Can Everett be Interpreted Without Extravaganza?

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Abstract

Everett’s relative states interpretation of quantum mechanics has met with problems related to probability, the preferred basis, and multiplicity. The third theme, I argue, is the most important one. It has led to developments of the original approach into many-worlds, many-minds, and decoherence-based approaches. The latter especially have been advocated in recent years, in an effort to understand multiplicity without resorting to what is often perceived as extravagant constructions. Drawing from and adding to arguments of others, I show that proponents of decoherence-based approaches have not yet succeeded in making their ontology clear.

1 Introduction

Everett’s ‘relative states’ formulation of quantum mechanics was proposed more than 50 years ago [1, 2], at a time when the Copenhagen interpretation reigned essentially unchallenged. Everett wanted to (i) retain the universal validity of the Schrödinger equation; (ii) eliminate the need for the collapse of the wave function; (iii) eliminate the need for an external observer; and (iv) offer a derivation of the Born rule.

Research on Everett’s approach has, over the years, largely focussed on the three themes of probability, the preferred basis, and multiplicity. This paper intends to succinctly assess where this research stands and what are the most significant open problems. I shall review the above three themes, emphasizing why I believe the third one is the most important. I will then comment on different ways of understanding multiplicity, arguing that the currently most popular one leaves crucial questions unanswered.
2 Probability and preferred basis

Everett claimed that “the statistical assertions of the usual interpretation [...] are deducible (in the present sense) from the pure wave mechanics that starts completely free of statistical postulates” [2]. More recently, the attempt to understand how probability emerges in Everett’s approach has focussed on decision theory (for a review see [3]). A number of investigators have attempted to derive the square amplitude measure and Born’s rule from natural decision-theoretic postulates. Specifically, they try to show that a ‘rational’ agent who believes he or she lives in an Everettian universe will make decisions as if the square amplitude measure gave chances for outcomes. The success of this program, however, is controversial [4].

A necessary condition for encountering distinct outcomes in Everett’s approach is that a product state evolves into an entangled state, i.e.

\[ |\phi\rangle|\psi\rangle \rightarrow \sum_i c_i |\phi_i\rangle|\psi_i\rangle = \sum_i c'_i |\phi'_i\rangle|\psi'_i\rangle. \]  

(1)

Although the representation on the left-hand side is essentially unique, the one on the right-hand side never is. Yet outcomes are understood as singling out a specific representation. This is the preferred-basis problem. In some circumstances decoherence theory may help to identify the appropriate basis [5].

With respect to multiplicity, Everett’s approach has been interpreted as involving (i) many worlds, (ii) many minds or, more recently, (iii) decohering sectors of the wave function. Although the themes of splitting and multiplicity are undoubtedly present in Everett’s original paper and thesis, the ontological basis of the approach is never made entirely explicit in this early work. There is, however, evidence that later in his life Everett was thinking in parallel-universes terms [6].

I have advocated elsewhere [7] that in quantum mechanics, the basic question of interpretation can be formulated as “How can the world be for quantum mechanics to be true?” This is related to what has been called the semantic view of theories [8]. There can be many consistent answers to the question just raised, and each one adds understanding. To achieve this, however, each answer should be formulated in as precise and as clear a manner as possible.

Within such a research program, it seems entirely acceptable if the probability measure is specified as an additional postulate, the way Everett did it.
or in terms of the frequency operator introduced by Hartle [9] and Graham. Likewise the preferred basis can be associated with beables corresponding to hidden variables, perhaps motivated by decoherence. There is, however, a pressing need to understand the true nature of multiplicity.

3 Multiplicity: many worlds and many minds

The idea of a real split into a multitude of worlds was first made explicit by DeWitt [10].

One of the first questions that come to mind is whether the split occurs every time that, as in (1), a product state transforms into an entangled state, even if the process is purely microscopic? DeWitt seems to answer the question in the affirmative. Since microscopic processes can often easily be reversed, the split itself has to be reversible, or at least reflect that reversibility.

If the split occurs only in some processes, like Everett himself seems to have been thinking [1], one should specify the precise conditions (enough mass, enough particles, ...) in which it takes place. In other words, one must add elements to minimal quantum mechanics. Vaidman, for instance, defines the concept of a world in terms of macroscopic objects, and writes the quantum state of a world as [11]

\[ |\Psi_{\text{world}}\rangle = |\Psi_{\text{object}_1}\rangle |\Psi_{\text{object}_2}\rangle \ldots |\Psi_{\text{object}_N}\rangle |\Phi\rangle. \] (2)

Since object\(_i\) is macroscopic, this immediately raises the question of the classical-quantum distinction. Further interrogations involve the precise time when the split occurs, whether it occurs on an equal time hypersurface or on the light cone, etc.

Instead of splitting in the strict sense, Deutsch [12] postulates a process of bifurcation. There is at any time an infinite number of worlds, which neither increases nor decreases. A bifurcation at a given time is associated with a particular interpretation basis.

If splitting is restricted to specific processes, it can be taken as reversible or irreversible. An irreversible split will entail differences with unitary quantum mechanics. Indeed in this case, the state in a given world is given by \(|\phi_i\rangle|\psi_i\rangle\). The reverse measurement interaction would not bring this back to the initial state (although it would bring \(\sum_i c_i |\phi_i\rangle|\psi_i\rangle\) back to the initial state).
Such are questions that must be answered for the many-worlds approach to be well-defined. Answering them is also necessary for the quantum measurement problem to be solved, since the gist of the solution precisely consists in the splitting of worlds.

