The Wave-Function Is a Multi-Field

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It is generally argued that if the wave-function in the de Broglie–Bohm theory is a physical field, it must be a field in configuration space. Nevertheless, it is possible to interpret the wave-function as a multi-field in three-dimensional space. This approach hasn't received the attention yet it really deserves. The aim of this paper is threefold: first, we show that the wave-function is naturally and straightforwardly construed as a multi-field; second, we show why this interpretation is superior to other field interpretations; third, we clarify common misconceptions.

Contents

1 What Is the Wave-Function?

The wave-function is a very peculiar object. It is mathematically defined on a very high-dimensional space, and yet it is supposed to determine the motion of particles in three dimensions. We need to translate this mathematical picture into a coherent ontological

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story. Two very broad strategies have been pursued to elucidate what the wave-function may be: either it is a beable (that is, as something existing), or it is an abstract entity. Some Humeans, for example, have taken the latter strategy and relegated the wave-function to the best-system (Callender, 2015; Esfeld et al., 2014; Miller, 2014). In this role, the wave-function is the most efficient summary of the behavior of particles. For dispositionalist, on the other hand, the wave-function exists as something real (Esfeld et al., 2014; Suárez, 2015). Other interpretations can be assigned to either mode of existence.

Having clarified *what* the wave-function is, one may find out *where* the wave-function exists. It can exist here in three-dimensional space, somewhere in a different physical space, or nowhere in any physical space at all. Again in a Humean best system the wave-function would be nowhere because it is an abstract object. If one were to reify configuration space, the wave-function would live somewhere in this space. The following passage by John Bell is usually interpreted to suggest such that:

> No one can understand [the de Broglie–Bohm] theory until he is willing to think of ψ as a real objective field rather than just a 'probability amplitude'. Even though it propagates not in 3-space but in $3N$-space. (1987, p. 128)

On this point, we disagree with Bell. We aim at showing that the wave-function can be indeed construed as a beable here in three-dimensional space, namely, as a *multi-field*. It will turn out that the multi-field is a non-local beable. We will contrast this view with two other field interpretations of the wave-function: the marvelous point interpretation by David Albert and the local fields approach by Travis Norsen. Our aim is to show that the multi-field incorporates the best of both worlds: an ontology in three-dimensional space without changing the mathematical formalism.

2 The Multi-Field

The multi-field view amounts to considering the wave-function as a generalization of an ordinary classical field. A classical field specifies a definite field value for each location of three-dimensional space. A charged particle that is posited at a given location will feel the force generated by the value of the field for that location. The multi-field generalizes this concept to N-tuples. Given an N-particle system, the wave-function as a multi-field specifies a precise value for the entire N-tuple of points in three-dimensional space. The multi-field thus determines, given the actual positions of N particles, the motion of particles.

In the first-order formulation of the de Broglie–Bohm theory, the multi-field specifies the velocity of particles, whereas in the second-order formulation the acceleration for each particle is specified. In other words, the multi-field assigns a "multi-velocity" (first order) and a "multi-acceleration" (second order)—induced by a multi-quantum force—to the configuration of N particles. The multi-velocity and multi-acceleration then generate the velocities and accelerations for each single particle of the configuration.

There is an important difference between the classical field and the multi-field. In the classical case, the field produced by N particles can always be decomposed as a sum of the fields produced by single particles. As the wave-function is not produced by "quantum sources", the multi-field of an N-particle system is not decomposable into a sum of single-particle quantum fields—if the wave-function is factorizable, it can be decomposed into single-particle wave-functions, but they are not produced by the particles. Thus, the multi-field rather is a holistic or relational field assigned to sets of N particles.

