Many Worlds with both "And" and "Or"

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Abstract

According to the many-worlds interpretation of quantum mechanics (MWI), all results occur after a measurement. This seems to make an observer-independent understanding of the Born probabilities impossible. In this paper, I propose a new way to solve the problem of probability in MWI. It is suggested that different worlds exist in different sets of instants, and all worlds exist in a time-division multiplexing way during an arbitrarily short time interval. Since there is only one world at each instant, the Born probabilities can be understood in the usual way. Moreover, since there are many worlds during a time interval, MWI also gives predictions different from those of single-world quantum theories. Finally, it is pointed out that this version of MWI introduces no additional ontologies and postulates when assuming a plausible realist interpretation of the wave function.

The many-worlds interpretation of quantum mechanics (MWI) is perhaps the most popular but also the most controversial theory about the quantum world (Everett, 1957). According to MWI, all results occur after a measurement, each of which exists in a world. Then, how to make sense of the Born probabilities? The received view is that this problem of probability cannot be solved in the same way as in standard quantum mechanics. The opponents of MWI argue that since there is no single unique result after a measurement, probabilities make no sense in the theory (see, e.g. Maudlin, 2014). While the proponents of MWI argue that single unique results are not needed, and the problem of probability can be solved by resorting to the functional definition of probability related to a rational agent (Wallace, 2012). In this paper, I will propose a new way to solve the problem of probability in MWI. It is suggested that after a measurement, there is a single unique result at each instant, but all results occur in respective sets of instants and they coexist in a time-division multiplexing way during an arbitrarily short time interval. This suggestion is supported by a plausible realist interpretation of the wave function. It may not only solve the problem of probability in the standard way, but also clarify the issue of whether MWI gives predictions different from those of single-world unitary quantum theories.

Consider a typical measurement in quantum mechanics, in which a measuring device or an observer M measures the z-spin of a spin-1/2 system S being in a superposition of two different z-spins. According to the linear Schrödinger equation, the state of the composite system after the measurement will be a superposition of M recording z-spin up and S being z-spin up and M recording z-spin down and S being z-spin down:

$$\alpha \left|up\right\rangle_S \left|up\right\rangle_M + \beta \left|down\right\rangle_S \left|down\right\rangle_M , \tag{1}$$

where α and β are nonzero and satisfy the normalization condition $|\alpha|^2 + |\beta|^2 = 1$.

According to MWI, there will be two (sets of) worlds after this measurement, in each of which there is a successor of the original M who obtains a definite result, either z-spin up or z-spin down. In other words, all results occur after this measurement. But the Born rule requires that the probabilities for the original M to obtain the results z-spin up and z-spin down are not both one but $|\alpha|^2$ and $|\beta|^2$, respectively. It is usually thought that the existence of many worlds is not compatible with the Born rule when assuming probabilities are attached to alternatives as usual (Maudlin, 2014). Alternatives can be expressed using "or", and the Born rule requires getting an "or" at the end of a measurement rather than an "and" under this assumption. It seems that both the opponents and the proponents of MWI agree with this view.

However, I disagree with this received view. My proposal is that there are both "and" and "or" in MWI. Concretely speaking, there is a single unique result or world at each instant after a measurement, and thus the problem of probability can be solved in the standard way. Moreover, different results or worlds exist in different sets of instants, and they coexist in a time-division multiplexing way during an arbitrarily short time interval. In this way, MWI will give predictions different from those of single-world unitary quantum theories.

In the above experiment, at each instant after the measurement, M obtains a single unique result, either z-spin up or z-spin down, with the Born probability $|\alpha|^2$ or $|\beta|^2$. This is the "or", and it ensures that MWI agrees with the Born rule. Moreover, there is also an "and". During an arbitrarily short time interval after the measurement, there are two successors of the original M, who exist in different sets of instants and obtain different results, and they coexist in a time-division multiplexing way. The emergence of two worlds here is a consequence of the Schrödinger evolution for the wave function (Gao, 2021b, 2022a).

