Comments of “The World in the Wave Function” by Alyssa Ney

Valia Allori, Philosophy, Northern Illinois University

Pacific APA – April 6th, 2021

“The World in the Wave Function” by Alyssa Ney is a terrific piece of work: it manages to be a popular book, making accessible a topic such as the metaphysics of quantum theory, and at the same time an academic book, significantly contributing to the literature on the subject, namely the metaphysics of quantum mechanics. The book is always extremely clear in the argumentation and very accurate and thorough in exposing the various positions.

I have three comments on which I wish to focus on. The first comment has to do with the role of intuitions; the second with scientific realism and explanation, and the last point has to do with symmetries.

1-The Role of Intuitions

The book defends wave function realism, the view that the fundamental ontology of the world is a high-dimensional field represented by an object called the wave function. While this view is often met with an incredulous stare (given that the wave function is a field in a high-dimensional space rather than in three-dimensional space, as electromagnetic fields) Alyssa argues instead that, contrarily to this reaction, this is the view which *most respects our intuitions*. In fact, she argues, while initially the view was defended as the only one which could make sense of quantum entanglement, this is not the most compelling argument for it, as there are alternative views which can equally account for this phenomenon. Rather, Alyssa argues that wave function realism is best defended when one notices that it is the only account which preserves two features which a theory should intuitively possess, namely locality and separability. Very roughly, a theory is separable if the whole is the sum of its parts (vertical determination), and it is local if what happens in a region does not affect what happens in another spacelike separated region (horizontal determination). Alyssa argues that wave function realism is separable because each state (wave function) is completely determined by the amplitude and phase in each point in the high-dimensional space of the wave function. Moreover, she maintains that wave function realism is local because, regardless of the quantum theory one considers, there is never action at a distance: even in GRW, collapses are not caused by anything. Also, Alyssa argues that all the three-dimensional correlations have an explanation in terms of the behavior of the wave function in the high dimensional space.

No other alternative quantum ontology is both local and separable. Spacetime state realism (according to which the wave function is understood as a characterization of abstract features of spacetime regions represented by the reduced density matrix for that region), the multi-field interpretation (the ontology is the wave function, but it is seen as a poly-wave in three dimensions), the view that the wave function is a property (relational, structural or dispositional), priority monism (which postulates relations between spatially separated particles determined by features of the cosmos), relational and existence holism (respectively according to which objects have relations which do not supervene on the intrinsic properties of their parts, and according to which only the whole exist) are all non-separable. In contrast, while separable, the primitive ontology approach (according to which the ontology is always some three-dimensional object) is nonlocal. So, Alyssa argues, since the only approach which can keep both separability and locality is wave function realism, then wave function realism should be preferred.

Why should we care about a theory having these features? Because they are intuitive, says Alyssa. However, one could object that the locality and separability we intuitively care about are in three-dimensions: it is what it is familiar to us, we model and manipulate systems under the assumption that the world is three-dimensionally local and separable. Instead, wave function realism guarantees them in the high-dimensional space of the wave function. Alyssa argues nonetheless that high-dimensional locality and separability are also intuitive and should be preserved on this basis. After analyzing several potential reasons, which ultimately fail, of why that may be she writes that high-dimensional locality is an intuitive notion because "for something to act, it must be located where it acts. Otherwise, it wouldn't be it itself that is so acting, but something else, or nothing at all" (p. 127). And high-dimensional separability is intuitive because it preserves Humean supervenience: in the high-dimensional space of the wave function, all properties are determined locally. And to preserve Humean supervenience is desirable because it is simple, as we do not have to postulate any additional (relational or otherwise) fact to account for the phenomena.

While I am convinced that we should use intuitive theories (because of their convenience, fruitfulness, explanatory power and so on), I am not entirely persuaded by Alyssa's argument that high-dimensional locality is intuitive and thus it is worth caring about. I think that pointing out that locality is needed to make sense of physical action to show that nonlocality is counterintuitive is effective *only if* we think of three-dimensional locality. In fact, the way in which we understand physical action which conflicts with nonlocality is through three-dimensional space: we see, three-dimensionally, stuff acting on other stuff, and that's why we do not understand how something over here, three-dimensionally speaking, is affecting something over there remaining the same object localized here.

Regardless, I find the intuition argument intriguing, also because it allows Alyssa to extend the general motivation for wave function realism to relativistic quantum theories as well: the point is not that the ontology has to be the wave function in configuration space; rather the ontology is the one that makes the theory under consideration local and separable. With that in mind, Alyssa argues, I think successfully, that she can overcome the worries that wave function realism could not extend to relativistic theories.

