quantum reports

Editorial

The Many-Worlds Interpretation of Quantum Mechanics: Current Status and Relation to Other Interpretations

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This is a preface to a Special Issue of *Quantum Reports* devoted to the results of the workshop "The Many-Worlds Interpretation of Quantum Mechanics: Current Status and Relation to Other Interpretations" [1]. As I said in my contribution written before the conference [2], I was optimistic about bringing the MWI closer to consensus. More than two decades ago, I wrote an entry in the Stanford Encyclopedia of Philosophy on the MWI [3]. It is well cited, with very few critical notes, so I gathered the impression that what I presented there is the MWI as viewed by the community. The conference, which brought together a significant part of the community, showed that I was very wrong about that. There were many interesting discussions, but what I learned is that there is a striking diversity of views about the MWI.

I saw many radically different understandings of the concept of a world even among the most enthusiastic proponents of the MWI such as Deutsch, Wallace, Saunders and myself. Contrary to others, I do not consider decoherence with the environment as a definition of world-splitting. In my view, the universe is a superposition of worlds in which all macroscopic objects are well localized; i.e., it is a collection of classical worlds. Deutsch [4], however, writes,

> ... if reality—which in this context is called the multiverse—is indeed literally quantum-mechanical, then it must have a great deal more structure than merely a collection of entities each resembling the universe of classical physics.

Apart from a different semantics—"multiverse" instead of "universe" and "universe" instead of a "world"—this quote presents a very different view.

Saunders [5] views "worlds" within "decoherent histories" formalism rooted in the quantum description itself; this is completely different from my approach, in which a "world" is a concept of an agent that helps to explain her experience. Bigaj [6], who analyzes the consistent histories formalism, writes,

> It seems to me that the only realist, objectual interpretation of a framework is that frameworks refer to some observer-independent and distinct realities. It is hopefully not too far-fetched to call these realities "worlds"

Ridley's [7] counterparts of worlds are

> distinct time-localized 'universes' existing at single times [8] ... built out of parts with opposite time orientations.

Waegell [9] admits that his "local space-time model"

> is fundamentally different from the many-worlds theory of Everett, which is delocalized in the configuration space and describes global worlds in a particular Lorentz frame.

Waegell's contribution complements several works presented in the conference attempting to build local (separable) quantum mechanics. These include Bedard [10], Rubin, Kuypers [11], Tappenden and Faglia.

Citation: Vaidman, L. The Many-Worlds Interpretation of Quantum Mechanics: Current Status and Relation to Other Interpretations. *Quantum Rep.* **2024**, *6*, 142–146. https://doi.org/10.3390/quantum6020011

Received: 16 April 2024
Accepted: 17 April 2024
Published: 18 April 2024

My reading of Wallace [12] is that worlds are effectively autonomous branches, the mutual independence of which is ensured by decoherence:

> ... [the universe] must be understood as describing a multiplicity of approximately classical, approximately non-interacting regions which look very much like the 'classical world'.

This is a widespread view; see, for example, the review of Allori [13] from which I took Wallace's last quotation. More than two decades ago, Wallace [14] wrote,

> Everettians [...] may legitimately and meaningfully use the terminology of many worlds without being required to represent these worlds in their formalism.

This resonates with the statement of Lu [15]:

> The existence of a world is approximate and could be vague and indefinite in EQM.

Lazarovici [16] writes,

> there are many different interpretations of the Many-Worlds interpretation ... but even the best-elaborated ones remain vague about how the theory is supposed to make contact with familiar physical reality. I consider this the most serious problem of Everettian quantum mechanics.

The vagueness of the concept of a world in the MWI is a serious problem, but in the workshop, we witnessed even more radical proposals. Cuffaro and Hartmann [17] proposed to change the standard approach in physics which starts with closed systems by taking open systems as the basic concept. In this view, the systems in a world and the worlds themselves are described by density matrices instead of pure states. Chen [18] also prefers the density matrix description, but speculates that the world is "strongly" deterministic, a proposal that resonates with the superdeterminism discussed by Argaman. Zwirn [19] suggested adopting "Convivial Solipsism":

> We need to abandon our usual picture of the world. Reality is entirely relative to each observer, and there exists no absolute reality that could be shared by all observers.

Vedral [20] introduces the q-wave function and states:

> The worlds only emerge fully when we have fully orthogonal states of observers ... each alpha particle tract is orthogonal to every other one, which means that you can think of them as different worlds.

