Does a Whole Need to be Made Up of Parts?

An Analysis of "Quantum Entanglement, Bohmian Mechanics, and Humean Supervenience"

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Quantum theory has been proven useful for the past century as the best predictive technique for the outcomes of experiments on the atomic and subatomic level, helping mathematically explain wave-particle duality and the statistics behind measurements of such particles. However, interpretations of non-local behavior from Bell's inequalities and what exactly measurement entails can muddle any interpretation of the physics that is actually occurring. Of note, there exists a strain of thought known as Quantum Holism which claims that quantum mechanical systems can give rise to a failure of whole-part Humean Supervenience, necessitating a radical rethinking of classically applied metaphysical reductionism. In "Quantum Entanglement, Bohmian Mechanics, and Humean Supervenience," Miller argues that these claims are falsifiable within Bohmian interpretation of quantum phenomena, and that realism and separability can both be preserved without holism. In this paper, I will summarize Miller's argument, investigate context and broader questions surrounding her arguments, and critically evaluate points that seem less cogent to me.

Miller's argument can be divided into three parts: the first explaining how Lewis conceives of Humean Supervenience and the premises that Maudlin present towards the necessity of Quantum Holism, the second rejecting Maudlin's argument by introducing Bohmian ontology to seemingly troubling cases for separability in quantum mechanics, and the third tying in general holistic concerns within a synthesis of Humean Bohmianism.

David Lewis's studies in the philosophy of physics led him to his notion of Humean Supervenience, inspired by Hume's strong adherence to metaphysical reductionism along with empiricism in the 18th century. Lewis's adherence to reductionism pulls from the analytical notion of supervenience in what he calls whole-part supervenience; he describes the physical world as: "For short: we have an arrangement of qualities. And that is all. There is no difference

without difference in the arrangement of qualities. All else supervenes on that." Miller provides an analogy of this strongly physicalist and realist claim as the "Humean manifold" being like a "pointillist painting," wherein the complexity of the physical world emerges from just those points.

On the other hand, there has been a significant belief that the results of quantum mechanical experiments, under a realist assumption, pose a true threat to any sort of reductionism that Humean supervenience implies. Tim Maudlin, in particular, has stated that realism about quantum mechanics renders incompatibility with separability in Humean supervenience, which he defines to be the worldview where "the complete physical state of the world is determined by the intrinsic physical state of each spacetime point and the spatio-temporal relations between these points." Metaphysical holism, which Miller and Maudlin define to be the belief that "there exists some whole with intrinsic properties at a time that fail to supervene on the intrinsic properties of and spatio-temporal—i.e. spatial—relations between its point-sized parts at that time," hence posits a direct contradiction to separability. That whole which has holistic intrinsic properties that fail to supervene are in the physical state of the universe, so the universe cannot be separable.

Now Miller notes that Maudlin's most essential claim for holism and non-separability is that any minimally realist interpretation of quantum mechanics implies metaphysical holism. This is supported by an example experiment for entangled particle pairs. Maudlin considers a pair of particles split into left and right trajectories through stern-gerlach magnets at some spin orientation. In what is called the singlet state, there is a one-half probability of the left particle going up and the right particle going down and a one half probability of the left particle going down and the right particle going up. In contrast, the triplet state has a one-half probability of

both particles going up, and a one half probability of both particles going down. Here Maudlin would claim that the singlet and triplet states differ in some intrinsic whole (the wave function), but not in anything manifest in individual particle intrinsic properties or their relations between them. More specifically, Miller explores the types of ways that wave functions with the same individual parts can differ, categorizing three distinct modes of divergence. Type (a) differences are phase factor differences, type (b) differences are in symmetric transformations, and type (c) differences are all differences that are not type (a) or (b). Maudlin goes on to propose that any realist interpretation of quantum mechanics would mean that a type (c) difference in a system implies that there is an intrinsic difference between the systems.

