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A Priority-Based Ontic Structural Realist Account of Bohmian Mechanics

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Abstract: I propose a priority-based ontic structural realist account of Bohmian mechanics in which particles are understood as thin, ontologically derivative nodes of a fundamental structure represented by the wavefunction. I argue that the wavefunction plays the role of this fundamental structure by determining the dynamics and providing the structural basis for the individuality of Bohmian particles. This account offers an alternative to existing structural realist interpretations by giving genuine ontological priority to the structure while preserving particles as real, albeit derivative, entities.

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Introduction

The status of the wavefunction is a central problem in Bohmian Mechanics (BM). In BM, particles always have definite positions, while the wavefunction determines their motion through the guiding equation. The main difficulty is the so-called *communication problem* (Hoefer, Solé 2019): how can a wavefunction defined on the higher-dimensional configuration space determine the motion of particles in ordinary three-dimensional space? Closely related to this are questions about whether the wavefunction should be understood as a physical entity, a law of nature, or something else entirely.

Several responses have been proposed. Wavefunction realism treats the wavefunction as a physical entity in configuration space, while the nomological interpretation understands it as part of the laws of nature. More recently, *structural realist interpretations* have attempted to avoid this dilemma by identifying the wavefunction with the world's fundamental structure (Esfeld, 2017), or by interpreting it as representing the primitive dependence relations between particles (Lorenzetti, 2022). These approaches preserve the holistic character of quantum mechanics while avoiding commitment to the wavefunction as an independent physical object.

This thesis also develops a structural realist interpretation of Bohmian Mechanics. However, it departs from existing structural realist accounts in an important respect: The particles *derive* their ontological status from a more fundamental structure that is metaphysically *prior to* them, which is represented by the wavefunction. This account departs from the existing structuralist readings of BM by giving genuine priority to the structure.

The thesis is organized as follows: Section 1 introduces Bohmian Mechanics and the communication problem. Section 2 discusses the main interpretations of the wavefunction, including wavefunction realism and the nomological view. Section 3 starts by introducing structural realism. After distinguishing eliminativist, moderate, and priority-based versions of ontic structural realism (OSR), it examines the two existing attempts to apply the framework to BM, and argues that both positions, although having structuralist intuitions, do not clearly reflect OSR's core claims. Section 4 develops the thesis's positive proposal: a priority-based OSR account on which Bohmian particles exist only as thin, weakly discernible nodes of a fundamental wavefunction-structure, individuated by their positions. I argue that the ontology of BM is best read not as two independently fundamental entities that need a causal bridge, but as one fundamental structure and its derivative particle configuration.

Section 1: Bohmian Mechanics and the Communication Problem

David Bohm revived de Broglie's pilot-wave theory in 1952, formulating a realist ontology for quantum mechanics. He was concerned with the question of what happens before and *between* measurements.

Bohmian mechanics postulates particles in the three-dimensional space with definite positions together with a wavefunction in the higher-dimensional configuration space that enters the dynamical equations. For an N particle system, the wavefunction is:

$\Psi(x_1, x_2, \ldots x_N, t) \in L^2(\mathbb{R}^{3N})$

The wavefunction evolves according to the Schrödinger equation:

$i\hbar\, \partial\Psi/\partial t = H\Psi$

Where H is the Hamiltonian, representing the total energy of the system. The Hamiltonian contains the potential term $V(q_1 \ldots q_N)$, which represents the physical interactions (masses, charges, and spatial relationships) between all particles.

Bohm's ontology consists of particles and the wavefunction. Unlike other interpretations, Bohmian mechanics also includes an explicit equation of motion for the particles. As Bohm and Hiley state, "The electron actually is a particle with a well-defined position... [that] is never separate from a new type of quantum field that fundamentally affects it" (1993, p. 29).

The dynamics of the particles is described by the guiding equation:

$dQ_k/dt = (\hbar/mk)\ \mathrm{Im}(\nabla k\Psi/\Psi)$

where Q_k is the position of the k-th particle. The wavefunction is evaluated at the actual configuration of all particles ($Q_1(t)...Q_N(t)$) at time t. In the case of an N-particle entangled state, the motion of any single particle therefore depends on the positions of all other particles through the wavefunction, which already signals the non-locality that is characteristic of the theory.

Bohm's original formulation makes the character of this guidance more transparent by writing the wavefunction in polar form (Bohm, 1952):

$\Psi(q,t)=R(q,t)e^{iS(q,t)/\hbar}$

where R is the real-valued amplitude of the wavefunction, and S is its phase. Substituting this expression into the Schrödinger equation and separating the real and imaginary parts yields two coupled equations. One is a continuity equation expressing probability conservation, while the other has the form of the classical Hamilton-Jacobi equation with an additional term:

$\partial S/\partial t+(\nabla S)^2/2m+V+Q=0$

where

$Q = -(\hbar^2/2m)\,\nabla^2 R/R$

The extra term Q is known as the quantum potential. It depends on the *form* of the wavefunction rather than its magnitude. Multiplying R by any constant leaves Q unchanged because the constant cancels in the ratio $\nabla^2 R/R$. What matters is therefore not how large the wavefunction is, but how it varies in its spatial pattern, as captured by the spatial Laplacian. The quantum potential is therefore sensitive to the geometry of the wavefunction rather than its intensity. This feature of the system already points toward an interesting new conception of physical interaction: the wavefunction does not push or pull the particle mechanically but shapes particle trajectories via its form. In that way, the features of the environment directly affect a particle's motion, explaining phenomena like interference in the double-slit experiment (Bohm, 1990).

The theory is easy to visualize in a one-particle system, where both the wavefunction and the particle are defined over three-dimensional space. As soon as we move to a two-particle system, however, the

guiding wavefunction resides in a six-dimensional configuration space, corresponding to the six degrees of freedom the two particles jointly possess. For N particles, it inhabits the abstract 3N-dimensional configuration space.