Note that this is very different from my approach, in which worlds should differ by macroscopic changes in macroscopic objects. Papineau and Rowe [21] adopt

> the "fission programme" version of Everettianism. In this version, which was originally adopted by Everett himself and is endorsed by perhaps the majority of his followers, any quantum "collapse" is followed by the macroscopic objects involved, including any observers, "splitting" in a way that results in actual "branches" for all outcomes with a non-zero probability.

Arve [22] writes,

> ... what is real is not directly represented by the wavefunction but by the gauge invariants. ... The success of describing our observations of physical systems and experiments with only the wavefunction gauge invariants demonstrates that a primitive ontology is not necessary.

Tappenden [23] instead suggests

> ... interpreting the universal wavefunction as representing a set of interacting deterministic universes which contain microscopic local beables. Objects in our environment become sets of objects which are macroscopically isomorphic but differ in their microscopic configurations. They are set-theoretically extended in configuration space, so to speak.

Stoica [24] also writes about local beables:

> The local beable ontology of the wavefunctional suggests interpreting these linear combinations as multiple ontic states coexisting in parallel. Since a macrostate is an equivalence class of microstates, probabilities arise by taking into account the possible microstates in each macrostate.

Willhelm [25], in order to solve the probability problem of the MWI, promotes a "centered Everett interpretation", which relies on a particular

> metaphysics of branches and agents: both branches and agents are four-dimensional entities. They extend through time as well as through space. So they are often called 'spacetime worms', and this view of branches and agents is often called the 'worm view'.

The "worm" view corresponds to a divergent world view, which I find meaningless without adding ontology on top of the wavefucntion, which Willhelm denies. He claims to refute my argument by stating that his concept is linguistically coherent, so it cannot be meaningless.

Several interesting talks (which can be viewed on the conference website [26]) were not published in this proceedings because they were published elsewhere. Aharonov [27] preferred an alternative to Everett's MWI. He proposed a solution of the measurement problem that avoids many worlds by postulating the future boundary condition. Gisin [28,29] presented the view that many worlds can be found even in classical physics, which, contrary to consensus, is not a deterministic theory. Maudlin [30] extended his criticism of the ability of the MWI to explain our world due to the onotology of the wavefunction being in the configuration space.

Other speakers questioned the validity of the MWI by analyzing particular experiments which they argued are challenging for the MWI. Elitzur [31] discussed a surprising interferometric experiment with "disappearing" particles. Renner [32] discussed a gedanken Wigner's friend experiment, and Jordan [33] suggested a feasible demonstration of a related interference experiment.

In my opinion, the fact that the MWI avoids action at a distance is its greatest advantage. Ney [34] discussed nonlocality in different metaphysical approaches to worlds in the MWI. Another major issue is probability in the MWI. Page [35] presented an approach inspired by cosmology. Saunders [36] suggested solving the problem by branch counting. I, however, do not see how this can be possible, and moreover, I claim that in the framework of the MWI, one cannot ask the question: What is the probability of a particular outcome of a quantum measurement? The question has no meaning since all outcomes take place. In my understanding of probability, it should be a unique matter of fact to talk about its probability. The comment of Saunders that if this question is meaningless, then the MWI will never be in the consensus does not persuade me, but I admit that it will take a long time. I hope it will be faster than the time it took people to accept that the Sun does not revolve around Earth.

Although I was unable to move the majority towards a consensus on the MWI, the workshop did not make me doubt the superiority of the MWI. I am encouraged by Wallace [37], who compared the MWI favorably with other interpretations, arguing that it has an advantage for generalization to field theory and beyond, and in particular, I am encouraged by the vision of Deutcsh presented at the end of the final session of the workshop. I can conclude with quotes from Huber [38], who conducted an extensive comparative review, writing that

> rival interpretations or theories either face limited applicability/conceptual incoherence, or can be reduced to MWI on closer inspection. ... Finally, I dare to make the following claim: poll results notwithstanding, the majority of the physics community in fact prefer (an unmodified) realist interpretation and are only Copenhagen advocates out of custom and convenience, or because they do not deeply question anti-realist assumptions or hidden-variable theories´

(limited) applicability. I dare to say that the majority may already subconsciously be 'many-worlders', and did not, mostly due to shut-up-and-calculate advice, rigorously reflect on their consciously preferred presuppositions or think them through to their logical endpoint.

Funding: This work has been supported in part by the Israel Science Foundation Grant No. 2064/19.

Conflicts of Interest: The authors declare no conflicts of interest.

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