Miller calls this proposition 1, with proposition 2 as "some entangled pairs are properly represented, at a time, by wave functions exhibiting a type-c difference even though there is no difference in the intrinsic properties of or spatio-temporal—i.e. spatial—relations between their single-particle parts at that time." These two propositions are Maudlin's metaphysical holism.

Miller then rejects proposition 1 using the Bohmian account of quantum mechanics. In this account, seeming quantum uncertainty is in reality just position-momentum uncertainty so that the guiding equation can take the true positions of all particles in the universe, along with the wave function, to deterministically predict motion. The spin state of a particle is non-intrinsic; for there to be quantum uncertainty in a particle's spin state is for there to be epistemic uncertainty in the position of the particle and measuring device.

Of note is the multiple ontologies that Bohmians propose. One by Albert, as described by Miller, is the existence of a single particle in high dimensional space (three times the number of particles in the universe) along with its wave function. Movement as described by the guiding equation is gyration of the particle, and the ordinary three-dimensional space we see is an

illusion. In this scenario, “realism” would mean an easy rejection of proposition 2, as the “real” single particle which quantum mechanics entails posits that the singlet and triplet pairs are actually part of the same particle, wherein system wave function differences can supervene upon that one universal particle. I touch more on this subject later in my later commentary.

The more standard Bohmian ontology consists of individual particles along with an ordinary spacetime manifold, along with the universal pilot wave function. For such a case, proposition 1 finds trouble for the singlet and triplet pair differences. Applying realism here to correlated and anti-correlated spins of the particle pair means that the difference in the system wave functions between the pairs is really just a difference in the particle and measuring device positions, hence restoring Humean supervenience on the relational properties of the particles. In general, any sort of type (c) difference in a system can be reduced to the intrinsic position of its parts. The Bohmian account here is hence a straightforward way to escape metaphysical holism, but there still remain certain questions Miller and I agree need greater thought. Why should we believe Bohmianism, and doesn’t the pilot wave being universal almost emulate holistic claims? For the former, Miller constructs a Humean Bohmian theory for readers to buy into that will be covered later.

Miller constantly emphasizes the misleading label of “guiding” in the guiding equation for good reason, as this way of thinking can make one perceive that the pilot wave function, which is a real physical entity, is pushing our particles around in space. But even if this particle-wave fundamentalism rejects proposition 1, it seems like the state of the world still cannot supervene on its particles properly when examining the pilot wave itself, at least for non-Albert ontology. Miller poses the question: “To what is the [wave function of the] universe relevantly related?” Regardless of the particles that exist in a universe, the wave function really only

provides probability distributions over trajectories, but given that only one actual list of trajectories obtains, it cannot be said that the wave function (and hence the global state) supervenes upon intrinsic relational differences between the particle mosaic.

The way to avoid such a holistic wave function is by treating it as nomological. Miller reiterates the argument by Goldstein and Zanghi that if the wave function were to be a physical law rather than a guiding entity, separability can thus be recovered. If the wave function is no longer a physical entity, then its supervenience need not be considered. This nomological treatment, however, can be anti-Humean in the sense that Lewis would also prefer facts to supervene on something empirical. This notion of physical statism is that "all facts about the world, including modal and nomological facts, are determined by its physical state." After all, facts must be encoded in the current fabric of reality since they must be able to predict the past and future of the universal closed system. Miller presents an argument against this possibility by treating the law of the pilot wave and guiding equation as merely descriptive and hence can be reduced to physical states of the universe.

Lastly, Miller constructs her thesis of Humean Bohmianism, or Bohumianism, which strictly adheres to Humean constructs of separability and physical statism. The insight here is to describe the pilot wave using the best system account (BSA) of Humean laws, wherein physical laws are a "summary of how the world evolves over time that strikes the optimal balance of simplicity and strength and perhaps other theoretical virtues." The wave function under this interpretation emulates our conception of masses and charges, which in reality can be divided into quarks and confusing subatomic particles, but under BSA can be thought of as actually real entities in the physical world. The wave function could also be thought of as similar to the Humean treatment of objective chance as a real nomological fact of the world. In this method,

we preserve separability through Bohmian particle fundamentalism, and we preserve physical statism by treating the pilot wave as a descriptive law of the world.