From a purely mathematical standpoint, this is unobjectionable: physicists routinely use high-dimensional spaces as computational tools. For the Bohmian realist, however, this presents a genuine metaphysical challenge. The configuration space cannot simply be dismissed as a representational device, because within the theory the wavefunction is standardly interpreted as playing a dynamical role in determining the particles' motion. This generates what Hoefer and Solé (2019) call the "Communication Problem":

1. Particles exist in three-dimensional physical space.
2. The wavefunction that guides them exists in a higher-dimensional configuration space.
3. This wavefunction (seems to) causally affect the particles' motion.

How can an entity in an abstract, high-dimensional space causally influence entities in our familiar three-dimensional physical space? A satisfactory Bohmian metaphysics should give a proper account of the status of the wavefunction that allows the theory to escape this problem.

The communication problem is usually presented as a problem of causal interaction between entities that occupy different spaces. However, a further difficulty comes from the nature of physical interaction itself. It is generally assumed that when one object exerts a force on another, the relation is not a one-way street: the affected object exerts a reciprocal force on the one that acted on it. However, the wavefunction 'acts on' the particles without any *back-reaction* from the particles upon the wavefunction. Thus, the communication problem amounts to two main difficulties: different spaces, and the absence of bidirectionality. Both of these problems amount to the fact that the wavefunction should not be seen as an ordinary physical field within the context of BM.

Therefore, rather than asking directly how the wavefunction "communicates" with the particles, this thesis will investigate whether that very formulation of the problem already presupposes a particular metaphysical picture of Bohmian mechanics: one on which the wavefunction and the particles are two independently existing entities standing in a causal relation. If the relation between the wavefunction and the particles is not fundamentally causal but *structural,* then the communication problem would

not arise. However, before developing this proposal, it is necessary to examine the principal existing positions on the ontological status of the wavefunction.

Section 2: Existing Positions

The communication problem arises only once one treats the wavefunction as a physical field. This position is often called "wavefunction realism" (Albert, 2013; Ney, 2023). Within Bohmian mechanics, one is tempted to treat the wavefunction as a physical field. The wavefunction, as Bohm himself emphasized, guides the motion of the particles. A natural way to think about its ontological status is therefore to interpret it as a physical field that "moves" the particles via the guiding equation. The field lives in the 3N-dimensional configuration space, and wavefunction realists treat that space as the fundamental arena of existence.

Wavefunction realism requires a modification in the Bohmian context, because the theory also assumes particles with definite trajectories. Albert (1996) introduces a "marvellous point": a material point that represents the entire particle configuration in configuration space, standing alongside the wavefunction in that same space. By placing the material point and the wavefunction in a single arena, Albert's account resolves one part of the communication problem: the difficulty of different spaces.

However, wavefunction realism faces the "macro-object problem": the challenge of explaining how the familiar three-dimensional world we perceive emerges from a fundamentally high-dimensional ontology. Albert's account treats three-dimensional objects and facts as *functionally emergent* from the fundamental configuration-space ontology. Nevertheless, this explanation is often found inadequate, since the relation between the fundamental reality in configuration space and our ordinary three-dimensional world remains metaphysically obscure. In addition, the initial appeal of BM (for many) comes from its similarity to classical physics, in which there are particles following definite trajectories. Relocating everything to a fundamental space and removing every particle in the universe except one does not provide an appealing picture for proponents of the theory.

It is worth noting that there are strategies, such as the multi-field view, that escape the difficulty of the two different spaces by relocating the wavefunction into three-dimensional space instead, reconceiving it as a 'field'[1] that assigns values to N-tuples of points in ordinary space rather than to points of a single configuration space (Romano, 2020; Hubert and Romano, 2018). This solution once again introduces

[1] For the metaphysical discussion on the multi-field, see: Romano, (2020)

the initial appeal of BM that we discussed above. Nevertheless, the multi-field solution does not by itself solve the difficulty of bidirectionality: there is still no influence of the particles back

upon the multi-field of the kind we find between charged particles and the electromagnetic field they source. Thus, although the multi-field approach provides an account of wavefunction as an ordinary physical field in 3D, it does not escape the communication problem.

Another possible solution is to think of the wavefunction as a nomological entity. This reading is primarily associated with the primitive ontology view[2],the Dürr–Goldstein–Zanghì (DGZ) approach, on which the fundamental ontology consists exclusively of particles (the elements of the primitive ontology), and the wavefunction is merely a law-like entity, or part of a law, describing the dynamics of those particles. This is the "nomological view."

The nomological view does not face the communication problem, since on this reading there is no physical interaction between two independently existing entities. All the physical interaction occurs between the elements of the primitive ontology. The wavefunction and the guiding equation simply describe these interactions and the resulting dynamics of the particles, and nothing more.

Nevertheless, the nomological view has its own serious difficulties. The wavefunction itself is governed by the Schrödinger equation, which dictates its evolution; and the fact that the wavefunction *has its own dynamical evolution* is a central difficulty for the view. Hoefer and Solé (2019) press three distinct challenges to the nomological view: First, the wavefunction is time-dependent, whereas laws are not generally taken to be time-dependent. Second, the wavefunction is itself subject to the Schrödinger equation, which is generally regarded as a fundamental law in its own right; if the wavefunction is also a law, one is forced to speak of a hierarchy of laws, which is metaphysically awkward. The third one is the problem of contingency: If the (universal) wavefunction[3] is a law, it inevitably excludes many

[2] Primitive ontology is the view, associated with Dürr, Goldstein, and Zanghì and developed extensively by Allori, is that any fundamental physical theory must specify a "primitive ontology", which is a set of basic entities living in threedimensional spacetime, whose behavior over time is what the theory is ultimately about, with all other formal elements of the theory (including the wavefunction) playing a purely nomological or auxiliary role in describing their motion. In Bohmian mechanics, the particles themselves are taken to be the primitive ontology, and the wavefunction is denied any independent physical status. See: Allori (2013) for the general framework.