The idea of the multi-field is not novel. It dates back to Forrest (1988, Ch. 5), where he introduces the concept of *polywaves* as a generalization of classical *mono-waves*:

> I posit polywaves, which are disturbances to polyadic fields. The familiar monowaves (monadic waves) are assignments to each location of some member of the set of possible field-values for that location. Likewise an [N]-adic polywave is an assignment to each ordered n-tuple of locations of a member of the set of possible field-values for that [N]-tuple of locations. The integer [N] is just the "number of particles". And the possible field-values are [N]-adic relations. (1988, p. 155)

In the original proposal by Forrest, the concept of polywaves is defined in the framework of standard quantum mechanics. The problem with this approach is that the integer N in the definition above cannot be straightforwardly understood as the number of particles, since in standard quantum mechanics a system is described only by the wave-function. This is the reason why Forrest's metaphysics seems to be constituted by pure relations between (empty) points of space, which seems to be a rather peculiar ontology. This problem is solved in the de Broglie–Bohm theory, where the integer N refers to the number of real particles, and the relations between particles are easily explained by the dynamical correlations induced by the multi-field as we have described above.

Belot (2012) was then the first to apply Forrest's polywaves to the de Broglie–Bohm theory and to dub this approach the *multi-field interpretation.* After a brief sketch of what a multi-field is Belot dismisses it for the following four reasons:

1. The multi-field doesn't have sources.
2. The multi-field violates the action-reaction principle.
3. The multi-field doesn't restore energy-momentum conservation.
4. The multi-field transforms under boosts differently from the electromagnetic field. (pp. 72-3)

These objections arise from the requirement that the multi-field must have the same features as classical fields. If a field has sources, then it is natural that it fulfills the action-reaction principle. Since the multi-field has no sources, an action-reaction principle is not expected.

That the multi-field doesn't to energy-momentum conservation is not correct. But for formulating the conservation of these quantities one needs to introduce the quantum potential Q, which is in essence the second derivative of the multi-field. So if the classical potential V and the quantum potential are time-independent (that is, the system is closed) the total energy of particles along their trajectories is conserved (Holland, 1993, p. 285):

$$\sum_{i=1}^{N} \frac{1}{2} m v_i^2 + V + Q = \text{const.}$$

A similar relation holds for the sum of the momenta. If $\sum_{i=1}^{N} \nabla_i (V + Q) = 0$ then

$$\sum_{i=1}^{N} \boldsymbol{p}_i = \text{const.}$$

In particular, a particle guided by a plane wave has constant momentum because it moves on a straight line.

For the ontology of the multi-field, we don't see why its transformation properties pose any dangers. It's indeed important to debate whether the de Broglie–Bohm theory is a Galilean or Aristotelian theory (Dürr et al., 1992; Valentini, 1997).

The multi-field account naturally explains the non-local behavior of Bohmian particles: since the value of the multi-field depends on N-tuples of points and not on single points, the behavior of a given configuration of particles is intrinsically non-local, as it were a single structure moving in three-dimensional space. The multi-field is thus a new type of field mathematically represented by the wave-function. It fills the physical space with precise values for every N-tuple of points. Particles will feel a certain velocity and a certain acceleration depending on the actual configuration $(\boldsymbol{x}_1, \ldots, \boldsymbol{x}_N)$ and depending on the precise value of the quantum field $\Psi(\boldsymbol{x}_1, \ldots, \boldsymbol{x}_N)$.

Although the multi-field is a physical field in three-dimensional space, its mathematical representation is given by the usual wave-function in configuration space. Therefore, the multi-field interpretation does not have to be confused with Norsen's view, which aims at defining the wave-function itself in three dimensions. We show how these views differ in the next section.

3 A Multitude of Fields Is Not a Multi-Field

Travis Norsen (2010) proposed a Bohmian quantum theory, in which there is no longer a wave-function in configuration space (see also Norsen et al., 2015). Instead, the main dynamical entity is the conditional wave-function associated to every particle in three-dimensional space.[1] The one-particle conditional wave-functions, however, don't suffice to recover all the predictions of the de Broglie–Bohm theory, since they cannot describe entangled states between particles. Norsen presents a nice example.

Imagine two particles that are about to collide. We can prepare the system in two different ways. In the first case, we start with a non-entangled wave-function (see Fig. 1), and in the second case, we prepare the system to be entangled (see Fig. 2). The initial particle positions are the same. And, more importantly, the initial conditional

[1]The conditional wave-function $\psi_t(x)$ of a particle is defined by the universal wave-function Ψ, once the positions of all the other particles in the universe $Y(t)$ are fixed: $\psi_t(x) := \Psi(x, Y(t))$.

wave-functions of both particles are the same, too. Yet, we can prepare each system in such a way that the particles move differently after collision.

