Uncomputable UV-complete theory and hidden variables interpretations beyond Bohmian particle mechanics

William Icefield

(Dated: July 21, 2020)

Abstract

When statistical models are used in social sciences, there is no presumption that actual reality is stochastic. Even if actual reality is deterministic, hidden and unobservable variables require a use of effective (in ordinary language, approximate) models, with number of variables potentially unrestricted. From the quantum reconstruction point of view, quantum mechanics can be interpreted as a statistical information-processing framework - therefore, the aforementioned view in social sciences can naturally be transported to quantum physics - this especially so given prevalent uses of effective theories. This naturally gives us the common framework behind hidden variables interpretations unconstrained by particular laws of deterministic motion. The measurement problem is cleanly identified as arising from missing hidden variables. However, hidden variables interpretations do not imply that a final UV-complete theory of physics has to be usable - the theory may be uncomputable, with inability to generate predictions. In such a case, an infinite sequence of effective quantum theories would have to be used. Therefore, even if hidden variables interpretations are correct, supremacy of the orthodox quantum mechanics framework may be upheld, which is supported by a combination of quantum reconstruction and computational complexity arguments. This allows us to bypass considerable difficulties of hidden variables interpretations in satisfying Lorentz invariance. Connections to entropic gravity are then explored.

Keywords: hidden variables interpretations of quantum mechanics, measurement problem, Bohmian mechanics, computable theory, effective theory, Lorentz invariance, quantum reconstruction, computational complexity, entropic gravity

CONTENTS

I. INTRODUCTION

There is a curious state of affairs in an understanding of quantum mechanics. In social sciences, a quantitative statistical model is used to make predictions but no one assumes that underlying reality has to be stochastic. It is missing variables we cannot fully account for that generate stochastic dynamics from roughly deterministic reality. As can be noted, what is meant by ‘missing variables’ would be interpreted more generally than the particular Bohmian concept of missing variables.

Somewhat surprisingly given above, quantum physicists are heavily averse to hidden variables interpretations. (And in some ways, rightly so, as we would come to see.) This is despite the fact that somewhat fundamental quantum theories in use are effective (in ordinary language, approximate) theories that can essentially be recast as theories with missing variables or missing information that a final theory of physics would provide. Therefore, this amounts to the belief that a final theory of physics has to be a quantum theory in sense that it is not a deterministic theory but a probabilistic theory.

A problem begins to occur though: for a final UV-complete quantum theory, how would the measurement problem be resolved? In particular, how would a measurement basis be determined? [1] A hidden variables interpretation provides an easy way out for the measurement problem, whether the issue is state (wavefunction) collapse or measurement basis - it is neglected hidden variables that generate the issue. This is one reason why despite the charge that Bohmian mechanics is an Everettian (many-worlds) interpretation in disguise [2, 3], Bohmnian mechanics is different from an Everettian interpretation.

Furthermore, the quantum reconstruction program that generates the quantum mechanics framework from epistemic requirements [4–6] suggests that the aforementioned statistics story is worth considering. After all, if the quantum mechanics framework is just a theory of inference and probability, why would it not be usable for naturally occurring 'missing variables' epistemic contexts?

It is then said that hidden variables interpretations do not work because of famous no-go theorems, such as the Kochen-Specker theorem [7–10]. However, these theorems actually state that hidden variables interpretations have to be contextual. Contextuality is then simply understood as a straightforward point that measurement results depend on how measurements are performed. Measurement processes change nature, which is why contextuality arises. This is how quantum physics and its hidden variables generalization are different from classical physics, where effects of measurement processes can often safely be assumed to not exist. [11–13]

Given this introductory context, the general hidden variables framework is explored that avoids difficulties hidden variables interpretations have in satisfying Lorentz invariance. The possibility of a UV-complete but uncomputable final theory is presented. When a final theory of physics is UV-complete but uncomputable, even if this theory is deterministic, quantum supremacy is upheld - for matter of making predictions and testing them, an infinite sequence of effective theories that are UV-incomplete but computable is inevitable. As argued in [14], there is no good a priori justfication as to why a theory of quantum gravity has to be a final UV-complete theory.

A combination of quantum reconstruction [4–6] and computational complexity arguments [15] is presented as to defend the quantum supremacy argument - even if a hidden variables interpretation is the correct view of quantum mechanics then, nothing may be extracted from additional features of a hidden variable interpretation since a final deterministic theory is uncomputable. We may be condemned to the orthodox quantum mechanics framework for all practical matters.