[3] Bohmian mechanics distinguishes the *universal* wavefunction, which is the wavefunction of the entire universe, from the *effective* wavefunction of a subsystem, which is derived from the universal wavefunction together with the actual configuration (Dürr, Goldstein, and Zanghì, 1992). This distinction matters for the nomological view because nomologists hold that only the universal wavefunction that has law-like status.

possible wave functions, imposing a kind of necessity to the initial conditions, which is also a conclusion some find to be unintelligible.

Since it has close ties with the primitive ontology, the nomological view assumes an object-first ontology: all there is, on this view, are particles with properties, together with laws that govern them. However, Bohmian particles are quite *particular*. Bohmian physicists strip them away from intrinsic properties and consistently locate those in the wavefunction instead. For instance, concerning *spin*, Daumer, Dürr, Goldstein, and Zanghì write that "roughly speaking, spin is merely in the wave function" (1996, p. 391), Tumulka states that "the spin is rather a property of the wave function" (2004, p. 1224), and Dürr and Teufel write that "spin is a property of the guiding wave function, which is a spinor" (2009, p. 165). Oriols and Mompart, in their textbook treatment of the theory, make the same point explicitly: "the spin is basically a property defined through the wave function of the particle" (2019, pp. 71–73)[4].

Positions are the only thing this ontology actually allows the particle to have. It is striking that a resolutely object-first ontology should have so little to say about what its objects are like: the particles are individuated by position alone, and every further property one would naturally expect an object to possess is handed over to the wavefunction instead. This shows an inherent incoherence within the proponents of the nomological view. An ontology that calls itself object-first while attributing all of its objects' properties essentially to a separate, nomological entity does not seem quite plausible.

This poses a serious challenge for the nomological view. The wavefunction, which is explained away by saying a 'nomological entity', plays a central role in BM[5]. Laws govern the behaviour of property earing things. How could then the proponents of the nomological view attribute these properties to a law or a lawlike entity? Something about the wavefunction needs to be doing more work than a mere law can do. If it is a nomological entity, it is a very particular kind of nomological entity: one that gives the Bohmian particles their 'intrinsic' properties.

The wavefunction in BM also has an additional role: it relates the particle configuration as a whole, accounting for the non-separable, holistic character of the theory, in a way not straightforwardly

[4] Spin is especially important because the wavefunction is fundamentally a spinor-valued function in configuration space.
[5] For a critical analysis of the conceptual and physical issues with nomological entities, see: Amblard, Drezet, (2025).

captured by an ontology of particles alone. Without the wavefunction, entanglement cannot be explained purely in terms of particles, since there is more to the global state of an entangled system. Since the wavefunction does not clearly fit into our standard ontological categories, metaphysicians such as Maudlin (2013) argue that the wavefunction should be considered as a *sui generis* entity. Wavefunction realism takes the wavefunction as a substantial physical entity; however, it still does not clearly fit with the standard account of physical entities. The nomological view tells us only how the dynamics unfold in this specific way, but it is silent about why they unfold holistically, and how Bohmian particles get their properties. I therefore think we should look instead to interpretations of the ontology that can explain *why* the particles are entangled and *why* their motion is holistically organized in the first place. I believe structural realism offers a promising framework for addressing this.

Section 3: Structural Realist Interpretations of BM

The previous Section argued that wavefunction realism and the nomological view each capture an important part of the wavefunction's role in Bohmian mechanics while failing to account for the other. Structural realism offers an attractive alternative because it can, in principle, preserve the advantages of both approaches. Like wavefunction realism, it takes the wavefunction to be ontologically significant rather than a mere mathematical convenience. Unlike wavefunction realism, however, it does not claim that the guiding equation describes a primitive causal interaction between two independently existing entities. Instead, the relation between the wavefunction and the particles can be understood structurally. On this reading, the communication problem is no longer posed as a question about causal influence between two separate objects, but as a question about the underlying structure that relates them.

3.1 Structural Realism

Before turning to the existing structural realist interpretations of BM, I will introduce the framework itself. Structural realism emerged as a response to the long-standing debate between scientific realism and anti-realism. Scientific realists hold that our best theories provide approximately true descriptions of the unobservable world; while anti-realists maintain that theories should be understood primarily as successful instruments for prediction rather than as literally true descriptions of an unobservable reality. Structural realism attempts to preserve the strengths of both positions by arguing that what science reliably discovers is not the intrinsic nature of unobservable objects, but the structure of the relations between them (Worrall, 1989).

The contemporary discussion distinguishes Epistemic Structural Realism (ESR) from Ontic Structural Realism (OSR). According to ESR, we should remain agnostic about the intrinsic nature of objects, since all that science gives us epistemic access to is their relational structure; objects may well exist independently of these relations, but their intrinsic properties are, in principle, unknowable to us. OSR takes this a step further. Rather than claiming merely that structure is all we can know, OSR holds that structure is ontologically fundamental: objects are not the building-blocks from which reality is constructed, but derive their identity from a more fundamental relational structure.

OSR is particularly attractive in the philosophy of quantum mechanics. Ladyman and Ross (2007) argue that quantum phenomena such as entanglement and non-separability are difficult to explain within a traditional object-first ontology: on which particles possess intrinsic identities independently

of one another. Quantum mechanics suggests that the behaviour of an individual particle can be understood only in terms of the global relations in which it stands to the rest of the system.

Although the present thesis develops an OSR interpretation of Bohmian mechanics, it is also motivated by the epistemic considerations that motivate ESR. Quantum mechanics repeatedly suggests that what our theories capture most successfully is the relational organization of physical systems rather than their intrinsic nature (ibid.).

Whether objects exist within OSR's ontology, and how they relate to the fundamental structure, is a long-standing internal dispute. French (2010) identifies three main positions:

Eliminativist OSR: the very constitution of the putative objects is dependent on the relations of the structure. (p.106)

Priority-based OSR: the identity of the putative objects, or nodes, is asymmetrically dependent on that of the relations of the structure. (p.105)

Moderate OSR: the identity of the putative objects, or nodes, is symmetrically dependent on that of the relations of the structure, and vice versa. (p.104)

Eliminativist OSR excludes objects from the ontology altogether, while priority-based and moderate versions retain them in different senses. French argues that in priority OSR, objects exist only in a "thin" sense as mere nodes within the fundamental structure. Whereas in Esfeld and Lam's (2008) moderate version, objects possess sufficient ontological independence to function as genuine relata. They are indispensable, because the existence of the fundamental structure is itself taken to depend on them.