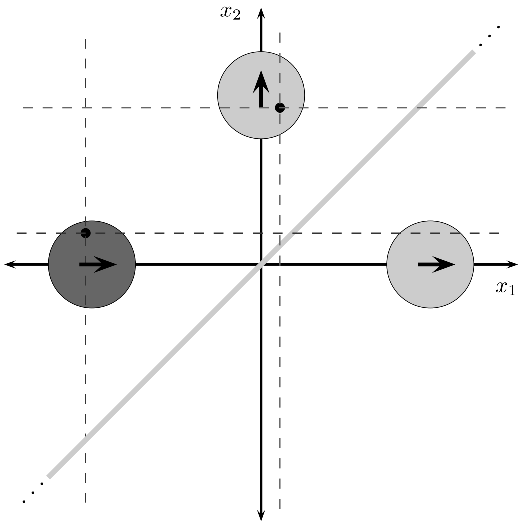

Figure 1: Scattering of two non-entangled particles represented in the two–particle configuration space. A particle moves parallel to the x_1-axis approaching a particle that sits at $x_2 = 0$. The potential of the resting particle is marked as a light grey diagonal line. Their initial wave-function is marked in dark grey. After scattering, the first moving particle stops, and the other particle moves upwards. The wave-function is then in a superposition indicated by two light grey wave-functions. (Picture from Norsen, 2010, p. 1867)

This shows that conditional wave-functions cannot do the job alone in retrieving all Bohmian trajectories. While conditional wave-functions can render the correct trajectories in the first example, they cannot do so for the entangled state. The information about entanglement gets lost in the definition of conditional wave-functions—that's the same for the reduced density matrix in an EPR experiment, where it merely gives us the statistics for one particle irrespective of what happens to the other particle.

Norsen's idea is therefore to add additional local fields to the conditional wave-functions to recover quantum entanglement. The task of these new fields is to change the conditional wave-functions of each particle in such a way that they render the correct trajectories even if the system is entangled; in fact, these fields are non-zero only if there is entanglement.

Norsen's theory of exclusively local beables makes the very same empirical predictions as the de Broglie–Bohm theory—it even predicts the very same trajectories—, but the price to be paid is a more contrived law for the evolution of all those local fields. First, it turns out that there are infinitely many such interacting fields since the evolution of the interaction fields requires further interaction fields... a never ending recursion. And it's not clear yet that one can get satisfactory results with only a finite set of these fields.

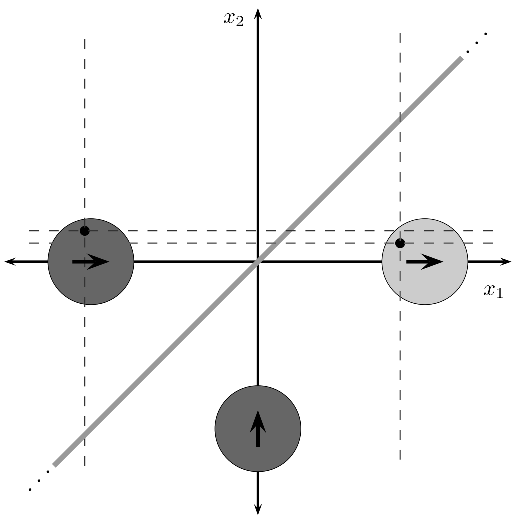

Figure 2: Scattering of two entangled particles represented in the two–particle configuration space. As in Fig. 1, a particle approaches a resting particle from the left and collides at $x_2 = 0$. Their entangled initial wave-function is depicted in dark grey. After scattering, the resting particle starts moving to the right parallel to the x_1-axis, while the other particle stops at $x_2 = 0$. The post–scattering wave-function is drawn in light grey. (Picture from Norsen, 2010, p. 1868)

Second, each conditional wave-function follows a modified Schrödinger equation, in which the other interaction fields are included. And these interaction fields themselves have their own evolution equation. This makes the theory mathematically very complicated and almost impractical for calculating empirical predictions.

