

Does Bohmian mechanics solve the measurement problem? Maybe not yet

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Abstract

It is widely thought that Bohmian mechanics solves the measurement problem by assuming that an observer's conscious perception of a measurement result is determined by the evolution of the Bohmian particles of her brain. In this paper, I present an argument against this received view. It is argued that when assuming that (1) quantum entanglement plays no role in our brain in forming our conscious perceptions and (2) a system whose elements have no causal connections does not have conscious minds, Bohmian mechanics fails to provide an explanation of our determinate conscious perception of the measurement result since observers in the theory cannot form conscious perceptions. This means that before we find plausible reasons to reject one or both of these two common assumptions in neuroscience and philosophy of mind, Bohmian mechanics does not solve the measurement problem.

Key words: Bohmian mechanics; measurement problem; particle; entanglement; observer; conscious perception

1 Introduction

Bohmian mechanics or the pilot-wave theory of de Broglie and Bohm provides an ontology of quantum mechanics in terms of particles and their trajectories

in space and time (de Broglie, 1928; Bohm, 1952). In order to solve the measurement problem (in a way different from the many-world interpretation), Bohmian mechanics assumes that the result of a measuring device is determined not by the branch of the post-measurement wave function in which its Bohmian particles reside, but by the configuration of its Bohmian particles. Moreover, an observer's conscious perception of a measurement result is also determined by the evolution of the Bohmian particles of her brain (Maudlin, 1995; Brown and Wallace, 2005; Lewis, 2007; Lazarovici, 2020; Oldofredi, 2021). In this paper, I will present an objection to this result assumption. It is argued that when assuming that (1) quantum entanglement plays no role in our brain in forming our conscious perceptions and (2) a system whose elements have no causal connections does not have conscious minds, observers in Bohmian mechanics cannot form conscious perceptions, and thus the theory fails to provide an explanation of our determinate conscious perception of the measurement result. This means that in order to solve the measurement problem, Bohmian mechanics must reject one or both of these two common assumptions in neuroscience and philosophy of mind, which seems to be a difficult task.

2 Bohmian particles, shadows and puppets

In Bohmian mechanics, a complete realistic description of a quantum system is provided by the configuration defined by the positions of its particles together with its wave function. The law of motion is expressed by two equations: a guiding equation for the configuration of particles and the Schrödinger equation, describing the time evolution of the wave function which enters the guiding equation. The law of motion can be formulated as follows:

$$\frac{dQ(t)}{dt} = v^{\Psi(t)}(Q(t)), \quad (1)$$

$$i\hbar \frac{\partial \Psi(t)}{\partial t} = H\Psi(t), \quad (2)$$

where $Q(t)$ denotes the spatial configuration of particles, $\Psi(t)$ is the wave function of the particle configuration at time t , and v equals to the velocity of probability density in standard quantum mechanics.

It is widely thought that Bohmian mechanics solves the measurement problem by assuming that the result of a measuring device is determined by the configuration of its Bohmian particles, and an observer's conscious

perception of a measurement result is determined by the evolution of the Bohmian particles of her brain (Maudlin, 1995; Brown and Wallace, 2005; Lewis, 2007; Lazarovici, 2020; Oldofredi, 2021). However, even though the result of a measuring device can be stipulated to be determined by the configuration of its Bohmian particles, it is not obvious that we can also make a similar stipulation for conscious observers without further justification.¹ Indeed, it has been argued that this result assumption for observers is inconsistent with certain theories of conscious perceptions such as functionalism (Brown and Wallace, 2005; Gao, 2019, 2022b). This may be not a major concern for many Bohmians, since they can deny functionalism (Lazarovici, 2020). But there is still one question that needs to be answered. It is: what theory of conscious perceptions is required by this result assumption for observers?

In order to answer this question, we need to know what the Bohmian particles really are. The Bohmian particles have positions and velocities in three-dimensional space. According to an influential view, Bohmian mechanics is committed only to particles' positions and a law of motion, and these particles have no mass, charge and other properties other than positions and velocities (Dürr, Goldstein and Zanghì, 1997; Allori et al, 2008; Esfeld et al, 2014; Goldstein, 2021). Moreover, the Bohmian particles have no interactions or causal connections with each other (when their effective wave function is not an entangled state).² Concretely speaking, for an effective product state of a many-body system, the motion of a Bohmian particle neither depends on other Bohmian particles nor affects the motion of other Bohmian particles; the motion of a Bohmian particle is determined only by its effective wave function, which is independent of other Bohmian particles of the system. In particular, a Bohmian particle may escape to infinity or disappear (when its effective wave function has nodes and it reaches a node), and its escape or disappearance does not affect the motion of other Bohmian particles either.

