarovici's ([2018]) complaint in labelling super-Humeanism a 'one-trick pony', since the determined super-Humean will only argue that, if the criterion of ontological simplicity is properly elevated, it will uniquely favour their primitive ontology. I intend to be less generous than Lazarovici. In what follows, I offer reasons for thinking the pony will stumble in performing its only trick.

3.2 Temporal dilemma

My second objection calls into question whether super-Humeanism can offer a realist account of the laws of nature, given its structuralist conception of matter and its notion of primitive change. I shall argue that these two commitments lead to a dilemma between two contrary views of time: the so-called A-theory of time, which posits an absolute distinction between past, present, and future; and the 'B-theory', which denies the existence of such a distinction (McTaggart [1908]).

On the one hand, super-Humeans require that particle configurations should change for the sake of empirical adequacy, and they require this change to be primitive. They cannot appeal to the so-called At-At theory of change advanced by Russell ([1903], pp. 469–73),[2] in which something changes by instantiating different properties at different times, because they reject the claim that the particles are characterized by intrinsic properties. Rather, super-Humeans embraces a structuralist conception of particles, in which particles are constituted by distance relations. Likewise, super-Humeans cannot embed the particle configurations as points within a primitive spacetime, because they adopt a Leibnizian conception of space, in which physical space is also constituted by distance relations.

Nor is it sufficient for super-Humeans to adopt a B-series of configurations, minus the usual background conception of spacetime, without explaining how the time-slices comprising this series are supposed to be individuated as temporal parts of a single structure. Super-Humeans

[2]Christened by Geach ([1969]) as 'mere Cambridge changes'.

claim that all of the matter points at a moment of time must be holistically individuated by the intra-structural relations that constitute a particular configuration, because they lack any intrinsic properties. Since these configurations also lack intrinsic properties, over and above their constituents, it seems that they would also have to be holistically individuated, in order to instantiate inter-structural relations across time-slices within a stack of configurations.

However, as Lazarovici ([2018]) points out, the relations that constitute both the particle configurations and the physical space in which they move are directionless, structureless and dimensionless.[3] As such, it seems that any binary relation might count as 'temporal'. In that case, it is difficult to see how super-Humeans who adopt a B-series of configurations can explain the structure of time. For instance, a scientist who sets up a measuring apparatus to measure the positions of particles, before measuring their positions, then makes the measurement, before writing the result down, does not set up the apparatus after writing the result down, nor make the measurement before setting up the apparatus. Yet why should the temporal order be transitive and anti-symmetric in a world made solely of distance relations? It is also difficult to see how super-Humeans can explain the difference between primitive change in the configuration of the particles, and a variation in their distribution along some dimension, without appealing to additional brute matters of fact. In the context of super-Humeanism, McTaggart's claim that only the A-theory can deliver real change gains force, as the theoretical cost of adopting a B-series begins to climb.[4]

In short, in order to get these Bohmian particles to change their configuration, it seems super-Humeans will have to 'clear the deck' of one set of distance relations, before replacing it with another. This suggests super-Humeans should adopt something like the A-theory of time, in which there is only one configuration of particles that exists at the present moment. (This appears to be Esfeld's position.)[5]

[3]Lazarovici ([2018], p. 82) complains that space is 'lost' by reducing all geometric structure to distance relations: 'There is nothing about the distance relations that would make them 3-dimensional [...] or put any other constraints on the dimension, curvature or topology of the physical geometry'.

[4]McTaggart ([1908]) claimed there can be no real or primitive change in the block-universe conceived in the B-theory of time, although many philosophers have disagreed with his claim.

[5]See (Esfeld and Deckert [2017], pp. 151–2): 'change exists, but not a whole ordered stack of configurations [...] Presentism, thus conceived, is the most simple and parsimonious ontology, since only one configuration exists'. However, Esfeld does not adopt a primitive arrow of time.

On the other hand, super-Humeans require the existence of an adequate supervenience base for the wave function, which must include facts about potential configurations for all of time. In Esfeld's view, this base is composed of an infinite number of time-slices, in which each time-slice consists of an arrangement of matter points. He requires the existence of such an extensive base because a law that includes the wave function does not supervene upon, and is not wholly made true by, the distribution of particles at a particular time. Of course, all Humeans who toy with presentism will face the problem of finding truth-makers for propositions about entities that do not supervene upon what exists at the present moment, such as universal laws of nature. However, there is an additional complication for super-Humeans seeking to accommodate quantum phenomena.