We now realize that Norsen *does not* present a theory of a multi-field. There are infinitely many ordinary local fields in physical space, which interact. In fact, this is instead a theory of a multitude of ordinary fields!

Still, Norsen's theory of local beables is sometimes confused with the multi-field:

> We may consider the multi-field option—this postulates a multitude of fields in 3d space, corresponding to each physical particle. Each of these fields is determined by the wavefunction in configuration space, [...] Yet, at each instant in time, a field is defined in 3-D space corresponding to each particle. (Suárez, 2015, p. 3211)

It is apparent that this is not the multi-field account that we have presented in the previous section. Indeed, in the multi-field account, there is no "multitude of fields" on physical space; rather, there is just one field that assigns a value to a set of N particles. You cannot decompose these values corresponding to each fields assigned to each particle because for entangled systems one can't attribute a wave-function to a single particle.

4 Against a Field in Configuration Space

David Albert (1996) argued that if the wave-function is a field it has to be a field in configuration space:

> The sorts of physical objects that wave-functions *are*, on this way of thinking, are (plainly) *fields* - which is to say that they are the sorts of objects whose states one specifies by specifying the values of some set of numbers at every point in the space where they live, the sorts of objects whose states one specifies (in *this* case) by specifying the values of two numbers (one of which is usually referred to as an *amplitude*, and the other as a *phase*) at every point in the universe's so-called *configuration* space. The values of the amplitude and the phase are thought of (as with all fields) as intrinsic properties of the points in the configuration space with which they are associated. (Albert, 1996, p. 278)

Since, in Albert's view, the wave-function is a physical field in configuration space, he takes this space as the fundamental space of physics, and so three-dimensional space with all the objects therein have to emerge from this high-dimensional space. Consequently, what fundamentally exist are not particles in three-dimensional space, but only one single universal particle in configuration space:

> On Bohm's theory, for example, the world will consist of exactly two physical objects. One of those is the universal wave-function and the other is the universal *particle*.
>
> And the story of the world consists, in its entirety, of a continuous succession of changes of the *shape* of the former and a continuous succession of changes in the *position* of the latter.
>
> And the dynamical laws that *govern* all those changes – that is: the Schrödinger equation and the Bohmian guidance condition – are completely deterministic, and (in the high-dimensional space in which these objects live) completely *local*. (Albert, 1996, p. 278)

The major reason for Albert to develop an ontology in configuration space is to have the wave-function as a *local beable*: the wave-function is determined by the local values it assigns to every point of configuration space. Hence, the motion of the universal particle is completely determined by the field value at its location, exactly as in classical electrodynamics, where the motion of a charged particle is determined by the value of the electromagnetic field at its location. We doubt, however, that this kind of locality is a universal principle for physical theories, especially in the quantum domain.

In our opinion, the major drawback of this interpretation is that it doesn't distinguish between the mathematical space and physical space. The fact that a physical object is mathematically defined in configuration space, does not necessarily imply that the object itself has to exist in configuration space. Nor does it imply that the world is $3N$ dimensional. We encounter a similar issue in the meaning of dimensions in classical mechanics. The number of dimensions to mathematically describe a physical object is given by the number of degrees of freedom that we need to describe the state and the motion of that object. For example, a rigid body that translates and rotates is represented in a six-dimensional space. But, of course, this does not mean that the rigid body is really a six-dimensional object: in fact, it exists in a three-dimensional space, but we need six degrees of freedom to fully describe its state of motion. Here the distinction between the mathematical representation and the actual physics is obvious, since everybody agrees on what a rigid body is.

Albert takes a different approach in quantum mechanics, as well as in classical mechanics. He starts with the mathematical formalism and searches for criteria in how to distill an ontology. His primary principle is locality: find the mathematical space in which the physical entities are locally defined. You may also call this principle *separability*, since it's about the ontology of objects and not about their dynamical behavior. For the de Broglie–Bohm theory this principle distinguishes configuration space as the space in which the wave-function is locally defined. So take this space as fundamental!

In classical mechanics, three-dimensional space and phase are separable. So here the locality principle does not single out one space over the other. Therefore, Albert invokes another principle here: take the local space that has the lowest dimension. Applying this principle, we get that the fundamental classical space is three dimensional.