Eliminativist OSR is typically refuted as being too revisionary: a world without objects (without particles, in the Bohmian case) is not, for many philosophers, a charitable picture of reality. A related and more general objection to OSR as such is that relations require relata: it is difficult to make sense of relations holding in the absence of objects that stand in them[6]. This is why priority-based and

[6] Proponents of OSR argue that this difficulty arises from our intuitions, and does not entail a logical impossibility— and argue that relations without relata are perfectly coherent. (See: Ladyman and Ross, 2007)

moderate versions of OSR appear more coherent at first glance, especially to proponents of primitive ontology, for whom objects are indispensable as the building-blocks of reality.

Moderate OSR, however, faces its own serious difficulties. Its two central commitments, as set out by Esfeld and Lam (2008), are:

(1) Relations require relata — that is, objects that stand in the relations.

(2) It is not the case that these objects necessarily have intrinsic properties over and above the relations that they bear to one another (p. 5).

On moderate OSR, then, objects exist, even though they need not have intrinsic properties—they are wholly constituted by the relations they bear. But it has been argued that if the objects are *nothing more* than the relations they bear, one could simply exclude them from the fundamental ontology altogether (French, 2010). It is difficult to make sense of the claim that the existence of the relations depends upon such objects: if that were so, the relations would end up depending on themselves, which is a redundant conclusion.

To summarize: moderate structural realism begins with objects and relations that are taken to be mutually dependent, which may not be a coherent position after all. Whereas, a priority-based structural realist holds that structure constitutes the fundamental level of reality, while objects exist only in a derivative, or "thin," sense, as nodes within that structure. This point needs further elaboration. Following French and Ladyman (2010), we can distinguish thick objects, whose individuality is grounded in intrinsic identity or *primitive thisness* (or *haecceities*); from thin objects, whose individuality is contextual, and whose physically relevant properties are determined by their structural relations. A thick conception treats an object's identity as determinate independently of the relational structure in which it happens to be situated. Even two objects that were qualitatively and relationally indiscernible, on this view, could each possess a distinct primitive identity of its own.

Although the conception of thick object must be removed, French and Ladyman emphasize that it does not require rejecting objects altogether. For instance, they defend that spacetime points can count as individuals "in a thin sense" while their individuality remains non-haecceitistic. Priority-based OSR provides a clear explanatory direction that runs from structure to objects. Unlike eliminativist OSR, objects are not eliminated from the ontology. And unlike moderate OSR they do not serve as the ontological basis upon which the structure itself depends. I believe priority OSR is the only version of

the view that secures the advantages of adopting OSR in the first place, without eliminating objects from the ontology altogether. Especially in BM, where the theory *prima facie* includes particles in its ontology.

I will close this section by setting out what a structural realist interpretation of Bohmian mechanics should satisfy: First, it should preserve the explanatory significance of the wavefunction, without reducing it to nomological entity. Second, it should explain the relation between the wavefunction and the particles by appeal to structure, rather than to a primitive causal interaction. Third, it should do so while preserving the priority of structure (or at least giving structure and objects equal priority). Now, we will see whether the existing structural realist interpretations of BM meet these criteria.

3.2 Structural Realist Interpretations of Bohmian Mechanics

3.2.1 Structural Realist Themes in David Bohm's Writings

Bohm himself displayed structural realist tendencies. He was aware of the communication problem, and expressed worry in Causality and Chance in Modern Physics[7]:

"Finally, our model in which wave and particle are regarded as basically different entities, which interact in a way that is not essential to their modes of being, does not seem very plausible. The fact that wave and particle are never found separately suggests instead that they are both different aspects of some fundamentally new kind of entity which is likely to be quite different from a simple wave or a simple particle, but which leads to these two limiting manifestations as approximations that are valid under appropriate conditions." (1957, p.117)

This passage shows that Bohm did not really think of the wavefunction and the particles as separate, independently existing entities. Recall from Section 1 that Bohm read this interaction in terms of form: the wavefunction does not push or pull particles mechanically; rather, the trajectories of particles are formed by the specific shape of the wavefunction. From a structural realist perspective, one may read this as expressing a structural rather than an intrinsic feature of the wavefunction that determine the particles' trajectories. Contemporary structural realist interpretations can be seen as attempts to make this Bohmian intuition metaphysically precise.

[7] It is also possible to see Bohm's structural realist tendencies in The Undivided Universe (1993), and Wholeness and the Implicate Order (1980). Both of these books talk about a fundamental structure from which both the classical and the quantum realm emerge, called the 'implicate order'.

3.2.2 Esfeld's Moderate OSR for BM

Esfeld (2017) develops a moderate OSR account of BM. The wavefunction, on his view, represents a structure that is instantiated by the elements of the primitive ontology. He writes:

"That structure is a concrete physical entity in space-time, consisting in a network of relations of entanglement encompassing all these elements: it relates the positions of all the particles to one another in such a way that the temporal development of each particle's position depends on the positions of all the others. Nonetheless, that structure exists over and above the elements of the primitive ontology, since it does not supervene on whatever intrinsic features those elements may have — not on their positions at any given time, nor on their spatio-temporal relations, nor on intrinsic properties such as mass and charge. Being a concrete physical entity, the structure can develop in time" (2017, p. 8).

We can summarize Esfeld's position as follows: His ontology consists of a fundamental structure, represented by the wavefunction and instantiated by the particles. The wavefunction is identified with the global entanglement structure, which Esfeld characterizes, in different places, as either a "nomological fact instantiated in the world" or a "holistic and dispositional property"[8] (p. 9). On his account, this structure is modal, and its modality is expressed either nomologically or dispositionally.