To bring out this difference, consider how the laws are represented in a classical world, according to neo-Humeans, and in a quantum world, according to super-Humeans. In a classical world, one configuration of properties P_i follows regularly from another P_j according to a law $L : P_i \rightarrow P_j$ that refers to distinct configurations of properties instantiated in the world at different times. However, in a quantum world, a best systems account of the world will include only positions and a wave function, which change from moment to moment, $L : (Q_i, \psi_i) \rightarrow (Q_j, \psi_j)$, while super-Humeans will insist there is nothing besides matter points which may serve as referents.

Yet matter points are constituted by nothing but distance relations: they have no intrinsic physical properties, since properties are on the same level as the wave function, which is merely part of the 'best system' account of how these matter points are distributed for all time. It follows that the truth of any propositions that pick out objects by their physical properties, including microscopic objects such as electrons with properties like mass and charge, will fail to supervene upon what exists at the present moment, but will depend for their truth upon nothing less than the whole stack of configurations for all time.

In short, in order to secure the supervenience base of the wave function, it seems super-Humeans will have to 'join the dots' by uniting each particle configuration as temporal parts of a single structure. This suggests super-Humeans should adopt the B-theory of time, in which the cosmos is comprised of a series of time-slices, where every slice is as real as the series of which it is part. However, if super-Humeanism entails both the A-theory and the B-theory of time, then it contains a flagrant contradiction. It appears, then, that super-Humeans are caught on the horns of a dilemma:

> Temporal Dilemma: Either (i) embrace the B-theory, by retaining eternalism, but abandoning Leibnizian space, or (ii) embrace the A-theory, by retaining primitive change, but denying eternalism.

To take the first horn of this dilemma, by embracing the B-theory of time, would be to abandon the minimalism of super-Humeanism. On the one hand, super-Humeans might form a B-series of configurations by embracing a substantival conception of spacetime. In doing so, however, they would introduce a difficulty concerning how the distance relations that constitute the particle configuration are to be embedded in spacetime without abandoning their structuralist characterization of matter. Yet to abandon either the Leibnizian conception of space, or the strong form of structuralism, would be to abandon super-Humean minimalism, which claims that its world-making relations are sufficient for constituting a world of physical objects.

On the other hand, super-Humeans might try to construct a B-series of configurations by adopting the so-called moving spotlight theory of time, which combines the eternalism found in the B-theory with the notion of objective becoming found in the A-theory.[6] In this case, we might think of the world as consisting eternally of a block of facts about distance relations in different time-slices, while requiring the existence of 'presentness' as a property of a time-slice, along with the properties of 'pastness' and 'futurity'. Primitive change in a block-universe may then be understood in terms of the instantiation of these properties. However, setting aside the problems that have been raised with the moving spotlight theory of time (Sider [2001], Section 2.1), such a move also violates super-Humean minimalism: by stipulation, there are no primitive or intrinsic properties in nature.

To take the second horn of the dilemma, however, by embracing the A-theory, would be to abandon the truth of a law of nature that includes the wave function, as well as the truth of propositions that refer to the physical objects that scientists interact with in their experiments. On the one hand, super-Humeans might attempt to compress the facts upon which they depend,

[6]The basic idea is found in (Broad [1923], pp. 59–60]), although Broad does not assert this theory.

by making facts about future time-slices depend upon facts about the primordial past (that is, a past time-slice). However, according to super-Humeans, there are no necessary connections between any of the time-slices. On the other hand, super-Humeans might attempt to soften the requirements of realism, by claiming that the truth of the laws of nature could be fixed at the end of the world (that is, a future time-slice). Super-Humeanism might then be reconciled with the A-theory of time by appealing to memory: just as the present configuration of particles may be supposed to contain the memory of past changes, so the eschaton may be supposed to contain the memory of every past change.

Yet it is difficult to see how memory could play a role in grounding the truth of any laws without endowing memories with the kind of necessary connections that all Humeans reject. Whether or not mnemonic impressions qualify as memories is surely consequent upon the laws of nature, whereas super-Humeans who appealed to memory to ground the truth of these laws would have to appeal to additional facts, over and above the positions of the particles, which are somehow correlated with their positions in past time-slices.

In any case, I doubt that the eschaton holds any hope in store for super-Humeans, however long their memories. Suppose they take the eschaton literally. In that case, they would have to believe that some future time-slice t_f will instantiate a primitive property of 'finality', such that the primitive arrow of change will not point to a future time-slice at time $t = t_f$. However, such a move is unavailable to super-Humeans who embrace a strong form of structuralism: by stipulation, there are no primitive or intrinsic properties in nature. Suppose they take the eschaton metaphorically instead. In that case, they would have to deny that there is some time-slice that is identical to the end of the world. If so, any law that depends for its truth upon the eschaton could not literally be true, and super-Humeans could not be realists about laws. Thus to take either horn of the temporal dilemma would be to undermine the super-Humean account of the truth of the Bohmian law, either by abandoning its minimalism, or by abandoning its realist stance toward laws. It appears the one-trick pony is doomed to stumble forever.