It is also interesting to notice that the appeal to intuitions have been a motivator for the primitive ontology approach as well. However, primitive ontologists such as myself use intuitions very differently: different principles or features of the theory are taken to be intuitive and thus worth keeping. For wave function realism, these features are locality and separability. For the primitive ontologists what needs to be preserved is the (reductive) derivation of macroscopic objects and their features from the microscopic ontology. For each approach we have a cost. The primitive ontology framework has the problem of nonlocality, and this is something that is openly accepted. Instead, wave function realism needs to solve the macro object problem, namely it needs to explain how the macroscopic objects and their features come out from the wave function. Here is, schematically, how the problem is solved in Alyssa's account. First, one recovers three-dimensional configurations from the wave function configuration using symmetries: the invariances in the states of the wave function manifest themselves in symmetries in a three-dimensional representation. Then, one finds the particles in this three-dimensional configuration using the notion of partial instantiation: particles' locations are properties which are partly instantiated by the wave function to a degree equal to the amplitude of the wave function.

This discussion is, I think, extremely helpful, as it clarifies the principles guiding these approaches, and allows for a better evaluation. To the primitive ontologist, one may ask: why care about an ontology of three-dimensional objects? Because we have direct experience of it, and we can (suitably) use reductive explanation, which worked well in classical mechanics, also in quantum mechanics. What about nonlocality? One may reply that, if the wave function is taken as nomological, then the charge may be seen as less severe. Be that as it may, as already pointed out, I am not sure the wave function realist can make a strong case about why we should care about (high-dimensional) locality. Moreover, I am not sure Alyssa succeeds in solving the macro object problem, as I discuss in the last section of this paper. Finally, the wave function realist rejects reductionism, as they recover three-dimensional objects via symmetries and partial instantiation. As I will argue momentarily, this has some interesting implications for their commitment to realism. Let's move on to that.

2-Scientific Realism and Explanation

Wave function realists are realists: they believe that our best theories can tell us about the nature of the world. Indeed, scientific realism is a motivator for many philosophers and physicists working in the foundation of quantum mechanics, including the proponents of the multi-field interpretation of the wave function, the spacetime state realists, the proponents of the wave function as a property account, the primitive ontologists, the monists, and the holists, but also others. Usually, the idea is that one needs to solve the measurement problem to begin the realist enterprise. However, I recently came to realize that this is not so straightforward. Let me try to explain that. First, notice that the measurement problem is, first and foremost, a problem for the empirical adequacy of quantum theory: we do not observe macroscopic superpositions that the problem emphasizes the existence of. The vast majority of realists, including wave function realists, reject the empiricist (orthodox) solution of this problem provided by von Neumann's collapse rule, because, they argue, this rule is not precise enough: What is a measurement?

What is a macroscopic object? Let me notice that historically some people such as Einstein and Schrödinger, wanted more than empirical adequacy, and saw the problem of incompatibility between quantum mechanics and realism as a problem of completeness: quantum theory is incomplete because the wave function lives in a high-dimensional space and as such cannot represent physical objects. This tradition has been recently taken up by the primitive ontologists. Let's call this perspective three-dimensionalism. So, there are three attitudes: empiricism, wave function realism, and three-dimensionalism. Correspondingly, there are three types of realism, each corresponding to different kinds of explanations. At one extreme, empiricists care about the adequacy problem (see the information-theoretic approach by Bub and Pitowsky, rainforest realism by Ladyman and Ross, or even Fuch's Qbism): they solve the measurement problem (getting rid of the macro superpositions) using the von Neuman rule to systematize appearances. Thus, they use a principle, kinematic explanation: there are some principles that lay out what can and cannot happen. In other words, empiricists solve the 'small' measurement problem, as Bub and Pitowsky would put it, of empirical adequacy. Most realists object that this position is not truly a realist one, but this is explicitly rejected by the proponents of these views. At the other extreme the three-dimensionalists, including the primitive ontologists, argue that one would not have finished their work until one completes quantum theory with a three-dimensional ontology. They use this ontology to provide a dynamical, reductive and constructive explanation of macroscopic objects, which amounts to more than just suppressing the macroscopic superpositions. They solve the 'big' measurement problem.

It is interesting now to consider the position in the middle, namely wave function realism. They do more than the empiricists because they want a precise solution of the measurement problem: they wish to eliminate macroscopic superpositions precisely, either by spontaneous collapse (GRW) or with decoherence (MW) or by supplementing the wavefunction (Bohm). In doing that, they provide a non-constructive explanation, by systematizing the data, just like the empiricists, but precisely rather than vaguely. Here's a table with the summary of the three types of realism.