In terms of broader context, “Quantum Entanglement, Bohmian Mechanics, and Humean Supervenience” does a great job at elucidating that even in a highly technical domain like quantum mechanics, metaphysical claims such as quantum holism require metaphysical backing. The initial argument by Maudlin that realism in an experiential setting can induce an expansive metaphysical claim about how the death of reductionism is not sufficient since it fails to establish an ontology of the universe. Miller in a later work, “Two Notions of Holism,” goes onto note that the “traditional focus on whole-part supervenience failure distracts from a root disagreement on metaphysical structure and its role in our theorizing.” WIthout clearly establishing metaphysical structure for which physical entities and nomological facts sit upon, quantum theories become riddent with inconsistencies. The Humean Bohmianism that Miller proposes is thus a great foundation for further metaphysical claims in quantum mechanics—adherence to particle fundamentalism grounds a discussion about still confusing realities like non-locality.

However much I do agree with Miller’s theories, I do find troubling the broad definition applied to nomological facts and physical laws. Here, the best system account seems completely arbitrary and able to be construed for any purpose, and I think it to be not a valid statement for objective chance to exist within the Lewis’s conception of Humeanism. The purpose of physical statism as it applies to facts is for there to still retain some reductive notion, and for objective chance regarding dice rolling or other frequentist probability measures, physics already presents an obvious reduction to the mechanics of the dice itself. The law of chance does not seem to be a real law since there exists a more reductive law of Newtonian mechanics that explains chance phenomena much better.

And in general, to me I think that a physical law must require some sort of invariance. For every single physical law universally agreed upon, we have a sort of frame of reference and relative position invariance—laws of relativity and electromagnetism have equal suggestions for how things play out regardless of the frame of reference or relative position. On the other hand, treating the pilot wave as nomological fails to retain this invariance, as the universal wave function is uniquely defined at every point in space. If invariance was not needed for nomology, then would it not be valid to claim that everything is indeed just a physical law? After all, everything in the universe is certainly described by facts, so ditching invariance can allow one to think that it is really only the facts that are real, not what is being described.

But regardless, Miller's rejection of quantum holism through Bohmianism explores and further reveals many avenues for which metaphysical claims for quantum mechanics need investigation. It would be a disservice for philosophers to stop considering these problems, as more than ever, what the universe actually is at the particle level can help ground something in this chaotic world.

Reflection

I thought that this class was great and really enjoyed the self-guided aspects. I can confidently claim that I enjoyed the seminars in this class more than any other class at Brown—there were few statements made without much backing, all the individuals seemed genuinely engaged in discussion, and the vibe of the discussion truly felt free flowing—I am glad to have had these experiences before leaving Brown. Something that I personally have an idealized conception of is the Viennese coffee shop, wherein scholars and even common folk from all walks of life would congregate and discuss the thousands of new scientific ideas, ideologies, philosophies, and cultural aspects that were prevalent throughout continental Europe in the late 19th and early 20th centuries. This is obviously not a picture-perfect representation of the history of the time, but I can claim that I really felt like this class embodied the same spirit of curiosity that I conceive.

For the final assignment itself, I unfortunately had many other commitments going on for my final term that I had to value for future academic and vocational purposes over this. I do think the topic I chose of Quantum Holism was an interesting one, but I do know that my resulting paper is not the best work I could do. I troublingly spent 80% of the paper just summarizing your article "Quantum Entanglement, Bohmian Mechanics, and Humean Supervenience" since it was so material dense and not covered in previous readings in the class. If I had more time and mental capacity, I would certainly try expanding much more on the 20% where I reference broader questions and my own thoughts. I also didn't have time to add in-line citations, so hopefully that doesn't matter too much.

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