I believe both characterizations are unsatisfactory from an OSR perspective. If the wavefunction simply is a nomological fact instantiated in the world, the view threatens to collapse into the nomological view examined in Section 2, since the wavefunction becomes a nomological entity governing the particles of the primitive ontology. And if it is instead a dispositional property, one remains committed to an object-first ontology after all. Esfeld's position, identifying the fundamental structure with a set of dispositional properties held by the particles, looks like structuralist language expressing the primitive ontology view.

It is worth elaborating on this last point. In The Structure of the World (2014), French addresses dispositionalism: the view that physical necessity is grounded in the intrinsic, causal powers of objects, as a major rival to OSR. He rejects it primarily because it presupposes an object-first ontology. On French's account, modality attaches to the laws and symmetries of the theory rather than to the objects

[8] Lorenzetti (2022) remarks that both of these notions conflict with the idea that the structure is a 'concrete physical entity'.

that figure in it: laws are inherently modal, as features of the structure of the world itself (French, 2014, p. 225). He argues for how causality should be conceived of once particles have been removed from the ontology as "seats" of causation, i.e., entities that themselves possess causal powers. According to him, physics should speak only of a "thin" notion of causation, one that amounts, at bottom, to metaphysical dependence.

In fairness to Esfeld, he does also gesture toward locating the structure's modality in a "nomological fact instantiated in the world" which resembles French's. Nonetheless, two accounts diverge sharply, because Esfeld's account is committed to a symmetric metaphysical dependence between the particles and the structure; whereas in French's picture, what we ordinarily call "objects" are merely derivative nodes, or placeholders, within a fundamental structural web. Esfeld's commitment to Moderate OSR motivates his idea that objects are fundamental. However, we have seen that proponents of OSR such as French think that this position is incoherent. Regardless, I believe that Esfeld's structural realist reading of BM is a significant improvement to the nomological view (given that its proponents also advocate an ontology in which Bohmian particles are essentially propertyless), however, he should give an adequate account of how the fundamental structure represented by the wavefunction depends on the particles, while preserving structural realist intuitions.

3.2.3 Lorenzetti's Coherentism

Lorenzetti (2022) offers a different structural realist account of Bohmian mechanics, drawing on Calosi and Morganti's (2021) metaphysical coherentism. In his proposal, the fundamental ontology consists solely of particles standing in "horizontal relations of symmetric ontological dependence." The holistic character of Bohmian mechanics is explained by a web of mutual dependence among the particles, rather than a fundamental structure standing over and above them.

Lorenzetti holds that BM is "fundamentally about the behavior of particles," citing Goldstein's remark that "for Bohmian mechanics the particles are primary, or primitive, while the wave function is secondary, or derivative" (2017, pp. 13–14). On this basis, Lorenzetti concludes that BM is inherently committed to a primitive ontology, and rejects both eliminativist and priority-based OSR for being "too revisionary." He agrees with Esfeld that moderate OSR is the appropriate framework to address BM. However, although his coherentist position is supposed to be a version of moderate OSR, the mutual dependence holds *between objects,* rather than between objects and a fundamental structure. He writes:

"According to the coherentist framework one should consider the Bohmian particles as the most fundamental entities, while maintaining that they ontologically depend on each other—at least concerning their particular positions." (p.12)

This passage shows that coherentism is explicitly an object-first ontology: in Esfeld's moderate OSR, objects remain fundamental, but the fundamental structure is at least on a par with them; whereas in Lorenzetti's coherentism, the objects do not depend on structure in any sense at all. Thus, I believe his coherentist position is too weak to be considered within OSR[9].

Even if one accepts that the theory is within OSR, coherentism is by no means a complete theory. The difficulties arise once one considers the status of the wavefunction. Lorenzetti writes:

"At this point, we can regard the universal wave function as a 'whole' stemming from the horizontal web of dependence relations between the particles that coherentism postulates. At the formal level, the wave function encodes the totality of those dependence relations. It should be stressed that the wave function is not, in this view, a fundamental physical structure on which the Bohmian particles are dependent on. Rather, it represents the dependence relations themselves holding among the particles. Thus, strictly speaking, the wave function is not a real fundamental ontological posit of the theory, even though it tracks objective features of the world." (p.12)

This passage illustrates that, the wavefunction is no longer a physical entity over and above the particles, nor a nomological entity that governs their dynamics. It simply encodes the relations of mutual dependence among particles. It does not have its own dynamics; it no longer obeys the Schrödinger equation. More importantly, although Lorenzetti follows the DGZ approach to BM, we have seen that properties apart from position are generally attributed to the wavefunction. Hence, coherentism has to give an account of how to recover these other properties from particle relations[10]. Additionally, if coherentism tries to recover Schrödinger equation from its framework, it would

[9] It should be noted that Lorenzetti himself is agnostic about whether his view is a structuralist one. He states that it has some "structuralist intuitions" but never really endorses OSR.

[10] It seems that the account would also face some problems with respect to positions. For instance, when one thinks about a one-particle system – BM could adequately describe its dynamics through the wavefunction and the guiding equation. In the single-particle case, the particle does not stand in any relation with another particle. Coherentism might not be able to account for such a world.

amount to saying that the structure that stems from the horizontal webs of relation has its own dynamical evolution, which would result in a more complicated ontological picture.

It should be noted that one of Lorenzetti's central motivations is metaphysical parsimony: coherentism only puts particles at the fundamental level. However, this economy comes at a cost: the holistic behavior of the particles must now be explained by primitive relations of mutual dependence between them, taken as brute facts. Whether this amounts to a genuine gain in parsimony is therefore questionable: replacing one primitive structure with a multitude of primitive dependence relations may simply redistribute the explanatory burden, rather than reduce it.