Let's compare the Bohmian particles with two familiar things: shadows and puppets. Shadows have the shapes and velocities of objects, but they have no other physical properties of objects such as mass and charge. Shadows always move with the objects they belong to. When objects interact with

¹As Lewis (2022) recently said, "Whatever the philosophical status of experience, the mental-physical connection is not something that philosophers or physicists can posit at their convenience."

²The effective wave function is the Bohmian analogue of the usual wave function in standard quantum mechanics. It is not primitive but derived from the universal wave function and the actual spatial configuration of all the particles ignored in the description of the respective subsystem (Dürr, Goldstein and Zanghì, 1992). Note that only this unentangled case is relevant to my following analysis.

each other, their shadows also appear to interact with each other. But there are no causal connections and interactions between shadows. The motion of one shadow does not affect the motion of other shadows. Moreover, the shadow of an object may disappear (when there is no light illuminating the object), and its disappearance does not affect the motion of other shadows either. When including both the wave function and the Bohmian particles in the ontology of Bohmian mechanics, the Bohmian particles are like shadows of the effective wave functions (when the entanglement between the effective wave functions can be ignored).

Take cats as an example. The (typical) Bohmian particle configuration of a cat has the shape of a cat, but it has no other properties of a cat represented by its wave function, such as mass, temperature and color etc. The Bohmian particles of a cat always move with the wave function of the cat.³ When two cats fight with each other and their wave functions interact with each other, their Bohmian particles also appear to interact with each other. But there are no causal connections and interactions between the Bohmian particles of the two cats. The motion of the Bohmian particles of one cat has no causal consequences upon the motion of the Bohmian particles of the other cat. The Bohmian particles of one cat may escape to infinity or disappear (when they reach a node of the wave function of the cat), and their escape or disappearance does not affect the motion of the Bohmian particles of the other cat.

When there are only Bohmian particles in ontology, these particles are more like puppets than like shadows. Puppets are controlled by a unified force, just like the Bohmian particles whose motion is governed by the universal wave function being a law (on the nomological view). Also like the Bohmian particles, puppets have no causal connections and interactions with each other. The motion of one puppet does not affect the motion of other puppets. A puppet can be removed, and its removal does not affect the motion of other puppets either.

³There have been worries about the reality of the wave function, since it is defined in a high-dimensional space, not in our three-dimensional space. This is also a main reason of why some Bohmians remove the wave function from the ontology of Bohmian mechanics (see, e.g. Esfeld et al, 2014). However, the wave function does not necessarily represent a physical entity in a high-dimensional space, and there are also ontological interpretations of the wave function in three-dimensional space such as the multi-field interpretation (Hubert and Romano, 2018) and the RDM of particles interpretation (Gao, 2017, 2020, 2022a).

3 A common assumption about the conscious mind

Our brain can generate the mind and make us have conscious experiences. But few people would think that a group of shadows or puppets, which mimics the neural activities in our brain, can also generate the mind. What is the essential difference between shadows or puppets and neurons? It is that there are (strong) causal connections and interactions between neurons, but there are no causal connections and interactions between shadows or puppets. The motion of every shadow or puppet does not affect the motion of other shadows or puppets. Removing any shadow or puppet does not affect the motion of other shadows or puppets either. But the activity of every neuron affects the activities of nearby neurons, and removing any neuron will also affect the activities of nearby neurons in general.