II. GENERAL HIDDEN VARIABLES FRAMEWORK

'The' single problem with Bohmian mechanics is that there is great difficulty in generalizing it to reproduce quantum field theories. This is because Bohmian particle mechanics is quite tied with the notion of particles due to its guiding equation, and how the guiding equation should be generalized to fields or be modified remains very unclear. [16] This is made harder by the fact that many attempts try to find a deterministic theory that directly reproduces known quantum field theories.

Suppose that, given the aforementioned difficulties, there indeed exists no deterministic theory that can be demonstrated to reproduce all empirical quantum field theories. Would this mean that deterministic hidden variables interpretations are dead? The answer is no - inability of demonstration does not equate to there being no such theory. This is about whether a theory is computable or not.

A. UV-complete but uncomputable theory

It may be that despite a deterministic theory indeed being a final theory of the universe, such a theory may not be computable as to provide us predictions. In such a case, all direct generalization attempts to produce a satisfactory deterministic theory are, for sure, bound to fail.

Instead of trying to derive a particular determinsitic theory then, we may instead look at the general framework by which hidden variables interpretations would work.

As the name implies, hidden variables suggest that there are variables we do not know well which create epistemic uncertainties that result in stochastic appearance. Just as in social sciences contexts, for empirical or explantory simplification reasons, some variables are not fully accounted in model or theory T_i. As we come to incorporate these variables, we get a more fundamental theory T_{i+1}, T_{i+2} and so on. There is no guarantee that a final deterministic theory can be computed and used for predictions with finite procedures.

For all practical purposes then, there is an infinite sequence of effective quantum (probabilistic) theories that define reality. Given finite constraints of our experience, we are condemned to discover only some of these effective theories, one more fundamental than the other.

B. Computational complexity and information processing constraints

It is intuitively easy to suspect that a hidden variables theory allows for computational advantages over conventional classical and quantum computers, given that a hidden variables theory would replicate a usual quantum theory despite being deterministic. This has in fact been theoretically explored in [15] with affirmation.

However, it is known that under reasonable informational constraints [4–6], a quantum theory may uniquely be reconstructed as a theory of probability and inference. Thus, it may seem that there must be some informational constraint underlying a quantum theory that a hidden variables theory must violate.

There is a way out though - if one is banned from accessing additional computational advantage of hidden variables, then the problem disappears. And indeed this is what happens when a final deterministic hidden variables theory is uncomputable. There may be other ways out, but these would all require providing finite specifications of a hidden variables theory that, as far as our current knowledge goes, all break down eventually due to quantum field theory issues. Furthermore, inaccessibility of hidden variables mostly amount to inevitability and supremacy of the orthodox quantum framework anyway.

The above quantum reconstruction - epistemic and information-theoretic constraint - point of view subsumes discussions about Lorentz invariance in relation to hidden variables theories as well. Different approaches to quantum reconstruction that point to uniqueness of a quantum theory can suggest how Lorentz invariance is a consequence of different epistemic principles, instead of itself having to be postulated. If so, then likely violation of Lorentz invariance is a heavily serious issue for a computable hidden variables theory, explaining away why it cannot satisfactorily reproduce known quantum field theories. And in such a case, even if a computable hidden variables theory satisfies Lorentz invariance, it either has no practical advantage over the orthodox quantum mechanics framework or is non-existent.

C. Ontic versus epistemic?

The idea of an uncomputable UV-complete final theory answers the question of what a purely epistemic interpretation [17] of quantum mechanics that denies ontological reality would mean. After all, would not knowledge require some underlying reality?

In case a final theory is uncomputable, one may respond as follows. One may choose to re-interpret a purely epistemic interpretation in terms of the hidden variables framework. There, it is postulated that there are infinitely many hidden variables. Therefore, we have no finite means of stating or specifying ontological reality. This condemns us to the project of epistemology instead of ontology. At best, we may assume that the sum of knowledge from an infinite sequence of effective quantum theories constitute deterministic yet inaccessible reality. That is, one is asserting that a quantum theory is inevitably effective and incomplete. In this sense, it makes no sense to think of each quantum state as a real entity.

D. Notion of spacetime in hidden variables interpretations

Recent entropic gravity approaches suggest an interesting possibility: gravity and spacetime may be a result of epistemic considerations. Once entropic data for matters are available, then in the semi-classical regime, one derives the Einstein field equations under the entropy extremization principle. [18]

Having asserted that a quantum theory necessarily is effective and epistemic, it may equally be argued that spacetime and gravity are only of provisional and epistemic nature - they are not part of concrete ontological reality. This is especially so if gravity needs to be captured in the quantum physics framework.