We think that Albert's approach to extract an ontology of the mathematical formalism of physics relies on a idiosyncratic understanding of what physical theories are. They are not bare mathematics! Only one part consists of formulas; the other part consists of a commentary to the formulas in order to tell us what these symbols refer to *in the world*. In particular, a good physical theory, like the de Broglie–Bohm theory, tells us by itself what the ontology is. No principle of locality is needed. And why should we be committed to this principle in the first place?

The primary task of physics is to explain what we observe, to explain our manifest image (to use a phrase of Sellars, 1963). A theory does so by proposing a scientific image, namely an ontology with corresponding laws of nature. Albert's scientific image consists of a point in configuration space that is locally guided by the wave-function. He gets the manifest image by an analysis of the Hamiltonian in the Schrödinger equation. The Hamiltonian has the structure of giving rise to a three-dimensional world, with tables and chairs, on a coarse-grained level.

In the multi-field view, the scientific image consists of many particles in three-dimensional space, guided by a non-local field on this very space. The advantage of this view is that the scientific image takes place in the same physical space as the manifest image: tables and chairs are really composed of particles. It's not sufficient to explain the manifest image just by the dynamical laws but also by how these laws give rise to the manifest image. That particles are situated in three-dimensional space composing tables and chairs is much more plausible and straightforward than a marvelous point in a very very high dimensional space explaining the behavior of tables and chairs by a functional analysis of the Hamiltonian (see also Emery, 2017, for an argument along these lines). The dynamics is not enough; it is also important how this dynamics is implemented in the ontology.

Besides, Albert's ontology is based on the assumption that our perception of the world is massively flawed. We may concede that perception can misguide us, but that there is this conspiracy of actually living in a $3 \cdot 10^{80}$ dimensional space (this is a number with 80 zeros!) without every noticing the other 10^{80} dimensions is hard to grasp. If there is a coherent conservative alternative, why should we adhere to this idiosyncratic ontology?

5 Advantages

In the following, we list the advantages of the multi-field interpretation in more systematic order. Some of the points have been mentioned above, but here we make them explicit.

General Physical Interpretation

The multi-field interpretation is largely independent of the concrete formulation of the de Broglie–Bohm theory in terms of a first-order formulation (Dürr et al., 2013; Valentini, 2010), second-order formulation (Bohm and Hiley, 1993), or quantum Hamilton-Jacobi formulation (Holland, 1993). In the first-order formulation the multi-field directly specifies the velocities of each particle. In the second-order formulation, the acceleration is specified by means of the quantum potential. We think, however, that the the multi-field interpretation is particularly useful for the second-order theory, because it allows to retrieve the entire classical scheme of how motion is generated: field → potential → force → acceleration.

The multi-field interpretation is also independent of the status of laws of nature. Recent interpretations, like the nomolgical interpretation, the Humean interpretation (Bhogal and Perry, 2017; Callender, 2015; Esfeld et al., 2014; Miller, 2014), or the dispositional interpretation (Esfeld et al., 2014; Suárez, 2015) require a commitment to what laws of nature are. For physicists may regard it as an advantage that they don't need to dig too deep into metaphysics in order to understand what the wave-function is.

The Entire Ontology in Three Dimensions

That Bohmian particles are guided by the wave-function is often taken merely as a heuristic intuitive metaphor. As the wave is defined in configuration space, it cannot directly influence the motion of particles. Having the wave-function as a multi-field, however, gives this intuition an ontological underpinning. The de Broglie–Bohm theory is hence a pilot-multi-wave theory, where the wave directly guides particles in three-dimensional space. This has also the advantage that there is an ontological continuity between one-particle and many-particle scenarios. A one-particle wave-function cannot be only visualized in three-dimensional space because this space mathematically coincides with configuration space, but there is indeed a wave in three-dimensional space. When this one-particle wave-function gets entangled with an external N-particle system, the new $(N + 1)$-particle system is still guided by a wave in three dimensions. The double-slit experiment provides a vivid example of the explanatory advantage of this view. While the particle goes through one of the slit, the wave literally enters both slits, thereby determining the motion of the particle and accounting for the characteristic interference pattern on the screen.