The many-minds view [13] places the split in consciousness rather than in the outside world. There is, in the words of Lockwood [14], “no good reason for supposing that the apparent macroscopic definiteness of the world is anything other than an artefact of our own subjective point of view.”

In the many-minds approach, kets $|\psi_i\rangle$ in (1) involve brain states and these are in a quantum superposition. There can either be one mind (believing $i$ with probability $|c_i|^2$), or an infinite number of minds, supervening on brain states.

Similar questions can be raised in the many-minds view as in the many-worlds view. What kinds of mind split? Only human minds, or also cats’ minds? What, in the quantum mechanical formalism, singles out brain states? Again these and similar questions must be answered before anyone can claim to have solved the measurement problem satisfactorily.

4 Decohering wave function

Everett’s way of solving the measurement problem involves asserting that statements “Observable $A$ has value $a_1$” and “Observable $A$ has value $a_2$” (with $a_1 \neq a_2$) are both true. The apparent contradiction is avoided by construing each statement as “Observable $A$ has value $a_i$ relative to value $b_i$ of $B_i$” for $i = 1, 2$. It has been argued [15, 16] that this solution of the problem of actuality is analogous to a solution of the problem of tense, where apparently contradictory statements “Event $E_1$ is now” and “Event $E_2$ is now” are made consistent by construing them as “Event $E_i$ is now relative to event $F_i$,” for $i = 1, 2$.

Formally, this solution of the problem of tense consists in adding a dimension to reality. The universe is not fully specified through its spatial, but only through its spatiotemporal, configuration. And this, in quantum mechanics, is essentially what many worlds do. The universe (say at a given time) is not adequately specified by giving a single spatial configuration. It involves many configurations, differing in macroscopic aspects, which can be indexed by an additional variable that can be viewed as an added dimension to reality.
The decohering wave function approach to understanding Everett denies that there is a genuine split into many worlds or many minds. The multiplicity is instead associated with sectors in the decohering universal wave function, in each of which sectors observables have values relative to other ones. To quote Wallace [17], “If A and B are to be ‘live cat’ and ‘dead cat’ then [different micro-world properties] P and Q [on which A and B supervene] will be described by statements about the state vector which (expressed in a position basis) will concern the wave function’s amplitude in vastly separated regions $R_P$ and $R_Q$ of configuration space, and there will be no contradiction between these statements.”

Can this attempt to avoid contradiction be understood in terms of added dimensions? The fact that there is no genuine split means that the added dimension referred to earlier, as a label for distinct worlds, is not available here. But then it is not clear why there is no contradiction. Obviously, the projections in real three-dimensional space of the live cat configuration space coordinates cannot overlap with the projections of, say, the Geiger counter coordinates. Why could they overlap with the projections of the dead cat coordinates? Would mass distributions in one branch behave as ‘ghosts’ to mass distributions in other branches?

One way to introduce extra dimensions is to use the ones provided by configuration space. This may be what Wallace and others have in mind. But the problem just mentioned does not disappear. How are we to make sense of projections in three-dimensional space, and determine what is allowed to overlap and what is not? Moreover, there is another problem with adding in all the dimensions of configuration space. Do we have in mind the full fine-grained configuration down to the level of subatomic particles? Or do we rather envisage some coarse-grained configuration? Proponents of the decohering wave function approach clearly mean the latter. But then one needs to specify what level of coarse graining is meant.

That need is denied by Wallace [17], who believes that “the somewhat blurred borderline between states where quasi-particles exist and states where they do not should not undermine the status of the quasi-particles as real—any more than the absence of a precise point where a valley stops and a mountain begins should undermine the status of the mountain as real.” But the analogy breaks down at a crucial point. Different levels of coarse graining will never make two similar mountains stem from just one, whereas Everettian multiplicity is here understood to appear at some level of coarse graining only.
To put Everettian multiplicity in perspective, Allori et al. [18] have emphasized the importance of the concept of primitive ontology, whose elements are the stuff that things are made of. Their analysis leads to the conclusion that they “do not see how the existence and behavior of tables and chairs and the like could be accounted for without positing a primitive ontology—a description of matter in space and time.”

Based on that, a specific ontology for the many-worlds theory, close to Schrödinger’s first interpretation of the wave function, was proposed through a three-dimensional mass density defined in terms of the full configuration-space wave function as [19]

$$m(x, t) = \sum_{i=1}^{N} m_i \int d\mathbf{x}_1 \ldots d\mathbf{x}_N \delta(\mathbf{x} - \mathbf{x}_i)|\Psi(\mathbf{x}_1, \ldots \mathbf{x}_N; t)|^2$$

$$= \sum_{i=1}^{N} m_i |\psi_i(x, t)|^2. \quad (3)$$

It can be shown that the live cat and the dead cat both contribute to the total mass density in three-dimensional space. In the words of Allori et al., however, “the universe according to [this theory] resembles the situation of a TV set that is not correctly tuned, so that one always sees a mixture of several channels.” Making sense of this is a challenge that proponents of the decohering wave function approach have to take up.

5 Conclusion

Everett’s approach to the interpretation of quantum mechanics can be understood in several different ways. Some of the questions and problems left unanswered in Copenhagen quantum mechanics or in the Dirac and von Neumann collapse theory also have to be resolved in Everett’s approach. It nevertheless appears that the more ‘extravagant’ understanding, namely that of many worlds, is the one whose basic ontology is clearest and which provides the logically sharpest solution to the measurement problem.

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