Depending on an effective theory then, spacetime and gravity can appear quite differently from each other. That is, depending on an observation scale, how we would experience spacetime may change. Note that the entropy extremization principle may be justified via reasonable epistemic axioms in [19].

III. CONCLUSION

A usual understanding of a probabilistic model naturally suggests a hidden variables interpretation of quantum mechanics, especially given uses in social sciences. However, quantum reconstruction arguments based on information processing and epistemic constraints suggest that a computable hidden variables (deterministic) theory is infeasible, together with a computational complexity argument. This suggests that the most natural conclusion is: a final UV-complete theory is uncomputable. In social science contexts, underlying potentially deterministic reality is never assumed to have finite number of hidden variables, so essentially uniform lessons apply for both social and natural sciences.

Under a final UV-complete theory that is uncomputable, the best we can do is an infinite sequence of effective quantum theories. The hidden variables framework offers a straightforward reason as to why the measurement problem arises - hidden variables cause it. Yet because a final theory is uncomputable, we cannot completely track and pin down the exact source of the measurement problem. As an effective theory, each quantum theory is to be interpreted in an epistemic way - quantum state is not a real entity.

This suggests that gravity may also only be of epistemic nature, given that gravity is considered to require the quantum physics framework. Then depending on an observation scale, how a subject experiences spacetime may differ.

DECLARATION OF INTERESTS

The authors confirm that no additional statement, such as conflicts of interest, is required.

---

[1] Maximilian Schlosshauer, "Decoherence, the measurement problem, and interpretations of quantum mechanics," Rev. Mod. Phys. **76**, 1267–1305 (2005).

[2] David Deutsch, "Comment on Lockwood," The British Journal for the Philosophy of Science **47**, 222–228 (1996).

[3] Harvey R. Brown and David Wallace, "Solving the Measurement Problem: De Broglie-Bohm Loses Out to Everett," Foundations of Physics **35**, 517–540 (2005).

[4] Borivoje Dakic and Caslav Brukner, "Quantum theory and beyond: Is entanglement special?" in *Deep Beauty: Understanding the Quantum World through Mathematical Innovation* (Cambridge University Press, 2011) pp. 365–392.

[5] Rob Clifton, Jeffrey Bub, and Hans Halvorson, "Characterizing quantum theory in terms of information-theoretic constraints," Foundations of Physics **33**, 1561–1591 (2003).

[6] Giulio Chiribella, Giacomo Mauro D'Ariano, and Paolo Perinotti, "Informational derivation of quantum theory," Phys. Rev. A **84**, 012311 (2011).

[7] Simon Kochen and E. P. Specker, "The Problem of Hidden Variables in Quantum Mechanics," Journal of Mathematics and Mechanics **17**, 59–87 (1967).

[8] Andrew M. Gleason, "Measures on the Closed Subspaces of a Hilbert Space," Journal of Mathematics and Mechanics **6**, 885–893 (1957).

[9] John S. Bell, "On the Einstein Podolsky Rosen paradox," Physics Physique Fizika **1**, 195–200 (1964).

[10] John S. Bell, "On the problem of hidden variables in quantum mechanics," Rev. Mod. Phys. **38**, 447–452 (1966).

[11] David Z. Albert, *Quantum Mechanics and Experience* (Harvard University Press, 1992).

[12] David Bohm and Basil J. Hiley, *The Undivided Universe: An Ontological Interpretation of Quantum Theory* (Routledge & Kegan Paul, 1993).

[13] John S. Bell, "On the Impossible Pilot Wave," Foundations of Physics **12**, 989–999 (1982).

[14] Karen Crowther and Niels Linnemann, "Renormalizability, Fundamentality, and a Final Theory: The Role of UV-Completion in the Search for Quantum Gravity," The British Journal for the Philosophy of Science **70**, 377–406 (2017).

[15] Scott Aaronson, "Quantum computing and hidden variables," Phys. Rev. A **71**, 032325 (2005).

[16] Tim Maudlin, *Quantum Non-Locality and Relativity: Metaphysical Intimations of Modern Physics* (Blackwell, 1994).

[17] Matthew Saul Leifer, "Is the Quantum State Real? An Extended Review of ψ-ontology Theorems," Quanta **3**, 67 (2014).

[18] T Padmanabhan, "Thermodynamical aspects of gravity: new insights," Reports on Progress in Physics **73**, 046901 (2010).

[19] J. Shore and R. Johnson, "Axiomatic derivation of the principle of maximum entropy and the principle of minimum cross-entropy," IEEE Transactions on Information Theory **26**, 26–37 (1980).