Section 4: A Priority-Based OSR Account of Bohmian Mechanics

In this Section, I propose an alternative structural realist account of BM, in which Bohmian particles are understood as ontologically derivative nodes of a fundamental wavefunction-structure[11]. The wavefunction-structure is over and above, and prior to the particles, which exist only in the 'thin' sense. Justifying the account requires 4 steps: First, the proper notion of priority should be given. Then, we must establish that Bohmian particles exist in the thin sense. Nevertheless, the fact that Bohmian particles exist in the thin sense does not entail that they are derivative. We have to argue that the wavefunction (or the structure represented by it) is prior to the particles. Lastly, to tie the picture together, we should establish how the particles derive their individuality from the wavefunction structure, by appealing to the guidance equation.

4.1 Priority in OSR

The first step is to establish what is meant by priority. The debate surveyed in Sections 2 and 3 has largely been conducted in terms of existence: does the wavefunction exist as a physical field, a law, or a structure? Schaffer (2009) argues that the primary task of metaphysics should no longer be to answer the Quinean question "what exists?", but rather "what is fundamental, or what grounds what?". All the views we have seen: wavefunction realism, nomologists, and structuralism, entail different conclusions about the fundamentality of the wavefunction.

[11] I use this notion to express 'the structure represented by the wavefunction'.

I would like to base the notion of priority in this thesis on French's characterization of priority-based OSR, where the identity of the objects are dependent on the fundamental structure, making them 'thin' objects. Hence, three claims must be supported: First, Bohmian particles should be understood as 'thin' objects. Second, the structure that gives their identity should be proposed. Lastly, we should establish that this relation is asymmetric.[12]

4.2 Bohmian Particles as Thin, Derivative Nodes

Bohmian mechanics might appear, at first sight, to pose a problem for ontic structural realism. Unlike interpretations of quantum mechanics that dispense with definite particle positions altogether, Bohmian mechanics posits a configuration of particles with definite positions in three-dimensional space at every time t, $Q(t) = (Q_1(t), ..., Q_N(t))$. If OSR holds that relational structure is ontologically primary, this might seem to commit Bohmian mechanics to a conventional particle ontology, on which the particles are fundamental objects possessing their own identities and intrinsic properties. I want to argue that this conclusion does not follow, because the mere existence of particles does not entail a thick conception of objecthood.

French and Ladyman refer to Saunders's notion of weak discernibility to further account for thin objects. Objects can count as individuals even without possessing intrinsic qualitative properties that distinguish them, if there is an irreflexive and symmetric relation that could ground their individuation (Saunders, 2006).

I would like to start by arguing that particle positions could account for weak discernability. Suppose two identical particles occupy positions $q_i(t)$ and $q_j(t)$ at time t. If they are distinct particles, they stand in a spatial relation of non-zero distance, $d(q_i(t), q_j(t)) > 0$; distance is an irreflexive and symmetric relation, since $d(q_i(t), q_i(t)) = 0$. The particles can therefore be distinguished through their spatial relations alone, without appeal to any intrinsic property that distinguishes one from the other.

[12] One might object that all this is too weak for classifying as a genuine case of priority- based OSR, since ontological dependence, as it figures in the grounding literature, is sometimes taken to be a stronger relation one on which the ground metaphysically necessitates, or at least entails, what it grounds (see: McKenzie, 2020). But this demands more of priority OSR than the view itself claims. French and Ladyman's own paradigm case is general relativity, where spacetime points are nodes individuated by the metrical structure of the manifold; yet the mathematical form of that structure does not entail which solution to the field equations is actual, since this depends on contingent boundary and initial conditions the structure does not fix. This is not taken to show that OSR about spacetime fails. What priority OSR requires is that the *identity* of the nodes. The present account uses this weaker (but original) criterion.

A particle does not need to possess *primitive thisness* to be an individual; it can be identified by its position within the configuration and its relations to the other particles. Particle q_i is not that particle in virtue of some intrinsic metaphysical label distinguishing it from q_j; it is, rather, the particle occupying a particular position within the configuration.

We can apply the same strategy to Bohmian particles, and argue that they exist in the thin sense: although identical, they are weakly discernible through their position. We have already seen that Bohmian particles are usually stripped away from their intrinsic properties such as mass and spin. Harvey Brown also draws attention to the unusual status of physical properties in BM. Brown notes that state-independent parameters such as mass are attributes of the wavefunction rather than of the particle, and suggests that the particle is "nothing more than a trajectory painted in space." (Brown et al., 1996, p.313). In this way, he flips the DGZ intuition that the particles are primary, and the wavefunction is 'derived' in BM.

This observation matters for the thin-object interpretation: if mass and other state-independent parameters are not best understood as intrinsic properties carried by the particle itself, then it should not be considered as a classical substance with a complete set of physical properties. The sole factor of individuation is position, allowing particles to be weakly discernible. Thus, their identity is tied to the wavefunction and to the dynamical structure that governs its trajectory. Brown's observation is crucial for the weak-discernibility argument. Together, the two considerations suffices for a 'thin' conception of Bohmian particles.

4.3 Could the Wavefunction Be Understood as a Fundamental Structure?

After establishing that in BM, particles exist in the thin sense, we should now clarify what the fundamental structure that weakly discerns them is. A very natural candidate is the wavefunction[13]. Throughout the thesis, the explanatory role of the wavefunction was repeatedly emphasized. We have also seen that Brown et. al., and the proponents of the DGZ approach, argue that the particles get their intrinsic properties from the wavefunction. However, to see whether the wavefunction can be thought of as a structure, we should get support from OSR.

[13] Another candidate is the entanglement relations, as Esfeld and Lorenzetti hinted towards; however the one-particle case poses a difficulty. And even in the multiple particle case, the wavefunction carries more information than the entanglement relations, such as amplitude and phase.

First, structural realists such as French (2014) place particular emphasis on mathematical structure and invariance: the physical significance of a theory does not depend primarily on the particular representation used to describe a system, but on the structural relations that remain invariant under the relevant transformations. The wavefunction is invariant under fundamental symmetry groups[14]. Since it encodes these invariant relations without depending on coordinate choices, it meets French's threshold for an objective, fundamental structure.