Today it is a common assumption in neuroscience and philosophy of mind that the parts of a system must have strong causal connections with each other so that it can generate the (highly) conscious mind. This makes sense, since if a system whose parts have no causal connections with each other can also generate the conscious mind, then the whole universe will have only one mind, not many minds as our human beings have. By comparison, the requirement of strong causal connections between the parts of a conscious system defines the boundary of different minds and permits the existence of many minds. One of the leading theories of consciousness is the Integrated Information Theory of consciousness (IIT) (Tononi, 2008, 2015; Fallon, 2022). According to IIT, consciousness requires a grouping of elements within a system that have physical cause-effect power upon one another, and the (de)activation of all or most elements has many causal consequences upon the (de)activation of other elements. The level of consciousness of a system is described by the integrated information of the system, which can be represented by a precise mathematical quantity Φ . A system whose elements have strong causal connections will have high Φ , while a system whose elements have weak causal connections will have low Φ . Our brain has very high Φ , and it is therefore highly conscious. By contrast, as for a system composed of shadows or puppets, since there are no causal connections between these shadows or puppets, the system will have zero Φ , which means that it is not conscious at all.⁴

⁴Another popular example is digital camera's photodiodes. Since all the photodiodes are in isolation from each other, the system does not integrate information and has zero Φ .

4 Can a Bohmian brain generate the conscious mind?

Now let's turn to the key issue: what if our brain is composed only of the Bohmian particles? can this Bohmian brain generate the conscious mind? We need another common assumption in neuroscience and philosophy of mind to answer this question. It is that our conscious mind is generated by the activities of some quasi-classical systems such as neurons in our brain without involving quantum entanglement. Due to environment-induced decoherence in our brain (see, e.g. Tegmark, 2000), the effective wave function of these quasi-classical systems is a product state, or in other words, each system has its own effective wave function or wavepacket, and the motion of its Bohmian particles is guided only by its wavepacket.

Then, as for shadows and puppets, we can similarly argue that such a Bohmian brain cannot generate the conscious mind. For example, according to IIT, a Bohmian brain will have zero Φ and thus it does not have conscious experiences, since there are no causal connections between the Bohmian particles of the nonentangled quasi-classical systems in the brain, and the whole system does not integrate information.

In fact, one can also argue that our brain cannot be composed only of the Bohmian particles or the neurons in our brain cannot be modeled by the Bohmian particles. The reason is that the removal of a Bohmian particle (e.g. when this Bohmian particle escapes to infinity or reaches a node of its wave function) does not affect the motion of other Bohmian particles, but the removal of a neuron will affect the activities of nearby neurons in general.

This result is against the received view. For example, according to Maudlin (1995), the correlation between the particle configuration in the observer's brain and the particle configuration of the measured system is *sufficient* for the observer to know the result of the measurement. However, as I have argued above, the correlation is necessary but not enough. Although the particle configuration in the observer's brain is definite and it also has a correlation with the particle configuration of the measured system, the brain composed of these particles may not form conscious perceptions due to lack of causal connections between these particles. If this is true, then Bohmian mechanics does not provide an explanation of our determinate perception of the measurement result, which means that the theory fails to solve the measurement problem.

5 How can Bohmian mechanics solve the measurement problem?

There are two possible ways to avoid the above result. One way is to insist that Bohmian brains can generate conscious minds even though there are no causal connections between the Bohmian particles. In this case, one must reject the common assumption that the parts of a system must have strong causal connections with each other so that it can generate the conscious mind. In particular, one must also admit that a group of shadows or puppets, which mimics the neural activities in our brain, can also generate the conscious mind. I think few people would take this step.

The other way is to conjecture that our conscious mind is not generated by the activities of some quasi-classical systems such as neurons in our brain, but generated by the quantum activities of some smaller systems in our brain which involve quantum superposition and entanglement (see, e.g. Hameroff and Penrose, 1996, 2014). In this case, the Bohmian particles for entangled states will have nonlocal connections, and the brains composed of these particles may be able to integrate information. Then IIT may also predict that such Bohmian brains can generate conscious minds. However, one must reject the common assumption that quantum entanglement plays no role in generating the conscious mind. Moreover, one also needs to construct a quantum theory of brain/mind to see if Bohmian brains in the theory can indeed generate conscious minds. Maybe some Bohmians would like to choose this way.

6 Conclusion

It has been a received view that Bohmian mechanics can solve the measurement problem by assuming that an observer's conscious perception of a measurement result is determined by the evolution of the Bohmian particles of her brain. In this paper, I argue that, contrary to the received view, when assuming that (1) quantum entanglement plays no role in our brain in forming our conscious perceptions and (2) a system whose elements have no causal connections does not have conscious minds, Bohmian mechanics fails to provide an explanation of our determinate conscious perception of the measurement result. It remains to be seen if Bohmian mechanics can solve the measurement problem by rejecting one or both of these common assumptions in neuroscience and philosophy of mind.

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