Simplicity

The multi-field view is different from Norsen's approach, which reduces the universal wave-function to a set of one-particle wave-functions. There, each particle has an associated local "pilot-wave" in three-dimensional space, so that an N-particle wave-function reduces to a set of local beables. But in order to make the theory empirically adequate and to account for entanglement, Norsen has to introduce an infinite number of interacting fields for the guiding fields. Thus, the formalism of the theory becomes extraordinarily complicated. This is due to the recursive structure of the local Schrödinger equation, leading to a kind of Taylor series for every local guiding field comprising a particle. This would be a totally new structure for a fundamental law of nature. Since the total infinite series of fields cannot be calculated, it is an open question at one order one can truncated this series to have approximately good empirical results.

We think that Norsen's attempt to write down a theory of exclusively local beables shows how unnatural it is to mathematically embed the wave-function in three-dimensional space. One of the great novelties of quantum mechanics is non-locality, and this is implemented in de Broglie–Bohm theory in a natural way by having the wave-function defined in configuration space. Norsen's approach is an attempt to reduce the (global) wave-function of an N-particle system to a set of one-particle wave-functions, one for each particle of the configuration. It is exactly the need to recover quantum non-locality that makes the theory extremely complicated.

The multi-field view, on the other hand, is much simpler: it is an interpretation of the wave-function as a new type of field in three-dimensional space. In particular, it does not require us to modify the definition of the wave-function, and so it does not require to modify the mathematical formalism of the theory. Quantum non-locality is encoded by having the mathematics in an abstract high-dimensional space. This explains quantum non-locality in the simplest way.

Instantiating a Non-Local Beable

For Maudlin (2013), the wave-function in the de Broglie–Bohm theory refers to a real physical entity that determines the behavior of particles. The wave-function is according to him best regarded as the mathematical representation of a new physical object: the *quantum state*. Yet, contrary to Albert, Maudlin suggests that we should not extract the ontology of the quantum state directly from its mathematical representation for the following reasons:

1. The wave-function contains some degrees of freedom that are merely gauge, since they do not lead to different quantum states. One example is the overall phase: wave-functions with different overall phases represent the same quantum state, since their empirical predictions are exactly the same.

2. The wave-function (for an N-particle system) is naturally expressed in configuration space because it refers to the positions of a real configuration of N particles in three-dimensional physical space.

Nevertheless, Maudlin does not specify which sort of physical entity the quantum state is. He merely describes it as a *non-local beable*:

> From the magisterial perspective of fundamental metaphysics, then, our precise quantum theories have a tripartite ontology: a space-time structure that assumes a familiar approximate form at mesoscopic scale; some sort of local beables (particles, fields, matter densities, strings, flashes) in that space-time; and a single universal non-local beable represented by the universal wave-function Ψ. (Maudlin, 2015, p. 356)

The multi-field idea, on the other hand, goes beyond Maudlin's characterization of the wave-function: it is a genuine physical field. Because of it's properties, the multi-field is a non-local beable. It is a beable since it is a physical object in three-dimensional space. And it is non-local since the value of the multi-field is specified not for one point but only for N-tuples of points. The multi-field thus explains what the quantum state is, and it instantiates a non-local beable.

6 Objections and Replies

In the course of writing the paper, we have received some critical remarks about the multi-field approach. We now mention the most important ones followed by our reply.

1. *The multi-field doesn't give us a new ontological understanding of the wave-function.*

   We regard the multi-field interpretation as a new ontological interpretation of the wave-function that has been so far ignored. This approach is incompatible with the nomological interpretation of the wave-function, and its metaphysical characterizations in terms of dispositionalism and Humeanism, although one may still ground the multi-field on an extended Humean mosaic that also comprises contingent non-reducible relations (Darby, 2012). But a detailed analysis goes beyond the scope of this paper.

2. *You don't change the formalism. How can the wave-function be something in three-dimensional space, if it is defined on configuration space?*

   There is a difference between the mathematical structure that we use to define a physical object and the ontology of that object. The multi-field interpretation is based on this distinction. The configuration space is the mathematical space that we need to describe a function which generally depends on $3N$ degrees of freedom (where N is the number of particles of the system); three-dimensional space is the physical space in which the object represented by that function is defined.