Second, it meets the modality criteria. We have seen that French argues that the fundamental structure should be modal, encoding the possibilities available to a physical system. The wavefunction is naturally understood in this way. In Bohmian mechanics, the wavefunction does not merely specify an actual measurement outcome. Rather, through the Born rule, a single quantum state determines the probabilities associated with a range of possible outcomes. The formalism does not associate a distinct wavefunction with each possible outcome. Rather, the same wavefunction encodes the modal structure of the possible outcomes.

The same point can be expressed in BM. A wavefunction should not be understood as specifying one particular particle configuration or trajectory independently of the actual configuration. Instead, it determines a dynamical structure relative to which different configurations and their possible evolutions can be understood. The actual configuration is just one realization within a broader modal structure. In this sense, the wavefunction contains information not merely about how the system is actually arranged, but about the physically possible configurations and evolutions available to it. This modal character makes the wavefunction a particularly natural candidate for the fundamental structure required by Priority OSR: the structure is not exhausted by the actual arrangement of its nodes, but encodes the space of possibilities within which those nodes can be realized.

Third, and most importantly, the wavefunction determines the dynamics, without needing to be classified as a traditional object. In other words, even though it is not a material entity pushing particles through space, it acts as a structure whose dynamical organization determines the trajectories occupied

[14] French uses the examples of Poincaré invariance or U(1) gauge invariance. In non-relativistic quantum mechanics, the probability distribution associated with the wavefunction is invariant under Galilean transformations.

by the configuration[15]. It plays a fundamental explanatory role without reintroducing the object-first metaphysics OSR is meant to reject.

4.4 Asymmetry: Why the Structure Is Ontologically Prior to the Particles

The last step is to discuss whether there is genuine asymmetry between the wavefunction and particles.

The formalism of BM clearly shows an asymmetry. We have already seen the bidirectionality problem: the wavefunction influences particle dynamics whereas the particles do not influence the wavefunction in any way. The guiding equation establishes the asymmetric dependence; given the relevant wavefunction and configuration, the evolution of the configuration is determined by the wavefunction. Since the particles are considered as individuals solely in virtue of their positions, and the wavefunction is responsible for their trajectories via the guidance equation; BM could be considered as an instance where priority-based OSR provides a very clear ontological picture.

To summarize: In BM, the configuration evolves according to the guiding equation, where the velocity field is determined jointly by the wavefunction and the configuration, making the velocity of any one particle depend on the configuration of the entire system. Ψ acts as the global structure that connects the particles in this holistic and irreducible manner. The resulting picture can be represented schematically as Ψ, giving rise to Q(t) and thereby to the individual trajectories Qi(t) – making the particles thin nodes of a fundamental wavefunction-structure, from which each derives their identity.

4.5 Objections and Replies

4.5.1 The wavefunction does not individuate particles

The last point comes with an important caveat. We argued that the wavefunction is central in determining the configuration, thereby individuating the particles, making them nodes of the more fundamental structure. However, the wavefunction is not a single agent: it determines the future evolution *given the initial configuration.* In other words, the guiding equation requires specifying the initial particle configuration to determine the particle trajectories.

[15] What kind of an entity the wavefunction is, or represents, needs more explanation. I will return to this point in the objections section.

If the wavefunction is not the sole entity that is responsible for deriving the individuality of the particles, can it be considered as the fundamental structure that everything else is dependent upon?

What determines the actual initial configuration remains an open question within the theory. However, this does not undermine the claim that the wavefunction represents the fundamental structure. As argued above, the wavefunction encodes the physically possible configurations and their dynamical evolution, thereby giving the system a modal structure in the sense emphasized by French. Some metaphysicians such as McKenzie (2020) argue that genuine priority requires determination. In other words, a genuine prior structure must determine every fact about the nodes. This is not how French thought of the structure. For him, laws and symmetries can account for the modal nature of the structure, encoding possibilities. He writes:

"Furthermore, these laws and symmetries encode the relevant possibilities and in so far as they are stable or robust under certain changes to initial conditions, can be regarded as necessary, in a certain sense. In this way the structure of the world can be said to be modally informed." (2014, p.302)

Thus, for him, priority does not necessitate a further mechanism that separates the actual from the possible. In our case, the fact that one particular configuration is actual does not require that the structure determine this configuration. Rather, the structure determines the space of possibilities and the dynamical relations among them, while the initial configuration specifies which possibility is realized.

In addition, the fact that we cannot derive a future state of a system solely from the wavefunction does not mean the wavefunction lacks a separate mechanism responsible for it. We simply do not know how the initial conditions are realized, but it does not mean that they are random. For instance, a candidate for such a mechanism could be the Bohmian typicality argument, where the quantum equilibrium measure provides the relevant statistical measure over configurations which allows the trajectories to be equivariant[16]. Hence, although the initial configuration is not determined by the wavefunction, it still provides the statistical measure relative to which configurations are regarded as typical.

[16] I would like to thank Ulaş Eyüpoğlu for this point. For more information on the typicality argument, see: Dürr, Struyve, 2020

4.5.2 What, and where, is the Wavefunction?

The central claim of this proposal is that the wavefunction represents a fundamental physical structure. So far, however, we have not established *where* this structure is. Is it in physical space, or in configuration space? Ψ is standardly defined on a higher-dimensional configuration space; if the fundamental structure is located there, it is unclear how particles in three-dimensional space are to be understood as its derivative nodes.

One way to escape this problem is to deny that the wavefunction is in configuration space at all. Configuration space's dimensionality reflects the number of degrees of freedom needed to describe a system's evolution, not a claim about how many spatial dimensions there actually are. On this view, the wavefunction can be reconstructed as a multi-field: an assignment of values to N-tuples of points in ordinary three-dimensional space, rather than to points in an independently fundamental higher-dimensional space (Hubert and Romano, 2018).

