REVIEW

David Wallace

The Emergent Multiverse:
Quantum Theory according to the Everett Interpretation

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> We have, then, a theory which is objectively causal and continuous, while at the same time subjectively probabilistic and discontinuous. It can lay claim to a certain completeness, since it applies to all systems, of whatever size, and is still capable of explaining the appearence of the macroscopic world. The price, however, is the abandonment of the concept of the uniqueness of the observer, with its somewhat disconcerting philosophical implications.
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> Everett 1957

After the recent experimental discovery of the Higgs boson, physics seems to be in a better shape than ever in explaining all observed phenomena. The basis of physics is quantum theory which has been confirmed with unprecedented precision. However, we do not witness a consensus among scientists that physics, at large, is finished and that we reached the stage of basic understanding of Nature. One of the main reason is that quantum theory is well confirmed only as a prescription for results of experiments, but it cannot explain the world we see. It predicts exactly the spectra of lights, but when we analyze an experiment detecting a single photon passing through a beam splitter, we have only prescription for a probability of detection. The equations of quantum theory describe waves. In parallel with the wave function corresponding to the detection of the photon, there is also a wave corresponding to a detector which remains silent. We see a detector which clicked or did not, but the theory describes both. Attempts to end up with one picture by collapsing the quantum wave function have not lead to attractive theories. In 1957 Everett proposed that it is our illusion that there is

just one picture: quantum measurement ends up with both. Since quantum measurements happen frequently, there are now numerous pictures. This is the many-worlds (or multiverse) interpretation.

In "The Emergent Multiverse" David Wallace provides a clear, coherent, and rigorous presentation of the Everett interpretation and, in my view, he succeeds to persuade a reader that this interpretation works! I myself need not to be persuaded. In the Introduction Wallace writes: "I would be neither surprised nor distressed if David Deutsch, or Max Tegmark, or Lev Vaidman were to regard parts of this book as completely wrong; I would be both surprised and distressed if they merely said that they advocated a different Everett interpretation." Indeed, there are parts with which I disagree, but Wallace's description of the theory is exactly the many-worlds interpretation (MWI) I believe in. His terminology is different (he avoids the term MWI), but what he describes is the MWI of Everett (who, for other reasons, also avoided this term). Although for me, apart from the philosophical price of accepting multiple realities, the MWI has no unresolved problems, I appreciate the difficulty of writing a persuasive exposition of this theory. I do not think that anyone succeeded before Wallace. Albert [1988] and Loockwod [1989] provided an excellent description of some aspects of the MWI, but did not present a complete picture. Barrett [1999] presents a wider exposition, but he is not sympathetic to the MWI. He concentrates on difficulties and does not attempt to present a complete coherent picture of the MWI. I find interesting insights in Deutsch [1996], but his book is good only for those who already believe in the MWI and does not provide good arguments for nonbelievers.

A main difficulty in the interpretation of quantum theory is the measurement problem and the MWI in Wallace's word "dissolves" it. The book explains the problem and shows how Everett made it disappear. Wallace presents a comprehensive historical review of the various objections and provides a very convincing answers to these, showing the superiority of the MWI relative to other alternatives. However, unless the reader has an unusually strong mathematical background, he will have to make a serious effort to see this. While Albert [1988] was afraid to scare the reader with the concept of a spin and complicated his book by simulating it with colors, Wallace uses positive operator valued measures (POVMs), C-star algebras, Borel measure, decoherence functional, decision-theoretic representation theorems and many other concepts that most physics graduates never encountered. The reader is assumed to have a significant philosophical background too, so the book

is fully accessible only to those few who can, like Wallace, have Ph.D. both in physics and philosophy. This problem is partly solved by clear guidance how to read the book skipping technical sections, but such reading reduces confidence. I believe that by cutting all these sophisticated parts (reducing the volume by half) Wallace could make his book a bestseller.

I understand that Wallace has a bigger ambition than just making a clear exposition of Everett interpretation and persuading that it explains perfectly all paradoxes and mysteries of quantum mechanics. In the last years, apart from this book, he published more papers developing and modifying the Everett interpretation than anyone else. A lot of this research, included in the book, is not really needed for establishing the basic thesis of the book as Wallace defines it: there is no quantum measurement problem. It is not needed for showing that if we take quantum theory seriously, literally, as a description of the world [multiverse], then the MWI is the best way to make a coherent sense of it. Wallace introduces POVMs for discussing the decoherent histories approach which hopefully can be generalized to a field theory. I have to admit that I was skeptical about this program before reading this book and remained so now. I was never been able to make sense out of consistent or decoherent histories approaches. While I certainly view the phenomenon of decoherence as crucial for the emergence of the multiverse, the mechanism is trivial, we do not need decoherence functionals etc. Wallaces "space time realism" is also oriented for dealing with quantum field theory. In his view things are simple in algebraic formulations of quantum field theory associating C-star algebra of operators with a particular region of space. I think that the measurement problem is part of quantum mechanics, not of a field theory. A simple model of von Neumann measurements is enough for analyzing this problem. In my view, solving the basic conceptual problems in the framework of quantum mechanics will allow us analysis in the field theory without encountering these problems again. It is on the level of quantum mechanics that we have paradoxes. We never experience cats in a superposition of being live and dead while the formalism is capable to provide a picture of only simultaneously present two states of the Shrödinger cat. The correspondence between our experience and quantum fields is so remote that severe paradoxes are not expected there.

Wallace devotes much attention to the problem of probability in the MWI. He convincingly explains why this framework is not inferior to other interpretations in spite of the obvious difficulty in defining probability of an outcome when all outcomes are realised. He includes in the book the thesis on which he

extensively worked in the last years following the pioneering work of Deutsch [1996] that the MWI is superior to other interpretation since the Born rule (postulated in the standard quantum mechanics) can be *derived* using tools of the Decision theory. In fact, about one third of the book is devoted to developing this thesis, most of Part II and almost all appendices. Like many others I am skeptical about the success of this program. The book is probably the best take on this: with no space limitations, with appropriately presented background and with full mathematical apparatus. But it is in no way accessible for a general reader. The reader who could easily be convinced that the MWI provides a proper answer to the measurement problem will have to work very hard to understand Wallace's derivation of the Born Rule.

In Part III Wallace largly returns to accessible language and he analyzes in detail important issues of locality, time symmetry and several separate topics which are in particular relevant to the MWI. Questions of identity over time, the (ir)relevance of Bell inequality, an option that the Universe is in a mixed state, quantum computation, a curiosity regarding speculation about time travel, all received clear, very intelligent treatment. I might not agree with all the conclusions, but Wallace chooses to discuss the right problems, presented in the proper context. It is a very extensive and authoritative review.

"The Emergent Multiverse" seems to be one book imbedded in another: a scientific monograph on derivation of the Born Rule imbedded in a general philosophical book on the meaning and success of the MWI. Both are good, but are directed at different audiences, so that two separate books would be much more effective. Currently, a specialist might be bored reading the introduction to quantum mechanics, while the general audience is surely scared by mathematical and Decision theory symbols. For a monograph on the Born rule, the presentation style is not particularly important, it is the validity of the argument that counts, but for a general book explaining MWI, the presentation is crucial. I find it excellent. The dialog interludes are insightful and entertaining. The quotations at the beginning of each section are incredibly to the point. (I borrowed one for this review.) I recommend to everyone, especially to skeptics of the MWI to read this book. Enjoy brilliant and engaging style. Skip freely complicate equations, believe the author: he understands Everett's theory very well.

References

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