Type of Realism	**Type of Problem**	**Acceptable Theory**	**Type of Explanation**
'Robust'	Completeness (3d ontology to allow for reductive explanation)	Primitive ontology (BM, GRWm, GRWf,….)	Constructive/dynamical
'Hybrid'	Precision (precise elimination of macroscopic superposition)	Pilot-wave theory, modified Schrödinger dynamics, many-worlds	Non-constructive (principle)/dynamical
'Weak'	Adequacy (empirically adequate elimination of macroscopic superposition)	Quantum mechanics with the von Neumann rule	Principle/kinematic

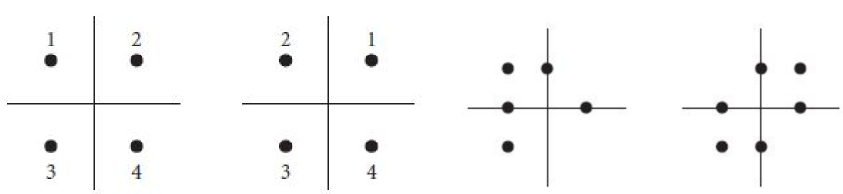
Notice how the wave function realists seem to lean too much towards empiricism: their approach reproduces appearances and systematizes the phenomena while they claimed they wanted more, as they claimed they wanted to find an understanding of the fundamental reality, like the three-dimensionalists do. If so, their theory should be dynamical and constructive. But their explanation of the macroscopic phenomena is instead fundamentally non-constructive, as wave function realists provide principles that would need to constrain the phenomena: Alyssa constrains the phenomena using symmetries However, wave function realists do not provide with a kinematic theory either, as they do care about the dynamics: they care about precisely getting rid of macroscopic superposition because they want a precise dynamical equation for all objects at all scales, not the von Neuman collapse for macroscopic object, and linear Schrödinger dynamics for the macroscopic ones. Also, Alyssa's account relies on the dynamics even if not constructively, by using the symmetries of the Hamiltonian (rather than its solutions) to recover three-dimensional appearances. Having a non-constructive explanation and giving importance to the dynamics seem to pull in opposite directions: the former pushes towards a 'relaxed' or 'weak' form of realism (like the empiricists), while the latter towards a 'robust' or 'strong' form of realism (like the three-dimensionalists and the primitive ontologists), making wave function realism a peculiar hybrid. There is in fact a tension between the desire of the wave function realist of a robust kind of realism, and the kind of explanation wave function realism actually provides, which is not constructive: she starts as a robust realist but she ends up close to the empiricists. If so, one may wonder *what the point of solving the measurement problem actually is*, if one can do without it, as the information-theoretical approach does. The point of solving the measurement problem was claimed to be to have a precise rule to specify the wave function collapse. But why would one want a precise rule if she cares only about the appearances? It seems one would care about the precision of the rule ultimately if she cares about the dynamics: it is because one wishes a unified dynamics which is applicable at all scales that one is interested on theories that precisely solve the measurement problem. However, why is the wave function realist interested in the dynamics, if they provide a non-dynamical explanation?

Relatedly, there is another problem for a wave function realist wishes to understand the macroscopic phenomena in terms of the microscopic ones, as it is done in statistical mechanics, in a constructive way. In other words: if someone wishes quantum theories to be about the wave function, then they should not be too attached to a constructive understanding in general, not only in quantum theory. However statistical mechanics constructively explains thermodynamics, and this arguably extends also to quantum statistical mechanics. But if the explanation provided by wave function realism is non-constructive, then there is a tension. How are these two explanations compatible? Alyssa argues that one goes from a point in the high-dimensional space of the wave function to three-dimensional general configurations (*via* symmetries) and then to three-dimensional macroscopic objects (*via* partial instantiation). Regardless of whether this strategy works, this is certainly nothing like the statistical mechanical reductive explanation of thermodynamics. So, to summarize, this non-constructive explanation combined with the importance given to the dynamics has two consequences. First, this approach is realist only in a weak sense, too similar to instrumentalism than I think a wave function realist would want. Second, it is unclear how to reconcile this non-constructive explanation with the constructive explanation in statistical mechanics, if one wishes to argue that the explanation of the laws of thermodynamics should not substantially change when moving from the classical to the quantum domain. Now, let me address my final point.

3-Symmetries

Alyssa criticizes, I think convincingly, the appeal to functionalism (which has been used by David Albert to recover three-dimensionality from configuration space) to reproduce three-dimensional objects and space, arguing that space cannot be functionalized, and then and she proposes her own account. As I have summarized above, she uses symmetries to select three-dimensionality as privileged, and then she argues that three-dimensional objects stand in a mereological relation with the wave function: they are parts of the wave function, namely the whole. Let focus on the first step. First, I want to share some concern over the feasibility of the account, Second, I want to observe how, if the argument that wave function realism is an account without symmetries pulls through, this undermines the whole strategy. Let me begin with the first point.