3.3 Persistence problem

My third objection concerns whether super-Humeanism can offer an ontology of particles, given its structuralist conception of matter and Leibnizian conception of space. Specifically, I am concerned with a question raised by Lazarovici ([2018], p. 82): 'what provides for the identity of the matter points over time?'.

Clearly, a world made of matter points need not be a world that contains particles, which persist through time; it might contain flashes, which appear discontinuously throughout space. Since matter points are constituted by distance relations, we cannot appeal to their enduring properties in specifying their persistence conditions. Since matter points have no temporal parts that are instantiated in spacetime, we cannot appeal to their perdurance. The persistence conditions for an ontology of particles, in a world of matter points and primitive change, must be cashed out at the level of the ontic structure.

However, it is impossible to formulate persistence conditions for particles in terms of the persistence of the elements of this structure, since a set of distance relations has no identity over and above its members, such that it can survive a change in its membership. A world in which distance relations primitively change is a world in which one set of ontic relations come into being (or 'presentness') followed by another, where each set has a different identity from the previous set. Since there are no substances which instantiate these ontic relations, nor any primitive spacetime in which they are embedded, there is nothing to unite these sets of relations as a persisting subject of change.

A more promising solution might be to attempt to formulate persistence conditions for the particles in terms of the trajectories traced by the matter points instead. In a super-Humean world, it is a brute fact that the number of matter points in this world is fixed, and the distance relations between them are non-vanishing. Suppose that primitive change were discrete, such that, in the temporal interval (t_1, t_2) , where $t_2 > t_1$, there were only a finite number of numerically distinct time slices. In that case, it would be a world of flashes rather than particles, in which different matter points would appear at certain points along each Bohmian trajectory. However, suppose primitive change in this world were continuous, such that, in the temporal interval (t_1, t_2), there were an actually infinite number of time-slices. In that case, matter points would *prima facie* trace continuous trajectories that do not cross. We might think of Bohmian particles, then, as persisting by enduring.

However, I have doubts about the coherence of conjuring the identities of particles from their trajectories. To begin with, a set of trajectories need not represent continuous motion. Consider a world, W_1, in which there are three particles that follow continuous trajectories, and a second world, W_2, containing three particles whose trajectories result from splicing the second half of Particle 1's trajectory in W_1 to the first half of Particle 2's, and the second half of Particle 2's trajectory to the first half of Particle 1's, while the motion of Particle 3 is left unchanged. W_2 is a world in which Particle 1 hops to the site of Particle 2, just as Particle 2 hops to the site of Particle 1. The trajectories in W_2 are identical to those in W_1. Nonetheless, they represent discontinuous motion.

To eliminate the possibility that trajectories might represent discontinuous rather than continuous motion, super-Humeans will have to rule out the possibility of worlds like W_2, even though W_2 is empirically indistinguishable from W_1. In this respect, the super-Humean is in the same boat as the weak structuralist who introduces haecceities to secure the identities of the particles. In that case, the particles would not be matter points, but matter spaghetti, in which the essence of each particle is cashed out in terms of a densely ordered set of sets of distance relations. Yet this raises another difficulty concerning how distinct strands of matter spaghetti compose a single configuration of particles. In order for two or more strands to constitute Bohmian particles that trace continuous trajectories through space, we must find a way of coordinating simultaneity relations between the distinct sets of distance relations that belong to their different trajectories.

To tease out this difficulty, consider the case of a world of two particles, A and B, in which particle A traverses a trajectory between two distinct points in space, (x_1, x_2), and particle B traverses a trajectory between two different points, (x_3, x_4). In a super-Humean world in which change is continuous, the essence of a strand of matter spaghetti must be supposed to be dense in the spatial positions that constitute a trajectory. Yet why should we suppose that the ordering of positions in the interval (x_1, x_2), for one strand of spaghetti, should correspond to the ordering of the positions in (x_3, x_4), in another strand, in such a way that, for every infinitesimal increment δx in the position of A along its trajectory with each infinitesimal increment in time δt, there is a corresponding infinitesimal increment in the position of B?[7] The two strands might be coordinated in such a way that, as particle A advances from the spatiotemporal point (x_1, t) to $(x_1 + \delta x, t + \delta t)$, particle B jumps discontinuously in space from one point to another; for example, from (x_3, t) to $(x_4, t + \delta t)$. In fact, there are an infinite number of ways of pairing points in (x_1, x_2) with points in (x_3, x_4), and hence infinitely many more ways of making a world of flashes rather than particles.