However, we do not need the multi-field solution to work. The Ψ we are talking about is no longer an ordinary physical field like wavefunction realism endorses. Standard wavefunction realism, as developed by Albert (2013, 2015, 2019) and Ney (2021), is a first-order metaphysical thesis: it asserts that the wavefunction is concrete fundamental stuff, of a determinate categorical nature, located in a specific arena: in a high-dimensional space taken to be more fundamental than ordinary spacetime. However, a structural realist reading of Ψ differs significantly. We have stated that the wavefunction *represents* a fundamental structure from which particles derive their identity; we do not have to take it in the literary sense that wavefunction realism does. OSR's governing commitment is to the relations and roles that structure fixes, not to the categorical nature of whatever occupies them. Some presently unknown structure in spacetime might play exactly the functional role the wavefunction plays in standard quantum mechanics (the multi-field construction being one candidate) or the role might be played by something not spatially located at all. Once OSR is adopted, which of these obtains loses much of its significance, since it is the role itself, and not the identity of whatever occupies it, does the philosophical work.

4.5.3) "Too Revisionary"

We have seen that Lorenzetti dismisses priority-based OSR as too revisionary. Likewise, Esfeld is committed to primitive ontology and the equal fundamentality of objects. Primitive ontologists would argue that the appeal of Bohm's theory, unlike other interpretations of quantum mechanics, comes from its clear ontology of particles following determinate paths, similar to classical mechanics. If we replace this clear and intuitive picture with the structure, BM might not come off as appealing as before.

I cannot claim to have shown that structural realism is a better metaphysical framework than primitive ontology. That would require a much broader argument than the present thesis can provide. The claim of this thesis is that priority-based OSR provides a clearer and more coherent account of the relation between the particles and the wavefunction in BM. Moderate OSR preserves the fundamentality of both the particles and the structure, but this gives rise to an ambiguity concerning their metaphysical relationship. If the particles are already fundamental, while their individuality and physically relevant characteristics are determined by the holistic structure represented by the wavefunction, it becomes difficult to explain why the particles should retain fundamental status. Priority OSR resolves this tension by retaining the particles as genuine objects while treating their ontological status as "thin".

Additionally, French (2014) argues that physics should inform metaphysics, not vice versa. Thus, if the physics points toward a more holistic picture, the metaphysics should accompany it. In BM, the theory consists of propertyless particles whose motion depends on the *form* of the wavefunction; and the proper metaphysics addresses this feature rather than dismissing it, and is a structuralist one.

4.6 Summary and Limitations

In this Section, we have developed the priority-based structural realist account of Bohmian mechanics in four steps: First, I argued that Bohmian particles can be understood as thin objects: their individuality does not depend on primitive intrinsic identity or haecceity, but can be secured through weak discernibility since distinct particles stand in an irreflexive relation of distance. Brown's observation that state-independent parameters such as mass properly belong to the wavefunction rather than to the particle reinforced this thin conception. Second, I argued that the wavefunction satisfies French's criteria for a fundamental structure: it encodes invariant relations under the relevant symmetry groups, it is modal in the sense of encoding a space of physically possible configurations

and evolutions, and it determines the dynamics without needing to be classified as a traditional object. Third, I argued that the relation between structure and particles is genuinely asymmetric: the guiding equation shows the wavefunction determining particle trajectories, with no dependence running in the other direction. Finally, tying these three claims together, one can treat the wavefunction structure as ontologically prior to the particles.

This picture has a number of advantages over the alternatives examined in Sections 2 and 3. Most directly, it provides an answer to the communication problem set out in Section 1. If Ψ and Q are treated as two independently fundamental entities, their interaction is mysterious. But if Q is derivative from the fundamental structure represented by Ψ, this question does not arise. The guiding equation does not describe a causal influence from one independently existing substance to another; it expresses the dependence of a derivative particle configuration on a fundamental structure.

The account also avoids the difficulties of the moderate OSR alternatives. By assigning clear asymmetric priority to structure over particles, priority-based OSR gives a more coherent account of the relation between the wavefunction and the particles than either alternative, preserving its explanatory and unificatory role in BM.

Nevertheless, the picture is ultimately incomplete. First of all, the question of how the initial particle configuration is realized is open. Second, and more importantly, I remained agnostic about the categorical nature and spatial location of the fundamental structure that Ψ represents. To avoid reintroducing the difficulties that arise from different spaces in wavefunction realism, I must acknowledge that the proposal works best if the structure is in the same physical space as the particles. Additionally, if it is a concrete physical structure, we could account for its autonomous evolution through time via the Schrödinger equation. However, as I have argued before, this agnosticism also comes from OSR's own commitment to the *role of entities* over what they are. Whether that trade-off is ultimately acceptable, and how identification operates between the wavefunction and particles in more precise formal terms, is left for future work. What I hope to have shown is that priority-based structural realism addresses BM's central difficulty of giving an adequate account of the relationship between the wavefunction and the particles, without eliminating them from the ontology.

Conclusion

We have begun this thesis by trying to give an account of how the wavefunction in a higher-dimensional configuration space was supposed to be 'guiding' the particles in the three-dimensional space. Section 2 argued that wavefunction realism and the nomological view each solve this problem in their own respect; however, neither solution is quite convincing. Neither thinking of the wavefunction as a physical field in configuration space nor treating it as a nomological entity clearly captures its central role in BM as the entity that accounts for its holistic nature while assigning properties to the particles. And we have concluded that a structuralist reading is much more coherent.

However, existing structural readings also had their fair share of problems. Section 3 showed that Esfeld's moderate OSR risks collapsing back into the nomological view or reintroducing an object-first metaphysics through dispositionalism, which is not entirely suitable for OSR; while Lorenzetti's coherentism presupposes symmetric dependence among particles without a further dependence on structure.

In Section 4, we have proposed an alternative priority-based OSR account of BM, in which Bohmian particles can be understood as nodes within a larger structure, namely, the structure represented by the wavefunction. I would like to conclude by saying that this understanding could provide further justification for the holistic and non-local character of Bohmian mechanics, by providing an underlying mechanism that 'attaches' the particles to a fundamental structure.

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