Now the question is: how can both "and" and "or" exist in MWI? In order to answer this quesiton, we must turn to the realist interpretation of the wave function. The ontology underlying the wave function has been widely regarded as a physical field in a high-dimensional space or in our three-dimensional space, which exists throughout the space at the same time (Albert, 1996, 2013; Hubert and Romano, 2018; Wallace and Timpson, 2010). Then, the worlds represented by the result branches of the post-measurement superposition also exist at the same time at each instant. In this case, there is no "or" but only "and". This leads to the well-known problem of probability in MWI.

However, the field ontology is not the only possibility. I have proposed and developed an interpretation of the wave function in terms of random discontinuous motion of particles (RDMP) during the last 30 years (Gao, 1993, 2017, 2020, 2021b, 2022d). According to this interpretation, a quantum system is composed of particles with mass and charge, which undergo random discontinuous motion in three-dimensional space, and the wave function represents the propensities of these particles which determine their motion, and as a result, the state of motion of particles is also described by the wave function. So far, there are two plausible arguments supporting this interpretation of the wave function (Gao, 2017, 2020, 2022d).

It can be seen that the RDMP interpretation of the wave function provides a picture of many worlds with both "and" and "or" (Gao, 2022a). Many proponents of MWI may worry about and even dislike the randomness it introduces.[1] However, if the RDMP interpretation of the wave function is true, then no additional ontologies and postulates are introduced in the above version of MWI, and it is arguably the simplest realist version of quantum mechanics.

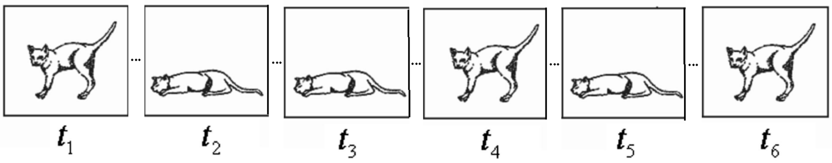

Figure 1: Schrödinger's cat in a time division multiverse

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[1] The main difficulty with the concept of probability in MWI results from the conventional view that MWI is a deterministic theory. However, that the dyanmics for the wave function is deterministic does not mean that the theory must be a deterministic theory. The many-minds theory is an example. By comparison, the RDMP interpretation of the wave function is a more natural and plausible possibility (Gao, 2020).

It has been a puzzle whether MWI gives predictions different from those of single-world unitary quantum theories such as Bohm's theory (Bohm, 1952). If the answer is yes, then how can MWI also agree with the Born rule? The above version of MWI may help answer this puzzle. The theory agrees with the Born rule (for the original measurer M); M obtains only one result at every instant after the measurement, and the probability of M obtaining this result is equal to the Born probability. But still all results occur after a measurement; different results are obtained by different successors of M, and they coexist in a time-division multiplexing way during an arbitrarily short time interval. In this sense, the probability of every result occuring is one during any time interval after the measurement, or in other words, the probability that there will be successors of M who obtain a possible result is one. Then, MWI and single-world unitary quantum theories will give different predictions about small-probability results: the former predicts that there will be successors who obtain small-probability results with certainty, while the latter predicts that the small-probability results will almost never occur (see also Gao, 2021a, 2022c). Note that this conclusion is independent of an analysis of the conscious experience of observers (Gao, 2022b).

Vaidman (2022) recently asked: why is MWI not in the consensus? I think the answer may be found from the opinions of the strongest but respectable opponents of MWI such as Tim Maudlin. On Maudlin's (2014) view, the ontology of MWI should contain beables (i.e. physical items existing in space and time), and the probabilities in MWI should be attached to alternatives and related to genuine uncertainties. Since the current formulation of MWI does not satisfies these requirements, it is not in the consensus. However, the above version of MWI satisfies these requirements. In this theory, the ontology is particles in space and time, and their random discontinuous motion forms a time division multiverse, in which different worlds exist in different sets of instants or different time subflows. Moreover, the Born probabilities indeed come from real randomness, and the Born rule can also be naturally derived from the picture of RDM of particles. Now, if the strongest opponents of MWI are also satisfied with it, then hopefully we will reach a consensus in understanding quantum mechanics in the near future.

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