Or again, consider the possibility of a cyclic cosmos, of the kind contemplated in the 1920s by Einstein, in which the universe endlessly repeats the same process of expansion and contraction, which takes place in a period T. Suppose Q_t represents the configuration of particles at some moment t. In that case, Q_t will be identical to the configuration after n periods, $Q_t = Q_{nT+t}$, where n is any positive integer. It follows that any matter point in a strand of matter spaghetti A that is coordinated with a matter point in a non-identical strand B can be coordinated with an infinite number of matter points in B, and likewise with an infinite number of matter points in every strand of matter spaghetti. Why suppose, then, that the matter points in Q_t instantiate a real relation of simultaneity? Indeed, why suppose that different strands of matter spaghetti compose a single particle configuration at all, such that every member of each strand must be paired with a member in every other strand and coordinated in time?

At this point, super-Humeans may appeal to the A-theory of time, in order to impose a preferred ordering upon all of the matter spaghetti and unite them within a single evolving configuration. However, as I have suggested, this move comes at a theoretical cost: a super-Humean world in which only one configuration of matter points exists at the present moment is a world in which the laws of nature and propositions referring to objects that scientists interact with in their experiments are left without truthmakers. The only alternative for super-Humeans who appeal to matter spaghetti is to pile on additional brute facts: it must be a brute fact that all of the matter spaghetti composes a single configuration, and it must be a brute fact that matter points pair up in such a way that they constitute a world of particles that travel together through space. In that case, super-Humeans will have to help themselves to uncountably many brute

[7] I am grateful to Robert Koons for suggesting this way to proceed with the argument.

facts to build a world of 10^{86} particles.

I conclude that there is small hope of super-Humeans deriving the identities of particles from their trajectories. Those who attempt to wrest themselves from the horns of the 'temporal dilemma' concerning the nature of time will thus find themselves caught on the horns of a 'persistence dilemma' concerning the nature of space:

> Persistence Dilemma: Either (i) abandon Leibnizian space, and embrace the At-At theory of change, or (ii) retain primitive change, but embrace particles with haecceities.

By seizing the first horn of this dilemma, we might explain how there are particles that persist, but must abandon any primitive notion of change: a particle that persists is one that perdures by tracing a worldline in spacetime, while any change in a physical system is to be explained by the instantiation of properties at different points in spacetime. However, super-Humeans who take this option must give up both their ontological minimalism and their primitive notion of change. How should the distance relations that constitute the matter points be embedded in spacetime?

By seizing the second horn of the dilemma, we can explain how there are particles which persist without abandoning a primitive notion of change: a particle may persist by enduring if it has an haecceity that exists over and above the distance relations in which it stands. However, super-Humeans who adopt this position must abandon their strong form of structuralism. How, then, should they understand a particle's capacity to change the distance relations in which it stands? Thus to take either horn of the persistence dilemma would be to undermine the super-Humean ontology of moving particles, either by abandoning its notion of primitive change, or by abandoning its conception of matter. It appears the one-trick pony isn't going anywhere until it solves its identity crisis.

4 Conclusion

Super-Humeanism purports to offer a minimalist account of nature that supports an ontology of physical objects and accommodates quantum phenomena, while avoiding a common objection against neo-Humeanism from quidditism. These results are achieved by combining the primitive ontology approach to quantum mechanics with ontic structural realism. According to super-Humeans, macroscopic objects are composed of microscopic matter points, which follow a Bohmian law of motion. These matter points are constituted by distance relations and they undergo primitive change.

However, I have argued that super-Humean minimalism comes at a theoretical cost and introduces conceptual problems. First, I argued that its notion of matter fails to discern between any number of Max Black worlds that contain symmetric particle configurations. Super-Humeanism is thus saddled with the implausible modal claim that a Bohmian particle configuration is necessarily asymmetric. Second, I argued that its parsimonious account of the truthfulness of the Bohmian law of motion leads to a self-undermining dilemma concerning the nature of time. For this law to be true, the particle configurations would have to support necessary connections. Finally, I argued that the super-Humean account of the identities of the Bohmian particles leads to a self-undermining dilemma concerning the nature of space. For particles to persist, they must have some identity over and above the distance relations in which they stand.

In short, it seems that super-Humeanism has problems which can only be solved by rejecting the minimalism imposed by its strong form of structuralism and lifting its Humean embargo against necessary connections. Esfeld ([?], p. 7) admonishes philosophers against the 'illusion' of supposing that, by enriching our primitive ontology beyond matter points, we can expect to achieve explanations that are any 'deeper' than those offered by super-Humeans. Yet it seems that Humean philosophers who adopt super-Humean minimalism do not thereby acquire superpowers for deflecting metaphysical trouble. This being the case, I suggest that metaphysicians and philosophers of science should balance Esfeld's injunction in favour of minimalism against some advice often attributed to Einstein, namely, that our models should be as simple as possible, but not any simpler.

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