   A simple example can be of some help here. Historically, the first formulation of classical mechanics was due to Newton. Newton's theory of mechanics was an ontological theory, that is, a theory with clear ontological commitments: particles moving in three-dimensional space accelerated by force acting on them. The same theory can be casted in the Hamiltonian formulation. Here, the system is represented by a particle moving in phase space with a trajectory described by the Hamiltonian function. Nevertheless, it is understood that the Hamiltonian formulation is just a mathematical representation of the ontological picture of classical mechanics given by Newton's theory. What we usually do in practice is to use both formulations simultaneously: the physical ontology of Newton's theory (that's what the world is built of) and the mathematics of the Hamiltonian formulation (which is often more convenient in doing calculations).

Quantum mechanics has followed an inverse path: the formalism of the theory is an extension of the Hamiltonian formulation of classical mechanics. And the historical mistake here was the attempt to extract from this formulation the physical interpretation of the theory. We regard the de Broglie–Bohm theory as the ontological theory of quantum mechanics (the analogue of Newton's theory for the classical case), which is a theory of particles moving in three-dimensional physical space acted upon by a multi-field. In a nutshell, the multi-field interpretation bears the advantages of Norsen's ontology (that is, having the wave-function physically as a field on three-dimensional space) and the simplicity of the standard formalism (that is, the wave-function as a mathematical object in configuration space).

3. *The multi-field runs into the problem of communication.*

   Suárez claims the following:

   > According to this view, the multi-fields are defined at each instant by the wave-function in configuration space, and the question is how the wave-function "communicates" to physical three-dimensional space in order to fix each of the fields and the positions of the particles for any system of N particles. [...] Also, note that the communication is curiously one way: while the wave-function fixes the physical properties, including positions, of particles in three-dimensional space, these have no effect back onto the wave-function, which essentially ignores which are the actual particle trajectories amongst all the possible trajectories compatible with the dynamics. (2015, p. 3212)

   It is difficult to see how the problem of communication arises in the multi-field approach. Indeed, there is a problem of communication when different physical entities live in *different* physical spaces and yet influence each other. But, in the case of the multi-field approach, both the guiding wave and the particles live in the very same space, namely, three-dimensional space. So, there is no problem of communication in the multi-field account.

   Moreover, the fact that the communication is "one way" is independent of the problem of communication; it's ought to be an objection to regarding the wave-function as a field in the first place. This can become a problem if we want the wave-function to behave like a classical field, where particles and field mutually affect each other. But there are good reasons to think that, if the wave-function is a field, it must certainly be a new type of field, possessing completely new physical features. The action-reaction principle may thus be thought of as a characteristics of classical fields, and it is better to abandon this principle in the ontology of quantum theory. After all, there is no logical inconsistency in thinking of particles not acting back on the field. This could just confirm that the type of physical interaction between the (Bohmian) particle and the multi-field is after all not a classical interaction.

4. *Fields have to be local and propagate with finite speed.*

   We disagree that these features are essential to fields, although they are crucial to classical fields. Fields are first and foremost continuous distributions of certain values. All other features about locality and dynamics are derived from the equations that implement these fields in the theory.

5. *One has always understood the wave-function as a relation between N particles.*

   As soon as one takes three-dimensional space as the fundamental space, the wave-function relates the motion one particle with the motion of all the other particles. In the same vein, the electromagnetic or gravitational field relates the motion of one particle to the motion of the other particles. So “relation” is a placeholder that needs to be specified. We think that understanding the wave-function as a mere set of relations between particles begs the question of what these relations are supposed to be. The multi-field is a concrete entity that specifies the physical meaning of these relations.

7 Conclusion

We have shown that the multi-field interpretation is a serious candidate for the ontology of the de Broglie–Bohm theory. It is the most conservative physical interpretation compared to the marvelous point interpretation and the local fields theory. Tim Maudlin regards the wave-function to be a non-local beable building on a thorough analysis of the work of John Bell. The multi-field interpretation starts from a completely different route, namely, by an analysis and extension of the classical field concept. In the end, the wave-function is a non-local beable because it is a multi-field.

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