If symmetries are important, it should be clear what they are. Alyssa writes that this means that, for instance, the laws are indifferent with respect to whether the state is ψ_1 or ψ_2 (respectively clumped around P_1 and P_2 , where P_1 and P_2 are points the high dimensional space of the wave function. For $N = 12$, let's take these points: $P_1 = (-1,1,0,1,1,0,-1,-1,0,1,-1,0)$; $P_2 = (1,1,0,-1,1,0,-1,-1,0,1,-1,0)$). But what does it mean that laws are indifferent? Does it mean that ψ_1 and ψ_2 represent the same thing? Clearly this is not the case in the high-dimensional space, given that one is clumped around one point, and the other around another point. So, it has to mean that if we go to the three-dimensional representation, they are symmetric with respect to the particles' permutation. Namely, if we exchange the so-found particles, the state remains identical (except for the particle label). This is the whole point of Alyssa's account: the invariance in the law (indifference) corresponds to a symmetry *only* in the three-dimensional representation. In other words, only in three dimensions the particles in ψ_1 and in ψ_2 are identical, *modulo* an exchange between particles. Here's the drawing in the book for N=12:



Three-Dimensional Image

Two-Dimensional Image

However, the account seems circular to me. In fact, what makes the three-dimensional representation privileged is that the invariance in the high-dimensional dynamics corresponds to a symmetry only in three dimensions. That is, if a law is invariant, then only in the three-dimensional representation ψ_1 and ψ_2 are symmetric. But now let's ask: Where does the invariance of the law come from? It seems to come from the fact that the coordinates in the wave function are the three-dimensional positions of the particles: we give them this meaning because we observe three-dimensional configurations. But if so, then we are assuming what we are trying to prove, namely that three-dimensionality is privileged. In other words, Alyssa says that the high-dimensional invariance corresponds to a three-dimensional symmetry, and from this one should conclude that three-dimensionality suitably 'emerges' from the high-dimensional space. However, why does this invariance exist in the first place, if not because of the three-dimensional symmetry? That is, I would claim the opposite of what Alyssa says: the symmetry in three-dimensions is the symmetry we observe, and it is because of this symmetry that we justify the invariance of the law in the high-dimensional space of the wave function. In other words, the reason why we have invariance in the high-dimensional space is that we have symmetry in three-dimensional space, rather than, as Alyssa wishes to say, the reason for a three-dimensional symmetry is the invariance of the law in the high-dimensional space. Said it in another way again, the reason why we have a high-dimensional invariance is that we wish to preserve a three-dimensional symmetry. This is because, when we construct a theory, we require it to have symmetries in three-dimensions. We use that Hamiltonian because of the observations we make in three-dimensions; rather than there is a three-dimensional (nonfundamental) space because we have that Hamiltonian.

Another related point is the following. Assume that one could justify high-dimensional invariance non-circularly, and that symmetries successfully pick out three-dimensional representation as privileged. Nonetheless, there is an inconsistency in attributing importance to symmetries. In fact, on the one hand in Alyssa's account symmetries are of paramount importance to recover three-dimensionality. On the other hand, however, if the wave function is a field (in configuration space) then there is no reason to think that it would transform the way needed under symmetry transformations to preserve the symmetry. Consider Galilei invariance: under a velocity boost a field would merely be shifted in velocity, $\psi(x) \rightarrow \psi(x - vt)$, and not multiplied by some exponential factor (as needed to make the theory Galilei invariant). Also, consider time reversal invariance: a field would simply flip time, $\psi(t) \rightarrow \psi(-t)$, but it would not transform into its complex conjugate (as needed to make the theory time reversal invariant). So, if the wave function is a field, then non-relativistic quantum theory loses (at least) Galilean and time reversal symmetries. This is in itself already an objection, as symmetries have been successfully used in theory discovery and evaluation. Regardless, one could of course bite the bullet and embrace this consequence, like Albert does. This seems however problematical for Alyssa's account: on the one hand symmetries play a crucial role in recovering the three-dimensional objects, but on the other hand, in her account quantum theory has no symmetries. If so, we don't actually have three-dimensional objects, and the approach does not solve the macro object problem. If not, then there has to be some symmetries which are preserved. But which ones? This leads us back to the Hamiltonian, and the reasons why it is what is it: do we consider this Hamiltonian, with such-and-such invariances, because this is the best way to account for the observed motion of three-dimensional objects, or because we value symmetries in general and we tend to maximize them? If the former, then the account is circular: we do not justify the invariance, if not in terms of three-dimensionality. If the latter, then we cannot truly use the Hamiltonian to specify which symmetries should be true of the theory, and the account is lacking something.

These remarks conclude my comments. Having said that, the book is an outstanding piece of work, and certainly is an important step in understanding the nature of the world as told us by quantum theories, and in general a great lesson on how to do naturalized metaphysics.